

CIRES  
2015  
annual  
report





COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

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**Cover photo: Mt. Cook in the Southern Alps, West Coast of New Zealand's South Island** Birgit Hassler, CIRES/NOAA

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# executive summary & research highlights

## From the Director



David Oonk/CIRES

Fiscal Year 2015 was another very strong year for CIRES, marked with a number of outstanding achievements, both in scientific research and in support of the NOAA mission. The commitment and talent of our world-renowned scientists, dedicated administrative staff, outstanding students and all the other members of CIRES have continued to ensure that CIRES' contributions to science, society and the university are something we should all be proud of. With awards of nearly \$80M in FY 2015, CIRES funding once again comprised nearly a fifth of the University of Colorado Boulder's research funding. Nearly half (46%, \$36.4M, page 10) of this amount was from our cooperative

agreement with NOAA—our core support base—and we continued to leverage this investment and the support from the university to secure \$38M in additional funding from a diverse array of other sources. Among these were NASA, the National Science Foundation, the Department of Defense, and the Department of Energy. With support from these and other sources, CIRES scientists published nearly 700 journal articles across the full spectrum of environmental disciplines in many of the world's most prestigious publications. We have played a critical role in the university's educational mission through our 18 faculty and our 176 undergraduate and graduate students in a wide range of departments across campus.

CIRES' record of outstanding research achievements, funding success, and educational contributions have contributed significantly to the University of Colorado Boulder's stellar ranking as the #2 university in the world for Geosciences (U.S. News & World Report), trailing only the California Institute of Technology.

Just as we are proud of our achievements in research and education, we are also proud to be valued partners in the execution of NOAA's mission. With 340 scientists and science support personnel located at the David Skaggs Research Center, and dozens

*With awards of nearly \$80M in FY 2015, CIRES funding once again comprised nearly a fifth of the University of Colorado Boulder's research funding.*

more on campus conducting NOAA-related research, we are an integral part of the important work being done at NOAA's Earth System Research Laboratory, Space Weather Prediction Center and the National Centers for Environmental Information.

The success of these partnerships is evident in the numerous publications co-authored by CIRES and NOAA personnel and various awards from NOAA and the Department of Commerce recognizing the outstanding achievements realized by NOAA/CIRES teams. Among these were the Silver and Bronze Medals awarded by the Department of Commerce, as well as a NOAA Technology Transfer Award. In addition, a team of more than 60 NOAA and CIRES scientists was honored with the COLABS/Governor's High Impact Award for their work seeking to understand the atmospheric impacts of rapidly expanding oil and gas development.

Looking to the future, CIRES researchers in NOAA's Earth System Research Laboratory are playing a significant role in ESRL's strategic planning, led by ESRL Director Sandy MacDonald and with his invitation. Of about 35 lead participants in that effort, 15 are CIRES scientists who work in the ESRL laboratories, roughly reflecting the makeup of ESRL. On main campus, we are excited to welcome four new CIRES fellows this year with expertise in hydrology, chemistry, geology and oceanography. All are leaders among their peers and will no doubt make significant contributions to CIRES and its mission.

From deep within the Earth to the top of the atmosphere and beyond, CIRES continues to explore and understand the world in which we live, often turning those discoveries into useful and actionable information that ultimately improves our relationship with our environment. We advance science, and we improve lives, and it truly is a privilege to lead such an accomplished and valuable organization doing such important work.

A handwritten signature in blue ink, which appears to read 'Waleed Abdalati'. The signature is fluid and cursive.

Waleed Abdalati  
CIRES Director



Research colleagues plan the day's radar surveys on Scott Glacier, Cordova, Alaska, March 2013.

Dan McGrath/CIRES

## CIRES: Science in Service to Society

CIRES—the Cooperative Institute for Research in Environmental Sciences—is an international leader in research that addresses some of the most 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, and leveraging NOAA investments with partnerships and funding from other institutions around the world. Our researchers use time-honored and cutting-edge approaches to study diverse aspects of Earth system science, with a focus on “use-inspired” research.

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. 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 scientists (often with NOAA and other colleagues):

- Showed that the Larsen C Ice Shelf in Antarctica is thinning from both above and below: Through warmer air temperatures and surface melting, and because of warmer ocean waters or shifting currents.
- Updated NOAA's 2014 Annual Greenhouse Gas

Index, which indicates that the warming influence from human-emitted gases continues to increase, up 34 percent since the index year of 1990.

- Led and coordinated the international effort to produce the quadrennial *2014 Ozone Assessment, including the Assessment for Decision Makers*, for the United Nations and World Meteorological Organization.
- Used a 3D printer to efficiently and inexpensively produce components of a particle spectrometer—to measure aerosol size and distribution in the atmosphere. CIRES researchers deployed the Printed Optical Particle Spectrometer on a tall tower, two unmanned aircraft systems, and a high-altitude balloon.
- Investigated the role of El Niño-Southern Oscillation in extreme precipitation events, finding evidence that strong El Niños increase the frequency of winter-to-early-spring heavy rain events over the upper Missouri River Basin and in parts of Texas (east and



**Lightning strike over Broomfield, Colorado.** Ben Castellani/CIRES



**Sampling for airborne microbes in a Boulder basement.** David Oonk/CIRES

northeast).

- Used models and observations to assess the role of climate change in California drought risk. Both show California getting hotter and wetter, a combination that has likely decreased the risk of agricultural drought in the state to date. However, future changes could shift the balance to more drought by the late 21<sup>st</sup> Century.

### Weather-Ready Nation Goal

CIRES scientists (often with NOAA and other colleagues):

- Completed developing and operationalizing the HRRR, High-Resolution Rapid Refresh weather model, which improves forecasts of severe weather. Five federal employees in the ESRL Global Systems Division team earned a Department of Commerce Gold Medal for this achievement in 2015, and their nine CIRES colleagues will be recognized with a CIRES Gold in May 2016.
- Evaluated several weather products important to the aviation community, including: Current Icing Potential

and Forecast Icing Potential versions 1.1; Icing Product Alaska; and Graphical Turbulence Guidance version 3.

- Conducted the Lidar Uncertainty Measurement Experiment (LUMEX) to compare the observations of newly available wind lidars, with unknown error characteristics. Wind lidars, which can determine the speed and direction of winds in the atmosphere, are critical in atmospheric science and increasingly to industry.
- Were integral to several multi-agency studies designed to help decision makers better understand the origins of air quality challenges in several regions of the country: SONGNEX in the U.S. West; WINTER from the Ohio River Valley east and south to the East and Southeast coasts; and DISCOVER-AQ and FRAPPE here in Colorado's Front Range. This work earned a team of 64 NOAA and CIRES scientists a 2014 Governor's Award for High-Impact Research, given by COLABS.
- Improved community access to and use of the Hurricane Weather Research and Forecast model and the Gridpoint Statistical Interpolator, which are important in NOAA operations and in the weather research and

development community.

- Diagnosed factors responsible for heavy daily precipitation events observed between 1979 and 2013 in the United States, finding evidence that sea surface temperature patterns linked to internal decadal ocean variability play a more important role than increased external radiative forcing.

### Engagement Enterprise

CIRES scientists (often with NOAA and other colleagues):

- Brought MADIS, the Meteorological Assimilation Data Ingest System, into operations at the National Centers for Environmental Prediction. MADIS ingests new weather data into a quality-controlled, organized system, making it accessible for weather forecasting, forecasters and the public.
- Completed a prototype Hazard Services program in the Advanced Weather Interactive Processing System II and began preparing it for operations in 2015. Hazard Services combines and improves on three applications



**Navajo and Apache peaks, Indian Peaks wilderness, Colorado** Nico Bayou/CIRES



**Graduate students set up a seismometer in Greeley, Colorado.** David Oonk/CIRES

currently used to generate various hazardous weather watches, warnings, and advisories.

- Installed the illuminated and illuminating Science on a Sphere® (SOS) at sites in six additional countries, bringing the total countries represented to 22 and total installations to well over 100. CIRES continued to work with SOS users, leading teachers' workshops and unveiling a flatscreen version of SOS for the classroom.

### Science and Technology Enterprise

CIRES scientists (often with NOAA and other colleagues):

- Transitioned the High Resolution Rapid Refresh model into operations to enhance the National Weather Service's forecasts of high-impact weather events such as severe thunderstorms and heavy precipitation bands. This work earned a Department of Commerce Gold Medal in 2015.
- Supported NOAA's High Performance Computing team, including acquiring a new system to deal with the intense computational needs of NOAA's Hurricane

Forecast Improvement Project.

- Released a new version of the World Magnetic Model (WMM), valid from 2015 to 2019. The WMM is the standard model for navigation, attitude, and heading systems used by several civilian and military organizations, including the U.S. Department of Defense, the U.K. Ministry of Defense, and the North Atlantic Treaty Organization.
- Developed, tested, and maintain software to support the Deep Space Climate Observatory (DSCOVR) satellite, which was launched February 11, 2015, and will deliver key space weather data to the NOAA Space Weather Prediction Center, the nation's official source of watches, alerts and warnings about potentially damaging space weather.
- Helped develop algorithms to turn nighttime lights data from the satellite-based VIIRS instrument (Visible Infrared Imaging Radiometer Suite) into useful information for researchers and regulators. A new boat detection algorithm identifies brightly lit fishing boats; another helps researchers estimate flared gas volumes.

- Developed five new digital elevation models (DEMs) and updated four others in support of 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.

# 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.*

Established in 1967, the Cooperative Institute for Research in Environmental Sciences (CIRES) facilitates collaboration between the University of Colorado Boulder and the National Oceanic and Atmospheric Administration (NOAA). Our 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.

## Collaborations

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
- Environmental Studies Program
- Geography
- Geological Sciences
- Molecular, Cellular, and Developmental Biology

### NOAA Earth System Research Laboratory (ESRL)

- Chemical Sciences Division
- Director's Office
- Global Monitoring Division
- Global Systems Division
- NOAA Environmental Software Infrastructure and Interoperability group
- Physical Sciences Division

## NOAA Centers

- National Geophysical Data Center (now part of the National Centers for Environmental Information)
- Space Weather Prediction Center

## CIRES Structure

CIRES research 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 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 50)
- Center for Science and Technology Policy Research (page 52)
- Earth Science and Observation Center (page 54)
- National Snow and Ice Data Center (page 56)
- Western Water Assessment (page 58)
- Education and Outreach (page 60)

## Other Programs

- International Global Atmospheric Chemistry Project (page 62)
- Visiting Fellows (page 64)
- Innovative Research Program (page 68)
- Graduate Student Research Fellowships (page 69)
- Diversity and Undergraduate programs (page 70)
- Awards (page 74)
- Events (page 78)
- Communications (page 80)

**A research aircraft lands in Broomfield during a 2014 campaign to better understand air quality challenges and climate change in Colorado's Front Range.** David Oonk/CIRES



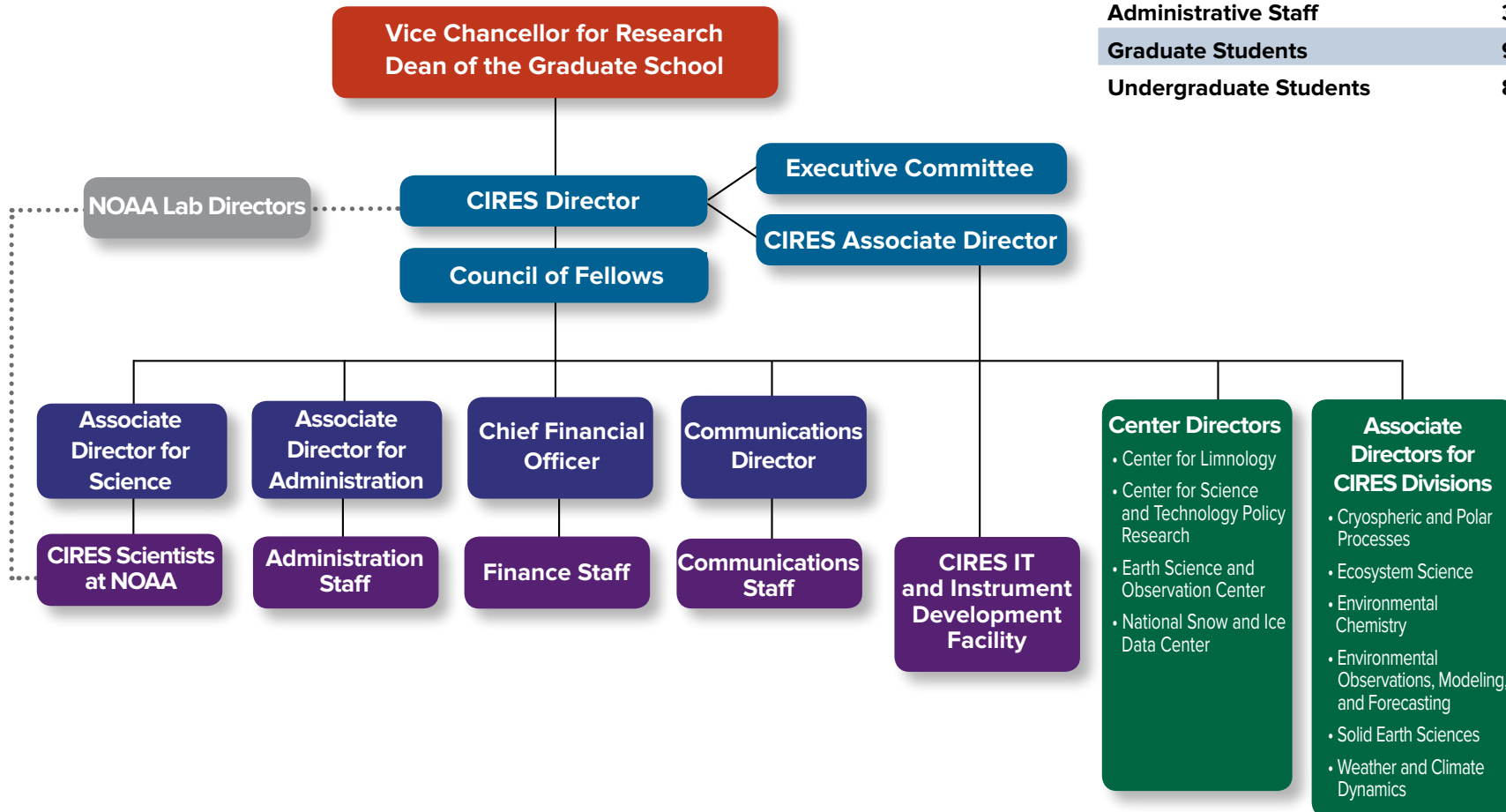


# Organization

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

servation Center, and the National Snow and Ice Data Center—and our other programs link NOAA to nine university departments. Coordination among all these entities is facilitated through the CIRES administration. During the University of Colorado Boulder's FY15, Waleed Abdalati led CIRES as director.

## CIRES Organizational Structure



## The CIRES Team FY2015

<b>Faculty Lines</b>	<b>18</b>
<b>Research Scientists</b>	<b>246</b>
<b>Associate Scientists</b>	<b>272</b>
<b>Visiting Scientists</b>	<b>21</b>
<b>Postdoctoral Researchers</b>	<b>22</b>
<b>Administrative Staff</b>	<b>35</b>
<b>Graduate Students</b>	<b>93</b>
<b>Undergraduate Students</b>	<b>83</b>

# Council of Fellows (June 1, 2014, to May 31, 2015)

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

**Richard Armstrong** CIRES Senior Research Scientist, National Snow and Ice Data Center (NSIDC); Associate Director for the Cryospheric and Polar Processes Division

**Stan Benjamin** Chief of the 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** Associate 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 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 of 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** CIRES Senior Research Scientist, NOAA ESRL PSD

**Steven Nerem** Professor of Aerospace Engineering

**Judith Perlwitz** CIRES Senior 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

**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 of Chemistry and Biochemistry

# Governance

## Council of Fellows

The Council of Fellows constitutes the “Board of Directors” and chief governing body of CIRES. Fellows are selected because of their outstanding achievements and abilities in diverse areas of environmental sciences. These university faculty, senior research scientists, and government scientists and Fellows form the core of our 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. During this reporting period, the Council of Fellows met: September 11, October 9, November 11, and December 11 of 2014; and January 22, February 19, March 19, and April 23 of 2015.

## 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. Annually, the Council of Fellows considers whether to entertain new Fellow nominations, which are drawn 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 70-72 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 (pages 64-66)  
Distinguished Lecture Committee (page 78)  
Graduate Student Research Fellowship Committee (page 69)  
Innovative Research Program Committee (page 68)

# Finance

During the university fiscal year of July 1, 2014, to June 30, 2015, CIRES had total expenditures of nearly \$80 million, including the university portion (graph 1).

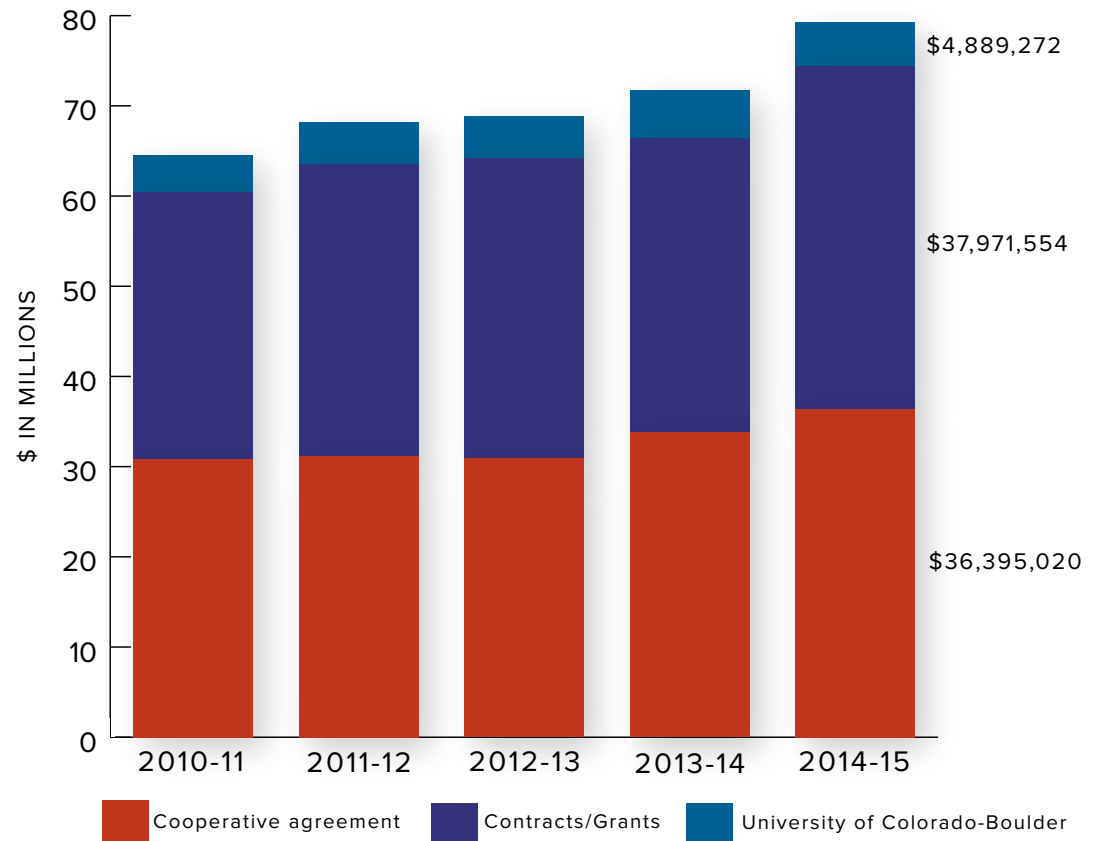
CIRES researchers enjoy enviable success in obtaining external research awards (48 percent of total expenses). On page 11, we provide a breakdown of contracts and grants by funding agency (graph 2).

Cooperative agreement expenditures by task for the reporting period (June 1, 2014 to May 31, 2015) are shown in graph 3. As of May 31, 2015, NOAA provided \$36,395,020 for the preceding 12 months of our Cooperative Agreement NA12OAR4320137.

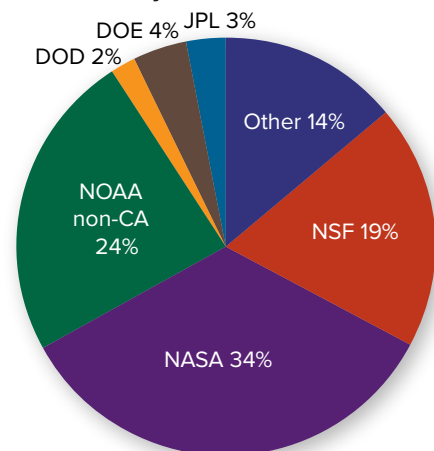
Task I funding is for CIRES administration and internal scientific programs, such as the Visiting Fellows and Graduate Student Fellowship programs; Task II funds CIRES' collaboration with NOAA's Earth System Research Laboratory, the National Geophysical Data Center (now National Centers for Environmental Information), 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.

In graph 4, we provide a breakdown of Task I expenditures from June 1, 2014, to May 31, 2015. The largest share (48 percent) of Task I base funds supports the CIRES administration, primarily salaries and benefits for the administrative staff. Our Visiting Fellows program received 8 percent of Task I base fund support and is subsidized by other institute funding. Task I also provides partial support of CIRES' Education and Outreach program, other research support, and the physical plant facilities.

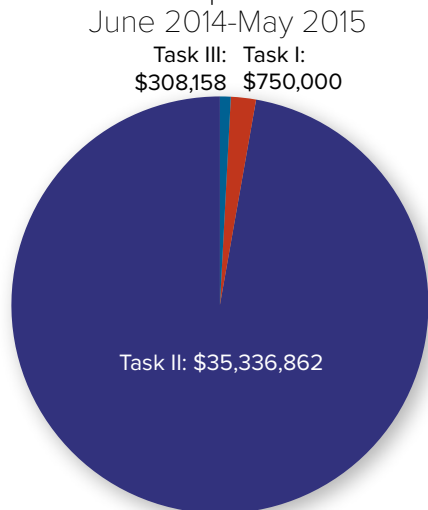
1. CIRES expenditures by funding source  
June 2014 to May 2015



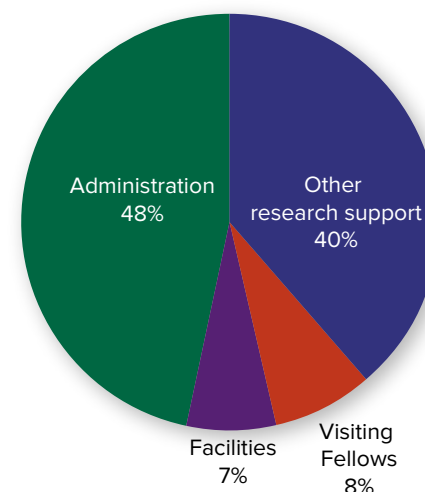
## 2. Funding breakdown by source



## 3. Agreement expenditures by Task



## 4. Breakdown of Task I expenditures



## Active NOAA Awards (June 1, 2014, to May 31, 2015)

NOAA Cooperative Agreements		Start Date	End Date	Amount in \$
NA12OAR4320137	Task I - CIRES Five-Year Cooperative Agreement Proposal	9/1/2012	8/31/2017	88,112,343.02
NA10OAR4320142	Task I - CIRES NOAA Cooperative Agreement 27-Month Scientific Workplan Extension 10/1/12-9/30/13	7/1/2010	9/30/2014	83,881,706.00

Award #	Project Name	Start Date	End Date	Amount in \$
NA09OAR4310063	Exploring The Dynamics Of High Latitude Carbon Balance	9/1/2009	8/31/2014	326,260.00
NA10OAR4310112	Maximizing The Potential Of Tropical Climate Proxies Through Integrated Climate-Proxy Forward Modeling	8/1/2010	7/31/2014	64,291.00
NA10OAR4310214	Western Water Assessment	9/1/2010	8/31/2016	4,150,933.00
NA12OAR4310142	Climate Literacy And Energy Awareness Network (CLEAN) Core Activities	9/1/2012	8/31/2014	81,529.00
NA12OAR4310136	Building Climate Science Into Land And Water Conservation Planning And Decision-Making In The American Southwest	1/1/2013	12/31/2015	198,778.00
NA13OAR4310063	Collaborative Research: Influence Of NO <sub>x</sub> And NO <sub>3</sub> On SOA Formation: Analysis Of Real-Time Field Observations	8/1/2013	7/31/2016	382,151.00
NA13OAR4310079	Improving CarbonTracker By Incorporating Constraints From Atmospheric O <sub>2</sub> Measurements And Ocean Biogeochemical Tracer Data	8/1/2013	7/31/2016	125,415.00
NA13OAR4310082	Improving CarbonTracker Flux Estimates For North America Using Carbonyl Sulfide (OCS)	8/1/2013	7/31/2016	307,488.00
NA13OAR4310085	Quantifying Observational Variability And Inverse Model Biases Of Planetary Boundary Layer Depths And Their Impact On The Calculation Of Carbon Fluxes In CarbonTracker	8/1/2013	7/31/2016	151,754.00

Award #	Project Name	Start Date	End Date	Amount in \$
NA13OAR4310083	Towards Assimilation Of Satellite, Aircraft, And Other Upper-Air CO <sub>2</sub> Data Into CarbonTracker	8/1/2013	7/31/2016	119,932.00
NA13OAR4310210	Climate.Gov Follow-Up Evaluation-A Study Of The Four NOAA Audiences	9/1/2013	8/31/2015	79,476.00
NA13OAR4310074	Quantification Of Fossil Fuel CO <sub>2</sub> By Source Sector Using Multi-Species Trace Gas Measurements In The Influx Experiment	9/1/2013	8/31/2016	111,786.00
NA13NES4830008	Seamless Digital Elevation Models For Sandy-Impacted Areas	10/1/2013	9/30/2015	282,317.00
NA14NWS4830004	Ensemble-Variational Data Assimilation And Prediction	2/1/2014	1/31/2015	280,000.00
NA14NWS4830007	Fy-2014 HFIP Physics Package Experiment	2/1/2014	1/31/2015	340,000.00
NA14OAR4830066	Extreme Precipitation And Flooding From Atmospheric Rivers: CIRES Labor Contribution	2/1/2014	1/31/2015	261,689.00
NA14NWS4830002	Stochastic Physics	2/1/2014	1/31/2016	882,000.00
NA14NWS4830003	Lower Boundary Ensemble Initial Perturbations In GFS	2/1/2014	1/31/2016	280,000.00
NA14NWS4830005	Multi-Model Post Processing	2/1/2014	1/31/2016	201,929.00
NA14OAR4830105	Establishment Of A NOAA Laboratory Activity For Observing System Simulation Experiments (OSSE)	4/1/2014	3/31/2016	301,616.00
NA14NES4830001	Enhanced Management Of And Access To Hurricane Sandy Ocean & Coastal Mapping Data	5/1/2014	4/30/2016	79,907.00
OCG6128B	Intergovernmental Personnel Act Agreement	6/1/2014	5/31/2015	233,033.00
NA14NWS4830010	MADIS Transition To NWS Operations	6/1/2014	5/31/2016	58,949.00
NA14OAR0110120	Climate Literacy And Energy Awareness Network (CLEAN) Core Activities	6/1/2014	5/31/2016	107,783.00
NA14OAR4830115	NOAA's High Impact Weather Prediction Project (HIWIPP) Test Program	6/1/2014	5/30/2017	250,119.00
NA14NWS4830033	GSI Enhancement For Variational Ensemble Cloud Assimilation	7/1/2014	6/30/2016	349,076.00
NA14OAR4830123	HIWIPP Assimilation, Ensemble Stochastic Physics And Parameterization Development	7/1/2014	6/30/2017	1,651,754.00
NA14OAR4830161	Mission Support And Analysis Associated With The Sensing Hazards With Operational Unmanned Technology (SHOUT) Project	7/1/2014	6/30/2017	1,236,200.00
NA14OAR4830169	CIRES' Contribution To The Sensing Hazards With Operational Unmanned Technology (SHOUT) - Data Management And Visualization	7/1/2014	6/30/2017	2,128,163.00
NA14OAR4830170	CIRES' Contribution To The Observing System Experiments And Observing System Simulation Experiments In Support Of The Shout Program	7/1/2014	6/30/2017	235,987.00
NA14OAR4310140	Basin-Wide Top-Down Estimates For CH <sub>4</sub> Emissions From Oil And Gas Extraction Using Aircraft Observations	8/1/2014	7/31/2016	178,288.00
NA14OAR4310142	Ground-Based Measurements To Study Fossil Fuels Production Operations Emissions Of Methane And Non-Methane Hydrocarbons And Their Atmospheric Impacts	8/1/2014	7/31/2016	200,229.00
NA14OAR4310251	Balancing Severe Decision Conflicts Under Climate Extremes In Water Resource Management	8/1/2014	7/31/2016	309,451.00
NA14OAR4830294	COG Support For High Impact Weather Prediction Project	9/1/2014	8/31/2016	744,512.00
NA15NWS4680009	Integrating Unified Gravity Wave Physics Into The Next Generation Global Prediction System	5/1/2015	4/30/2016	24,880.00

**Canyon de Chelly, Navajo Nation, Arizona.**

David Oonk/CIRES



# people & programs

## CIRES starts with people

The following pages highlight the diverse environmental science research conducted at CIRES, beginning with CIRES Fellows who are University of Colorado Boulder faculty or CIRES scientists (page 15).

Fellows pages are followed by reports on CIRES' four centers, two programs and an international research enterprise housed here (page 50).

Then, we report on our prestigious Visiting Fellowships; pioneering research funded by CIRES' Innovative Research Program; graduate and undergraduate programs including fellowship and diversity programs; and CIRES' communications work (page 80).

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 82).



## CIRES Fellows

### NOAA Scientists<sup>1</sup>

Stan Benjamin	Christopher Fairall
Randall Dole	Graham Feingold
David Fahey	Stephen Montzka

### CU-Boulder Teaching Faculty

Waleed Abdalati	José-Luis Jiménez	Mark Serreze
Roger Bilham	Craig Jones	Anne Sheehan
Maxwell Boykoff	Jennifer Kay	Robert Sievers
John Cassano	William M. Lewis Jr.	Margaret Tolbert
Xinzhao Chu	Peter Molnar	Greg Tucker
Shelley Copley	William Neff	Veronica Vaida
Lisa Dilling	R. Steven Nerem	Rainer Volkamer
Lang Farmer	Roger Pielke Jr.	Carol Wessman
Noah Fierer	Balaji Rajagopalan	Paul Ziemann

### CIRES Scientists

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

<sup>1</sup>We do not include Fellows pages for NOAA scientists in this report to NOAA.

**Researchers settle down under a starlit night, Scott Glacier, Cordova, Alaska, March 2013.** Dan McGrath/CIRES



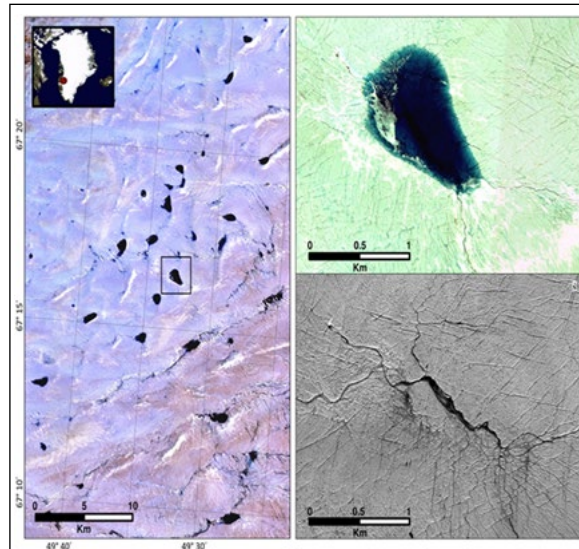


**Waleed Abdalati**

## 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 change the friction and deformation properties at the bottom of and within 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, and tracked the evolution of melt ponds from their formation through their drainage, 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 compaction of the near-surface firn (snow) on the Greenland ice sheet in order to improve the interpretation of satellite altimetry observations of ice-sheet-thickness changes. Greenland's recent warming temperatures and enhanced melt have significantly changed the compaction processes, and current field-based validation is essential for understanding these changes. Our group has recently deployed a network of eight stations, measuring

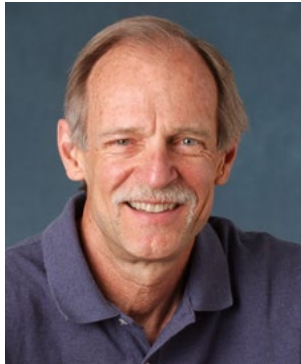


**True-color composite mosaic of WorldView-2 images of a 50 km x 25 km area in Greenland with 22 large melt lakes (left) and imagery of one of the lakes (shown with a rectangle in the left image) before and after drainage in the summer of 2011 (top right and bottom right respectively).** Moussavi et al, in preparation.

compaction at 33 boreholes across the ice sheet. This “FirnCover” network is the largest suite of compaction measurements ever deployed, and will be instrumental in significantly narrowing one of the largest sources of uncertainty in determining Greenland's contribution to sea level rise derived from airborne and satellite measurements of elevation changes.

Our third research area focuses on understanding the distribution and character of crevasses across the Greenland ice sheet. We have been using satellite and airborne lidar data and high-resolution optical satellite imagery to detect and map the distribution, spatial geometry, and evolution of crevasses across the ice sheet. Tracking the changing character of these crevasse features through time will allow us to better understand the mechanics that drive changes in the speed at which Greenland's glaciers flow to the sea.

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.



**Richard Armstrong**

## The CHARIS Project—The Contribution to High Asian Runoff from Ice and Snow

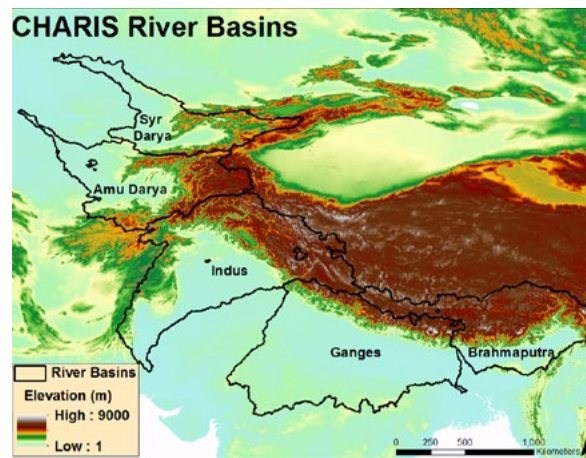
The CHARIS project operates with a dual mandate from its funder U.S. Agency for International Development to combine scientific research with capacity building to improve understanding of the regional water resources of High Asia. CHARIS is a cross-boundary exercise with University of Colorado Boulder scientists working directly with research partners at 10 institutions in eight different nations where ice and snow resources are located (Bhutan, Nepal, India, Pakistan, Afghanistan, Kazakhstan, Kyrgyzstan, Tajikistan). In this region, the amount, timing, and spatial patterns of melting snow and ice play key roles in providing water for downstream irrigation, hydropower generation, and general consumption.

CHARIS has achieved significant levels of effective cross-boundary collaboration and capacity building. CHARIS partners have participated in glaciology and hydrology short courses facilitated by CU-Boulder staff in Almaty, Kazakhstan (May 2013), and science conferences in Kathmandu and Pokhara, Nepal (November and December, 2013) and in Dehradun, India (October 2014), a hands-on training course including the application of digital elevation models to drainage basin delineation, mapping of glaciers and seasonal snow using satellite data, and the application of down-scaled reanalysis temperature data. In addition, in April 2015, CHARIS team member Adina Racoviteanu conducted

a three-day training course in GIS fundamentals and satellite remote sensing analysis for 18 faculty members at Sherubtse College, Kanglung, Bhutan.

In the study area, snow and ice both contribute significantly to streamflow, but no systematic in situ observations exist that can help distinguish between the two components of melt. Therefore, the specific research goal of CHARIS is to develop a melt model that can clearly

distinguish between seasonal snow and glacier ice melt at a large regional scale. We use a combination of Moderate Resolution Imaging Spectroradiometer (MODIS)-derived data sets to identify three surface types at daily resolution: 1.) Exposed glacier ice, 2.) Snow over ice, and 3.) Snow over land. We currently run several prototype melt models and compare results with measured river discharge, local sub-basin studies based on full energy balance modeling, as well as comparisons with isotopic and geochemical tracers used to identify and quantify the sources of water (ice melt, snow melt, rainfall, and ground water).



**Five CHARIS research basins.** Karl Ritter/NSIDC



**Group photo (Adina Racoviteanu is back row, 4<sup>th</sup> from left).** Sherubtse College



**Roger Bilham**

## Rising mountains, sinking gravity

Rivers, wind, rain, and ice are constantly at work eroding the surface of the Earth, dismantling rock in the mountains and transporting them as tiny fragments, eventually to the deep ocean floors. Because violent extremes of climate in mountains (and avalanches triggered by earthquakes) result in erosion rates that could level the highest of them to gentle hills in a few million years, their ubiquitous presence tells us that the mountains we see are actively growing. The ascent of mass upwards, as any mountaineer knows, demands energy, so exactly where does this energy come from?

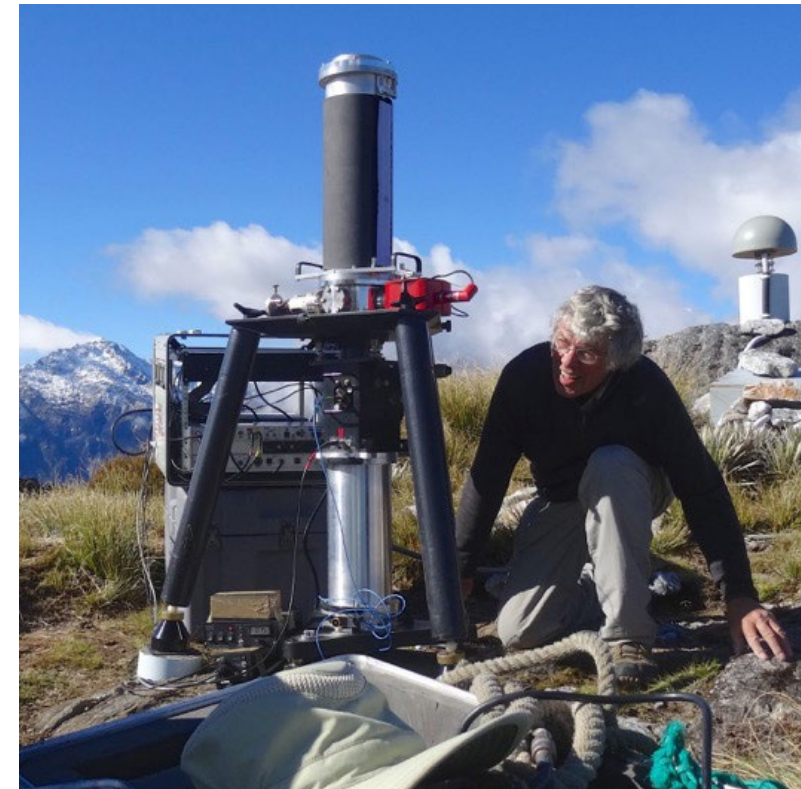
Three fundamental processes operate. The slow convergence between tectonic plates squeezes rock that rises, either through being pushed along upward sloping thrust planes, or through elastic and plastic processes akin to the kneading of dough (horizontal contraction results in vertical thickening). The third process is altogether unexpected. Imagine a block of wood floating on water. Now remove several v-shaped saw-cuts through the top half of the block. The block now floats higher in the water because it is lighter. Mountains effectively “float” on denser rocks in the Earth’s mantle and the erosion of river valleys causes the intervening ridges to rise.

Each of these three uplift processes is associated with subtle differences in the reduction in mass of rising mountains. At the turn of the millennium, an experi-

ment to distinguish their various contributions was conceived by New Zealand and CIRES scientists to compare the reduction of gravity (sensitive to mass changes) associated with the uplift of the Southern Alps. Gravity and GPS height were measured at 16 points in a transect across New Zealand’s south island, where uplift rates of up to six mm per year prevail. In 2014, we measured these same points to an accuracy of one microgal ( $\mu\text{Gal}$ ). Our measurements confirm that gravity reduced in the mountains (by about three  $\mu\text{Gal}$  per cm); however, even with 14 years of data, the anticipated contributions from the three candidate tectonic processes remain indistinguishable, largely due to unknown mass changes resulting from subsurface water table changes and glacier loss.

**Roger Bilham with the absolute gravimeter (left) and GPS sensor (on right) in New Zealand during 2104. A laser interferometer and atomic clock measure the acceleration of a mass in a vacuum to an accuracy of one part per billion, equivalent to a change in height of the mountains of 3 mm. The instrument is roughly 2 m high and weighs 200 kg with generator. The mass is dropped 200 times at the start of each hour for four to eight hours before being transported via helicopter to the next point.**

Roger Bilham/CIRES





**Maxwell Boykoff**

## Inside the Greenhouse

Over the years, I have drawn on tools from the social sciences and humanities, along with natural sciences, as I have pursued research in the spaces where formal climate science and policy find meaning in people’s everyday lives, and where public engagement influences climate science and policy priorities.

A project where these commitments manifest is “Inside the Greenhouse.” With Rebecca Safran (Department of Ecology & Evolutionary Biology) and Beth Osnes (Department of Theater & Dance), we have developed an interdisciplinary collaboration on creative climate communication called “Inside the Greenhouse.”

Through project work, we seek to deepen our understanding of how issues associated with climate change are or can be communicated, by creating artifacts (e.g., interactive theatre, film, fine art, performance art, television) and analyzing them while extracting effective methods for multimodal climate communications.

As part of this project, we have developed a two-course sequence across each academic year where we foster a deliberative space for University of Colorado Boulder students to critically engage and experiment with creative climate communications. Thus, they build capacity for more systematic, capable, and effective environmental communication strategies.

A second part of this project has been to build research projects that examine the efficacy of creative communications for enhanced awareness and engagement among segments of the public.

Third, we have held public events to spotlight accomplished climate communicators and interview them before a live audience about the process behind their communication products.

Fourth, we have developed an internship program to have our students leverage their experiences in our classes toward providing their services to graduate students and faculty on campus, and to community members, to highlight their work or serve their needs in creative climate communications.

Looking to scientific findings as the sole pathway to convince people to “do the right thing” risks overlooking many other influences contributing to ongoing debates regarding what are productive and “good” actions. These include cultural, political, psychological, and economic factors from the individual to the societal level. Through this project, we seek to operationalize these understandings, and improve creative climate communications in the 21<sup>st</sup> century.



**Inside the Greenhouse hosted guest William Kamkwamba at Casey Middle School, Boulder, Colorado. David Oonk/CIRES**



**John Cassano**

## Observing small scale atmospheric variability with unmanned aerial systems (UASs)

My research group studies a wide range of small-scale atmospheric processes, using both weather and climate models and various in situ observational tools. In 2009 and 2012, we flew relatively large (15 kg) Aerosonde unmanned aerial systems (UASs) to study air-sea coupling at Terra Nova Bay in the western Ross Sea, Antarctica, making the first in situ wintertime measurements in this climatically important area. These UASs allowed us to conduct long and complex missions, but required a six-person field team and a dedicated runway.

Starting in 2012, the Cassano research group began using smaller, less expensive UASs such as the Small Unmanned Meteorological Observer (SUMO). This UAS weighs less than 0.6 kg and has a wingspan of 0.8 m. Unlike the larger Aerosonde, this UAS can be operated by a field team of just two scientists and requires no dedicated facilities other than a laptop computer, making it ideal for use at remote field camps. In January 2014, a post-doctoral researcher in our group and I spent two weeks at a remote field camp on the Ross Ice Shelf making atmospheric boundary layer measurements with SUMO UASs. 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, as well as a



**SUMO UAS and a 30-m tall tower automatic weather station on the Ross Ice Shelf, Antarctica.**

John Cassano/CIRES

valuable data source to evaluate weather and climate models.

During the summer of 2014—with funding from a CIRES Innovative Research Proposal and in collaboration with scientists from the University of Colorado Boulder Department of Aerospace Engineering and the Department of Atmospheric and Oceanic Sciences—our research group deployed several different small



**DataHawk UAS developed by CU-Boulder Department of Aerospace Engineering.** Dale Lawrence/CU-Boulder

UASs at the National Renewable Energy Laboratory's National Wind Technology Center south of Boulder and at the Pawnee National Grassland in northeastern Colorado. During these deployments, we measured wind turbine wakes and the diurnal evolution of the atmospheric boundary layer.



**Thomas Chase**

# Evidence for the self-regulation of the Earth’s climate: Why do atmospheric temperatures display a clear physical limit?

with Benjamin M. Herman, Roger A. Pielke Sr.

Any lasting physical system must be self-regulated. Negative feedbacks to any regular disturbance must dominate. We have recently documented a well-known but perhaps underappreciated regulation mechanism in the Earth’s climate system—oceanic sea surface temperature-initiated convection, which keeps average temperatures in the most meteorologically important atmospheric level (500 mb, mid-troposphere) above the Earth’s surface in a statistically defined range

between about  $-42^{\circ}\text{C}$  and  $-3^{\circ}\text{C}$ . Northern Hemisphere mid-tropospheric atmospheric temperatures are clearly bracketed between these extremes as demonstrated in our data. Mid-tropospheric temperatures are significant meteorologically (i.e., for frontal identification and jet stream dynamics) and climatologically (e.g., changes in long term front and jet structures would be these brackets suggesting a limiting physical process or processes). This self-regulation of tropospheric temperatures constrains changes in jet stream and baroclinic storm dynamics and therefore constrains changes in climate variability.

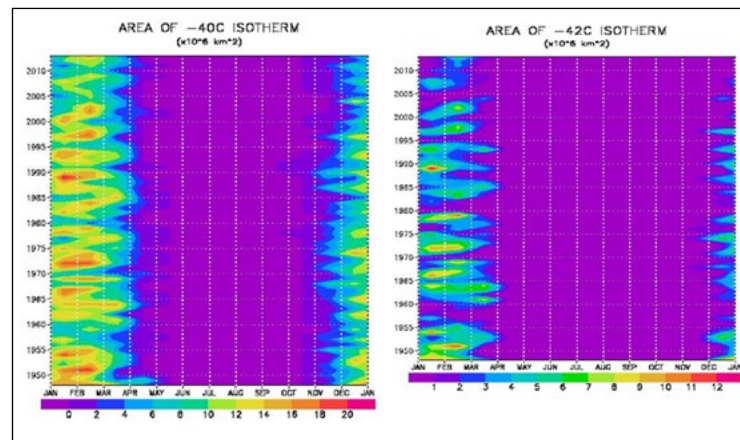
The figure shows the area of the  $-40^{\circ}\text{C}$  (left panel) and  $-42^{\circ}\text{C}$  (right) isotherm for

regions north of  $60\text{N}$  from reanalysis data vs. month and year. A notable feature is that the area of  $-40^{\circ}\text{C}$  begins to grow usually in November (non-purple regions to the right in each figure), reaches a maximum usually in January, and never grows larger despite the lack of solar energy inputs during the rest of the Arctic winter.

A similar physical behavior is seen in maximum temperatures dominated by the tropics. We investigated

the areal extent of the  $-5^{\circ}\text{C}$  and  $-3^{\circ}\text{C}$  (i.e., maximum) isotherm in the Northern Hemisphere; the  $-5^{\circ}\text{C}$  isotherm begins to appear in spring (April), but does not grow substantially as the northern summer proceeds—an indication of a physical limit. A further indication of this physical limit is that the area of the  $-3^{\circ}\text{C}$  isotherm is near zero in almost every year.

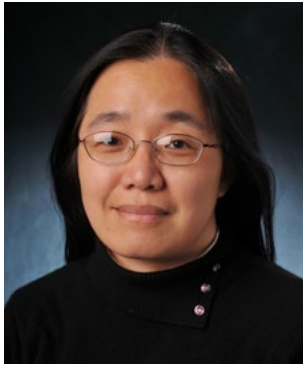
We have given multiple lines of evidence here that a natural self-regulation of the mid-troposphere exists which brackets temperatures in this atmospheric region within a band of  $-3^{\circ}\text{C}$  to  $-42^{\circ}\text{C}$ . Because jet stream dynamics, fronts, and baroclinic storm development are a response to the equator-to-pole gradient of layer averaged tropospheric temperatures (Pielke, 2013, Chapter 14), long-term trends in these weather processes, and therefore trends in climate variability, are constrained by this self-regulation. Based on these data, this will likely continue until sea surface temperature significantly changes to warmer than  $-2^{\circ}\text{C}$  in high latitudes, warmer than  $32^{\circ}\text{C}$  in the tropics, or both.



**Hovmuller-like diagram of the changes in monthly averaged area of the  $-40^{\circ}\text{C}$  and  $-42^{\circ}\text{C}$  isotherms for regions north of  $60\text{N}$  from NCEP-NCAR reanalysis 1979-2013.**

**Reference**

Pielke Sr., R.A. (2013). “Mesoscale meteorological modeling,” third edition. Waltham, MA: Academic Press-Elsevier.

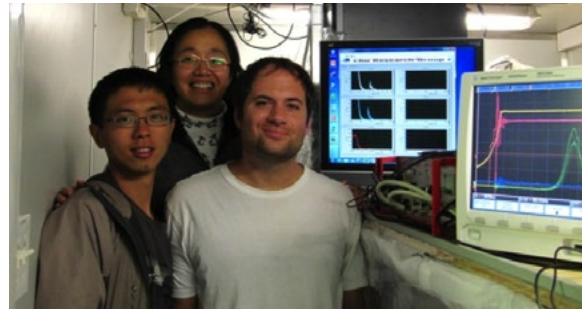


**Xinzhao Chu**

## A year of rich scientific harvest in lidar research

Successfully completing three major lidar development projects, graduating three Ph.D. students in Aerospace Engineering Sciences, and publishing several new discoveries mark a year of rich scientific harvest in lidar research! In September, the Chu Research Group achieved first light for the most advanced upper atmosphere lidar in the world: The Major Research Instrumentation (MRI) Fe Doppler lidar, which our team built and installed at Table Mountain, Colorado. The team also completed significant upgrades on a Na Doppler lidar at Cerro Pachon, Chile, and a K Doppler lidar at Arecibo Observatory, Puerto Rico, both during the summer of 2014.

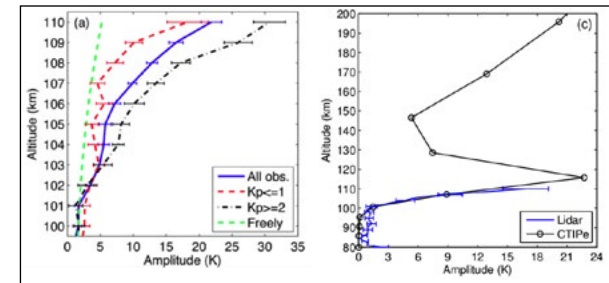
In collaboration with Tim Fuller-Rowell (NOAA and CIRES) and Art Richmond (National Center for Atmospheric Research), CIRES graduate student Weichun Fong conducted modeling studies to better understand the lidar-discovered fast growth of diurnal tidal amplitude with altitude above 100 km in Antarctica. We discovered that Hall-ion-drag induced adiabatic effects are responsible and such diurnal amplitude enhancement forms a concentric ring encircling the south geomagnetic pole and overlapping the auroral zone (Fong et al., GRL, 2015). From the simultaneous Fe Boltzmann and Na Doppler lidar observations at Table Mountain, the ratio of the downward fluxes of Fe and Na near the mesopause was measured to be  $2.57 \pm 1.09$  (Huang et al., GRL, 2015). We find that



**The first light of the MRI Fe Doppler lidar in September 2014 at Table Mountain, north of Boulder. CIRES graduate students Weichun Fong and John Smith with Professor Xinzhao Chu.** Xinzhao Chu/CIRES

the particles responsible for injecting a large fraction of the ablated material into the Earth's upper atmosphere enter at relatively slow speeds and originate primarily from the Jupiter-family comets.

We have four champions who have done outstanding Ph.D. research: John A. Smith, Zhibin Yu, Weichun Fong, and Cao Chen. John and Zhibin earned their Ph.D. degrees in December 2014, Weichun finished in the summer of 2015, and Cao is expecting a PhD in December 2015. We have also had four amazing student prizewinners in re-



**Left: Lidar-discovered fast growth of diurnal temperature tidal amplitude with altitude from 100 to 110 km at McMurdo, Antarctica** Fong et al., JGR, 2014 **Right: Successful reproduction of the lidar observations by the Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics (CTIPE) model.** Fong et al., GRL, 2015

cent years: Chihoko Yamashita (2011), Cao Chen (2012), Zhibin Yu (2013), and Weichun Fong (2015) who won first-place prizes in the Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) Student Poster Competitions, sponsored by the National Science Foundation. Over the last seven years, our students have won four 1<sup>st</sup> place prizes and three 2<sup>nd</sup> place prizes, and the latest is Weichun winning the first place prize in June 2015.



**Shelley Copley**

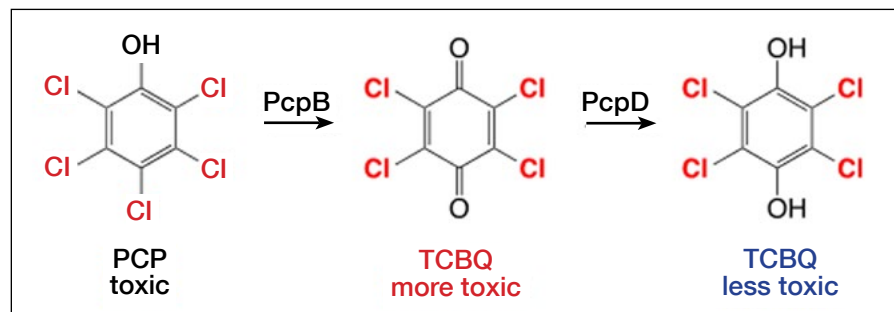
## Sequestration of a highly reactive intermediate during degradation of pentachlorophenol

Highly reactive intermediates are produced in many metabolic pathways. Preventing these intermediates from undergoing side reactions is important to prevent loss of flux through metabolic pathways and damage to other cellular molecules. Billions of years of evolution have led to exquisite mechanisms for controlling the fate of highly reactive intermediates. A common solution is channeling of an intermediate from the active site at which it is made in one protein to the active site at which it is consumed in another. An even more impressive solution is channeling through tunnels that connect multiple active sites in single proteins.

Formation of highly reactive intermediates poses a particular challenge for the degradation of anthropogenic pollutants when new metabolic pathways are cobbled together using promiscuous activities of previously existing enzymes. This problem is exemplified by the formation of tetrachlorobenzoquinone (TCBQ), a strong electrophile and oxidant, during the degradation of pentachlorophenol (PCP) by *Sphingobium chlorophenolicum*. We recently discovered that TCBQ is sequestered during the conversion of PCP to tetrachlorohydroquinone (TCHQ) by the sequential action of PCP hydroxylase (PcpB) and TCBQ reductase (PcpD). We expected that TCBQ would be channeled from one active site to another. To our surprise, we found that PcpD delivers electrons

to TCBQ while it is still in the active site of PCP hydroxylase. This interaction prevents damage to cellular constituents, particularly thiols, during degradation of PCP.

PCP hydroxylase and TCBQ reductase are encoded by an operon, and thus likely constituted a functional unit before the appearance of PCP in the environment. The original function of these enzymes is unknown, but may well have been degradation of a naturally-occurring phenol via a benzoquinone intermediate. Such intermediates are uncommon, occurring only when a good leaving group is present at the site of the initial ring hydroxylation. The recalcitrance of PCP in the environment may be due to the infrequent occurrence of a pre-existing hydroxylase/reductase enzyme pair capable of preventing the escape of TCBQ.



**The initial step in degradation of PCP produces an intermediate that is even more toxic than PCP itself.** Shelley Copley/CIRES





**Joost de Gouw**

## Atmospheric effects of domestic oil and natural gas production

Over the past decade, the United States has seen a strong growth in the domestic production of oil and natural gas as a result of technological advances in hydraulic fracturing and horizontal drilling. In our research, we address the question how this shift in our energy production and use is affecting the atmosphere.

Compared to coal, natural gas is a lower-carbon fuel, and the increased use of natural gas for power generation has led to significant reductions in the emissions of carbon dioxide, the most important greenhouse gas in the atmosphere. Natural gas is also a cleaner-burning fuel than coal, and the increased use has led to strong reductions in the emissions of nitrogen oxides and sulfur dioxide from power plants with important advantages for air quality. These compounds react in the atmosphere to form fine particles and surface ozone, which are chiefly responsible for air quality issues in the United States. On the flip side, the production of oil and natural gas is also associated with emissions of pollutants into the atmosphere. Natural gas consists mostly of methane, and even small leaks of this strong greenhouse gas can offset or even negate the reductions in carbon dioxide emissions that resulted from the shift of coal towards natural gas. Oil and natural gas also contain many other hydrocarbons that can be released into the atmosphere and contribute to the formation of ozone and fine particles.

To address the overall effects of these large shifts in our energy production and use on the atmosphere, I led the NOAA Shale Oil and Natural Gas Nexus (SONGNEX) study in the spring of 2015. A team of researchers from CIRES, NOAA, NASA, and several universities outfitted the NOAA WP-3D aircraft with a large suite of chemical instruments and sampled emissions associated with

oil and natural gas production in North Dakota, Wyoming, Utah, Colorado, New Mexico, Oklahoma, Texas, and Louisiana. The results will be used to quantify the emissions of methane and reactive trace gases into the atmosphere and to study the effects that these emissions have on air quality and climate.



SONGNEX research team in front of the NOAA WP-3D research aircraft. David Oonk/CIRES



**Lisa Dilling**

## The dynamics of vulnerability and adaptation

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. My research asks 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?

Recent reports and scholarship suggest that adapting to current climate variability may represent a “no regrets” strategy for adapting to climate change. Addressing “adaptation deficits” and other approaches that target existing vulnerabilities are helpful for responding to current climate variability, but we argue that they may not be sufficient for adapting to climate change. With colleagues, I am working on why the dynamics of



**CIRES graduate student Meaghan Daly and research assistant Shiyo Alakara talk with Maasai villagers as part of a research project on improving information for climate adaptation in Tanzania. The work is funded by the United States Agency for International Development.**

Lisa Dilling/CIRES

vulnerability matter for adaptation efforts. We draw on vulnerability theory and the natural hazards and climate adaptation literatures to outline how adaptation to climate variability, combined with the shifting societal landscape, can sometimes lead to unintended consequences and increased vulnerability. Moreover, we argue

that public perceptions of risk associated with current climate variability do not necessarily position communities to adapt to the impacts from climate change. We suggest that decision makers faced with adapting to climate change must consider the dynamics of vulnerability in a connected system—how choices made in one part of the system might impact other valued outcomes or even create new vulnerabilities. We suggest a need for greater engagement with various publics on the tradeoffs involved in adaptation action and for improving communication about the complicated nature of the dynamics of vulnerability (Dilling 2015).

### Reference

Dilling, L., Daly, M. E., Travis, W. R., Wilhelmi, O. V., & Klein, R. A. (2015). The dynamics of vulnerability: why adapting to climate variability will not always prepare us for climate change. *WIREs Climate Change*, 6, 413–425. 10.1002/wcc.341



## Lang Farmer

# Deep crustal anatexis, magma mixing, and the generation of epizonal plutons in the Southern Rocky Mountains, Colorado

In 2014–2015 Farmer’s research group completed studies of the origin and evolution of magmatism in Colorado over the past 40 million years. This magmatism is of interest first because it occurred some 1,000 km inboard of the nearest plate margin, where magmatism is usually concentrated in the Earth. In addition, some of the igneous rocks formed during this time in Colorado are responsible for the production of economic molybdenum ore deposits now found in the state.

This project was the focus of the doctoral thesis completed by CIRES graduate student Kristin Jacob. Kristin’s thesis involved geological, geochronological, and geochemical studies of igneous rocks now exposed in the Never Summer Mountains along the western margin of Rocky Mountain National Park. Her work on the intrusive igneous rocks that comprise the crest of the mountain range clearly demonstrated that these rocks were derived from magmas formed by melting (anatexis) of existing continental crust during the infiltration into the crust of mantle-derived magmas produced at greater depth. What made the work unusual is that Kristin was able to determine exactly what melted in the crust by comparing the chemical characteristics of the anatectic melts to those determined directly for the deep crust in Colorado; this was because samples of the crust had been brought to the Earth’s surface by kimberlites emplaced in

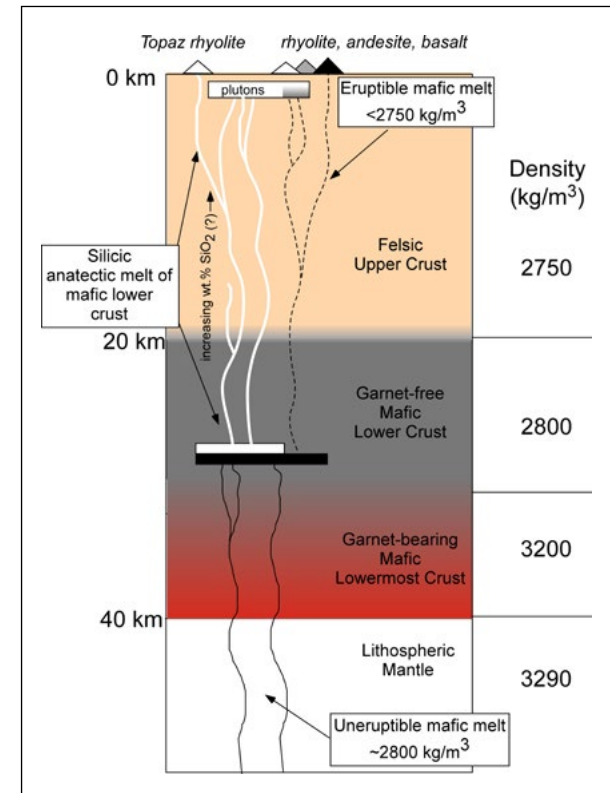
the Front Range area some 300 million years ago. Kristin concluded that crustal anatexis must have occurred in the upper portions of the lower continental crust, and not at its base where mantle-derived magmas might be expected to stall (figure). At this level in the crust, melting of fluorine-rich minerals in the crust apparently scavenged molybdenum and delivered it to the upper crust, forming the ore deposits observed today. These results were published this year in the journal, *Contributions to Mineral and Petrology*.

### Reference

Jacob, K. H., Farmer, G. L., Buchwaldt, R., & Bowering, S. A. (2015). Deep crustal anatexis, magma mixing, and the generation of epizonal plutons in the Southern Rocky Mountains, Colorado. *Contributions to Mineral and Petrology*, 169. 10.1007/s00410-014-1094-3

**Cartoon depicting a small-volume magma system operating beneath north central Colorado 30 million years ago.**

*Contrib. Mineral. Petrol.* 2015, Lang Farmer/CIRES





**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 ESRL. 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.

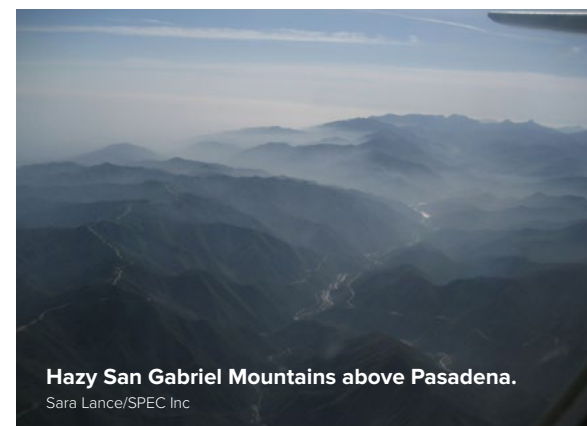
Our research approach involves making reliable measurements of the species that control tropospheric chemistry through comprehensive, integrated field studies that utilize state-of-the-art airborne, ship-based, and ground-based instrument packages that are deployed in regional assessments conducted throughout the United States followed by a systematic analysis and appraisal of the results. Since 1999, NOAA and CIRES have jointly undertaken nine 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 2010 CALNEX (California at the Nexus of Air Quality and Climate Change) field study. The details of the study are given in the recently published study overview (Ryerson, T.B. 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 are published in the peer-reviewed scientific literature, with an additional four papers submitted and 35 in preparation (<http://tinyurl.com/CalNex-papers>). Second, scientific findings from the CALNEX study have been distilled into a statement of findings concerning 23 policy-relevant science questions that were formulated by the California Air Resources Board in consultation with NOAA (<http://tinyurl.com/owu3qzp>). This directly provides badly needed information on current national environmental concerns. Finally, the data from CALNEX and the studies preceding and following it (<http://tinyurl.com/o2qz6ku>) are available to the scientific community to compare with ongoing studies to better understand and predict the atmospheric environment of the future.

In 2015, I intend to assist in the interpretation and reporting of the data taken during the recently completed (March/April 2015) SONGNEX 2015 (Shale Oil and Natural Gas Nexus) study, a comprehensive field measurement project that was aimed at better understanding the



atmospheric effects of changing energy use in the United States on regional and local air quality and regional and global climate forcing. A description of the study can be found in the SONGNEX White Paper (<http://tinyurl.com/pea9t43>).

### Reference

Ryerson, T. B., et al. (2013). The 2010 California Research at the Nexus of Air Quality and Climate Change (CalNex) field study. *Journal of Geophysical Research Atmospheres*, 118, 5830–5866. 10.1002/jgrd.50331



Noah Fierer

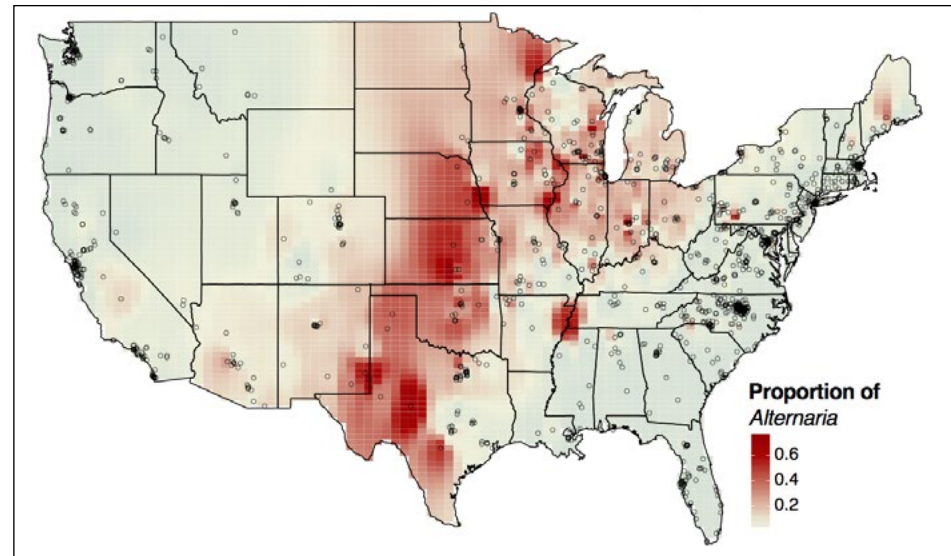
## Building a continental-scale atlas of airborne microbial diversity

Microbes are ubiquitous and abundant in the atmosphere. There are typically millions of bacterial and fungal cells per cubic meter of air and these microbes are inhaled every time we step outside. Although most of these microbes are harmless, some can cause disease in livestock, plants, and humans. For the 20 percent of the U.S. population that suffers from asthma or seasonal allergies, airborne microbes are particularly important, given that they are common triggers of allergies.

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, home occupants, home design, and surrounding land-use types influence microbial air quality inside and outside our homes.

My group has been using recent advances in high-throughput DNA sequencing to describe bacterial and fungal diversity in dust samples collected inside and outside more than 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 country to participate in the scientific process.

This broad-scale survey has not only allowed us to build the first maps of U.S. airborne bacterial and fungal diversity, we have also been able to predict what types of bacteria and fungi we are exposed to when breathing the air inside or outside our homes. For example, we have shown that fungal diversity varies as a function of local climate conditions and that we can use information on the hundreds of fungal taxa found in individual dust samples as a novel forensics tool to identify the geographic origin of that sample. Likewise, we have shown how the presence of dogs or cats in a home can lead to consistent changes in the types of bacteria found inside our homes. We are



**Relative abundance of *Alternaria* genus fungi in house dust samples. *Alternaria* is one of the main triggers of allergies and allergenic asthma. Darker colors indicate higher relative abundances.** Noah Fierer/CIRES

currently expanding on this work to more specifically understand how exposures to plant, fungal, insect, and bacterial allergens vary across the United States.



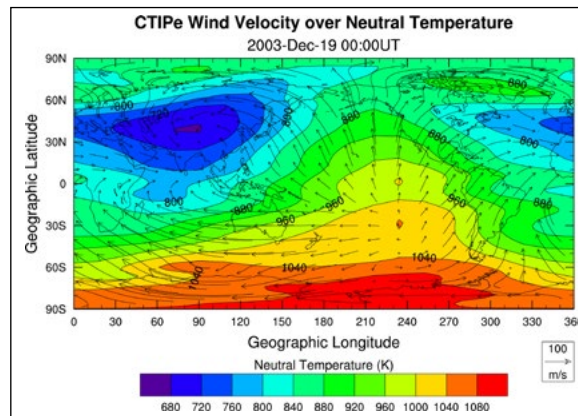
**Timothy Fuller-Rowell**

# What does the upper atmosphere really look like?

Our traditional paradigm of the upper atmosphere has been influenced by physical models of the thermosphere and ionosphere system, together with empirical models derived from the accumulation of observations over several decades. The conventional image of, say, the global temperature distribution at 200 km would look something like the smooth pattern in Figure 1. At mid and low latitudes, you see the expected higher temperatures on the dayside from heating by solar extreme UV radiation. Since this is the December solstice, the southern hemisphere appears hotter, and the magnetospheric sources at higher latitudes add an extra heat source. A plot from an empirical model would look more or less the same. The main point from this image is that the pattern is smooth, and displays little in the way of variability.

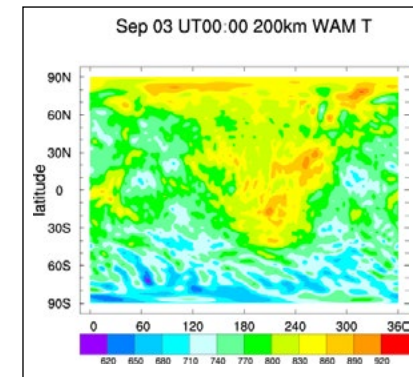
In contrast is Figure 2, taken from a “whole atmosphere model.” You can still make out the basic day/night temperature differences but the overall pattern is now dominated by structure and variability. Which of the two is closer to reality? It’s hard to make the same image from observations, so we have to piece together information from a variety of sources to answer this question; however, all indications are that the picture from the whole atmosphere model might be what the upper atmosphere really looks like.

These new whole atmosphere models, even with their



**Figure 1. The pattern of temperature in the upper atmosphere we have come to expect from physics-based or empirical models, from a coupled thermosphere-ionosphere-plasmasphere physical model.** Mariangel Fedrizzi

relatively coarse spatial resolution, have changed the paradigm of how we view the upper atmosphere. The source of the structure and variability arises from waves propagating from the troposphere and stratosphere, driven by the normal day-to-day changes in terrestrial weather patterns. The neutral atmosphere, which makes up over 99.9% of the upper atmosphere, is the carrier of the waves, but they



**Figure 2. This is probably a much more realistic rendition of the upper atmosphere if we could only image it from space. The figure is from a whole atmosphere model including all the tropospheric natural variability we expect from the weather.**

Observations also show that intense weather or convective storm complexes can be seen as concentric rings of ionospheric disturbance. Higher resolution versions of whole atmosphere models will be able to model these space weather impacts across the rich spectrum of waves.

collide with the tenuous plasma; then, through ion-neutral interactions, the neutral atmosphere imprints its variability on the ionosphere. The undulations in the ionosphere affect the propagation of radio waves, impacting communications and navigations.



**R. Michael Hardesty**

## Lidar remote sensing for weather and climate research

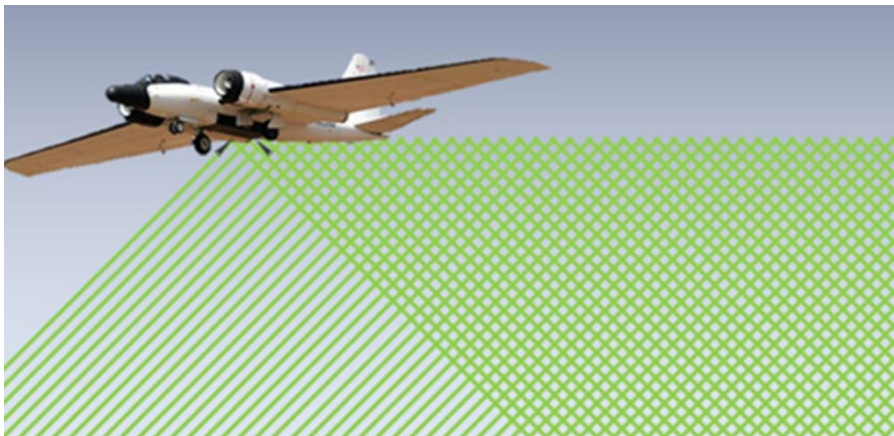
We continue to investigate new lidar (light detection and ranging) technology and applications directed at understanding important climate processes and improving atmospheric forecasting. Building on two decades of experience working on state-of-the-art Doppler lidar development, we have deployed a number of commercial Doppler instruments to support greenhouse gas emission characterization and wind energy forecasting. One such application is the Indiana Flux Study (INFLUX), for

which we have operated a compact commercial Doppler instrument near downtown Indianapolis for almost two years. The primary goal of INFLUX is development of techniques for estimating emissions of carbon dioxide and methane from large-area sources (e.g., urban areas and oil and gas fields). Such techniques are critical for assessing current emissions and evaluating future changes. The lidar utilizes different scanning methodologies to estimate profiles of horizontal and vertical wind velocity,

vertical velocity variance, and backscattered signal power three times per hour. Results provide information on mixing layer depth, mixing strength, and horizontal transport, which are used with aircraft observations and incorporated into inverse models to calculate fluxes and emissions. The lidar measurements have shown that daytime mixing layer depth varies significantly over time scales of tens of minutes as large-scale

updrafts and downdrafts affect the top of the layer. We also observed that the commercial lidar used at INFLUX was sometimes unable to reach the top of the layer during clear conditions; we are currently modifying the instrument to increase sensitivity.

We are also studying satellite-based Doppler lidar as a candidate for measuring wind profiles over remote areas of the globe. Observing System Simulation Experiments have shown that assimilation of wind information from an orbiting lidar instrument would improve weather forecasts and prediction of significant weather events; it would also aid climate research by improving reanalysis data sets used to assess important changes in long-term atmospheric variables. In cooperation with Ball Aerospace, we are assessing an aircraft version of a space-based wind lidar design. An aircraft campaign is planned for spring 2016 to evaluate the lidar's sensitivity and precision. A successful test will potentially pave the way for eventual deployment on a space platform such as the International Space Station.



**Diagram showing the scan pattern for deployment of a wind lidar on the NASA WB-57 aircraft to test the feasibility of measuring winds from a space platform.** Ball Aerospace



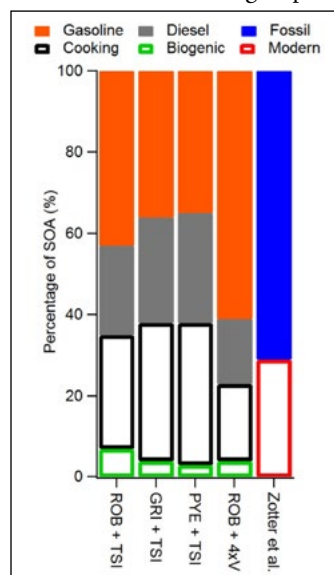
**José-Luis Jiménez**

## 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 submicron aerosol mass, include anthropogenic pollution, biogenic compounds, and biomass burning. The amount, properties, and evolution of OA are poorly characterized, and our group combines field, laboratory,

and modeling research to better constrain them.

We recently completed a modeling study using measurements collected during a



**Estimated fractional contribution to SOA mass from gasoline vehicles, diesel vehicles, cooking emissions, and in-basin biogenic emissions, in addition to fossil vs. modern carbon contributions in Los Angeles.**

Hayes et al., 2014

large collaborative study in Los Angeles (CalNex). We evaluated the amount and chemical composition of secondary OA (SOA) predicted by different models. The amounts of SOA from diesel vehicles, gasoline vehicles, and cooking are estimated as 16–27 percent, 35–61 percent, and 19–35 percent, consistent with the observed fossil fraction, 71 percent (figure). We propose a simple model to predict SOA concentration and oxygen content from urban emissions. This work points to important anthropogenic sources of non-fossil carbon from cooking. Results are extrapolated to global budgets.

In addition to ongoing analysis from field campaigns (SOAS, BEACHON-RoMBAS, CalNex, DC3, SEAC4RS), this year we:

- participated in a campaign in the Amazon (GoAmazon14/15) to investigate OA during the dry season, where air has a range of influences including pristine tropical rainforest, urban pollution, and biomass burning;
- flew our airborne aerosol mass spectrometer on the NCAR C130 in the U.S. Northeast (WINTER campaign), focused on photochemical and multiphase chemistry, emissions, and transport in wintertime;
- conducted chamber studies at CU-Boulder focused on SOA formation from terpenes (emitted by coniferous trees) and  $\text{NO}_3$  (formed from ozone and

anthropogenic  $\text{NO}_x$ );

- participated in the FIXCIT chamber study at Caltech, on isoprene (emitted from deciduous trees) chemistry;
- conducted an indoor chemistry study in a CU-Boulder classroom;
- pursued several instrument development and characterization efforts for advanced mass spectrometers that are the main tools of our research; and
- developed and evaluated models of radical chemistry in oxidation flow reactors.

Another major focus has been designing and building a shared lab facility with dual atmospheric simulation chambers with controllable temperature, humidity, and visible/UV light. They will be used to study gas and aerosol chemistry for a variety of conditions found in the atmosphere.

### Reference

Hayes, P. L., et al. (2014). Modeling the formation and aging of secondary organic aerosols in Los Angeles during CalNex 2010. *Atmospheric Chemistry and Physics Discussions*, 14, 32325-32391. 10.5194/acpd-14-32325-2014



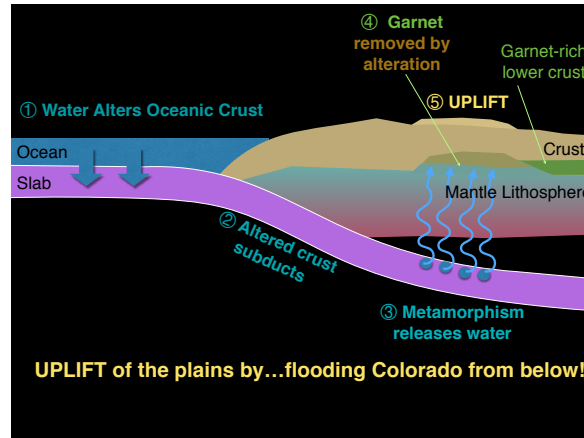


Craig Jones

## Elevating Colorado with water

An ongoing mystery has been the reason why Denver (and much of the surrounding High Plains) is a mile above sea level. Although deformation to the west of the Mile High City might explain the elevation of the mountains, the plains to the east lack both the kinds of faults that would thicken the crust and produce uplift and significant volcanic activity, since the region was at or below sea level some 70 million years ago. Because of the lack of evidence for some event that would alter the Earth's surface, most scientists have looked to changes in the mantle lithosphere under the plains to support these high elevations.

This year I published a paper with CU-Boulder Geological Science professor Kevin Mahan, CIRES Fellow and Geological Science professor Lang Farmer, and former CU-Boulder students Will Levandowski and Lesley Butcher, suggesting a heretofore-unexplored possible explanation for the High Plains. Samples of the deep crust brought up by volcanoes in Montana and Wyoming reveal gradual changes from low elevations to high elevations. Under the low areas near Canada, the lower crust is rich in garnet, but samples farther south have progressively less garnet. Garnet is a very dense mineral; when replaced by less dense phases, the crust becomes more buoyant and rises. The trigger for the removal of the garnet is the addition of water—in this case, water rising up from a subducted slab of ocean floor that passed under the region some 45 to 75 million years



Elevating Colorado with water, a short animation:

<http://tinyurl.com/nv5ktu7>

ago. Such water had not been known to rise into the crust, but a sample of the deep crust from the Four Corners area contained minerals dating this hydration event to that same 45 to 75 million years ago.

Although this hypothesis is consistent with seismological observations in the region, future work will be necessary to fully define the importance of this mechanism in supporting the High Plains.



The High Plains. Craig Jones/CIRES



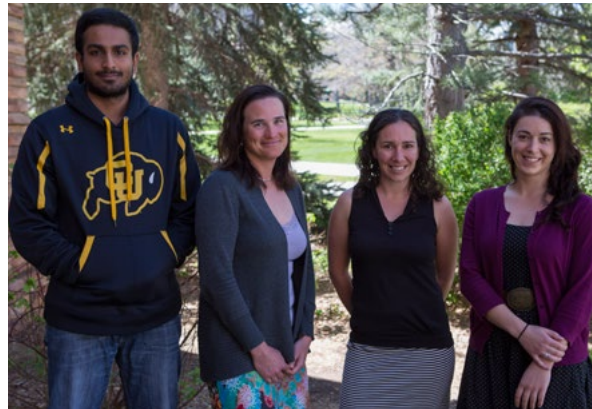
**Jennifer Kay**

## Influence of Southern Ocean clouds on global climate

The poorly observed and rapidly changing polar regions present many exciting research opportunities of global importance. My group uses satellite observations and global coupled climate modeling to understand the processes controlling polar climate change and variability. We work at the nexus of observations and modeling.

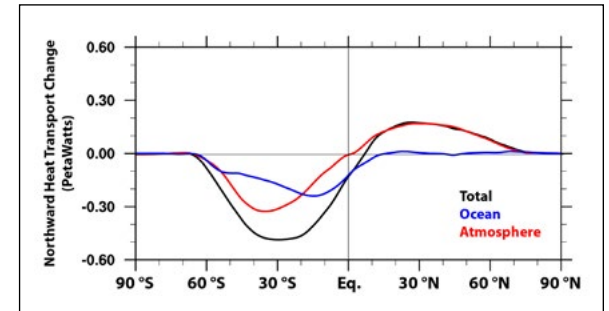
Atmospheric and Oceanic Sciences (ATOC) Ph.D. candidate Ariel Morrison researches the processes controlling Arctic cloud formation, vertical structure, and phase. ATOC Ph.D. candidate Vineel Yettella researches precipitation changes in extratropical cyclones in a warming world. Honorary group member Line Bourdages (McGill University) researches Arctic temperature inversions and visited the group for the spring semester. The Kay group (photograph) has had a busy and productive year. Here, we describe results from a paper recently submitted to the *Journal of Climate*.

The Southern Ocean is the cloudiest place on Earth. No doubt I am obsessed with understanding the influence of the intriguing cloud structures found there on the global climate system. Working with Vineel and external collaborators, I dramatically reduced long-standing shortwave radiation biases in a state-of-the-art global coupled climate model by improving the match between observed and modeled cloud supercooled liquid water in Southern Ocean clouds. The global energy budget



**Kay group in spring 2015. From left to right, Vineel Yettella, Jennifer Kay, Line Bourdages (McGill University), and Ariel Morrison.** David Oonk/CIRES

and circulation impacts of the shortwave radiation bias reductions I made are profound. The resulting cooler, brighter Southern Ocean and warmer, dimmer tropics increased poleward heat transport and strengthened atmospheric jets, especially in the Southern Hemisphere (figure). However, perhaps the most exciting result was a null result with relevance to global climate dynamics. In response to Southern Ocean cooling, cross-equatorial heat transport increased in the ocean, but not in



**Brightening Southern Ocean clouds produce large changes in atmosphere and ocean heat transport and circulation.** Adapted from Figure 8, Kay et al., *J. Climate*, submitted

the atmosphere. As a result, a proposed atmospheric teleconnection that links Southern Ocean cooling with northward shifts in the Intertropical Convergence Zone was not found. These results provide concrete evidence that Southern Ocean clouds impact global atmospheric and oceanic circulation patterns in fundamental and surprising ways. Next up is understanding the implications of these results for climate feedbacks. Specifically, does having more realistic Southern Ocean clouds change the sign of the negative Southern Ocean cloud-climate feedback?



**William M. Lewis Jr.**

## Efficiency of designed and evolved energy production systems

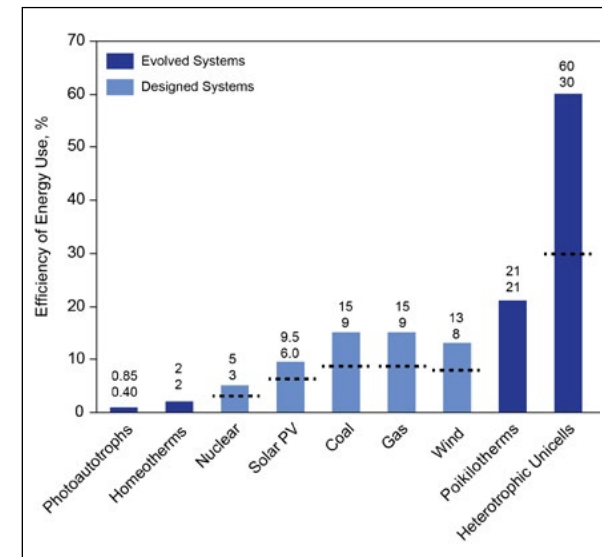
Dominant designed energy production systems include those based on fossil fuels, nuclear power, solar energy, and wind energy. The efficiency of these energy production systems is continually maximized technologically, thus constraining cost per kilowatt of energy.

A living organism is an evolved energy producing system whose efficiency is determined by natural selection, which is the cause of evolution in metabolic functions. Because living organisms have been exposed to the forces of natural selection for at least 3 billion years, it would seem that organisms must have reached some limits of efficiency reflecting absolute physical constraints. Therefore, it is interesting to compare efficiencies of designed and evolved energy systems, but this has not been done in a comprehensive way.

Surprisingly, evolution of organisms has resulted in a great range of efficiencies (0.8-60%), whereas the designed sources of energy have a much narrower range of efficiencies (5-13%, figure). Diversity in energy efficiency of organisms is explained by evolutionary tradeoff between efficiency (percent allocation to growth) and capacity (energy flux per unit mass). Algae and vascular plants (autotrophs) have low efficiency and low capacity because their energy production system (photosynthesis) involves the synthesis of organic matter from CO<sub>2</sub>, which is energetically expensive and is drawn from a

source (sunlight) that is weak per unit area. Other organisms (heterotrophs), which do not conduct photosynthesis, show much higher efficiency because they use photosynthetic byproducts created by plants, thus avoiding the necessity of forming organic matter from CO<sub>2</sub>. Unicellular heterotrophs (e.g., bacteria) are extraordinarily efficient (e.g., 60%) and have high capacity, but their capacity declines rapidly with increasing size, and thus cannot compete directly with multicellular organisms, which have lower efficiency but higher capacity. Mammals and birds are very inefficient (e.g., 2%), but have extraordinary capacity because of their sustained high body temperature. Poikilotherms (invertebrates, reptiles, amphibians, fishes) lie between the extremes, with higher efficiency but lower capacity than mammals and birds.

Because natural selection has produced varied strategies in the tradeoff between efficiency and capacity for distinct forms of life, living organisms show a much wider range of efficiencies than designed energy systems. Designed energy systems have a much simpler motivating mechanism, (i.e., economic value constrained primarily by efficiency and very little by capacity).



**Energy efficiency expressed as free energy allocated to final use for evolved (final use: growth) and designed (final use: work) energy systems under favorable conditions (bar height) and characteristic conditions (mid bar mark).** William M. Lewis Jr/CIRES

fellows



**Peter Molnar**

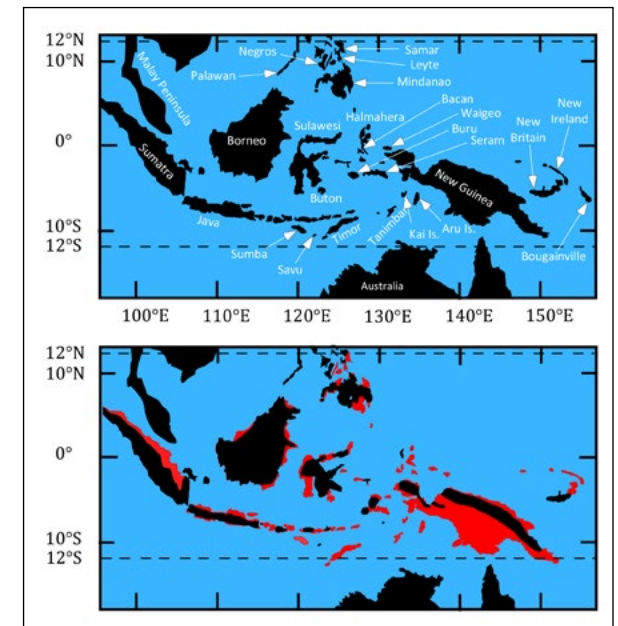
## Growth of the maritime continent and its possible contribution to recurring ice ages

The areal extent of the Maritime Continent (the islands of Indonesia and surrounding region) has grown larger by ~60% since 5 Ma (figure). Tim Cronin (Harvard University) and I argue that this growth might have altered global climate in two ways that would have contributed to making recurring ice ages possible. First, because rainfall over the islands of the Maritime Continent not only is heavier than that over the adjacent ocean, but also correlates with the strength of the Walker Circulation, the growth of the Maritime Continent since 5 Ma may have contributed to the cooling of the eastern tropical Pacific since that time. Scaling relationships between the strength of the Walker Circulation and rainfall over the islands of the Maritime Continent and between sea surface temperature (SST) of the eastern tropical Pacific and the strength of easterly wind stress suggest that the increase in areal extent of islands would lead to a drop in that SST of 0.75°C. Although only a fraction of the 3-4°C decrease in SSTs between the eastern and western tropical Pacific, the growth of the Maritime Continent may have strengthened the Walker Circulation, increased the east-west temperature gradient across the Pacific, and thereby enabled ice sheets to wax and wane over Canada since 3 Ma. Second, because the weathering of basaltic rock under warm, moist conditions extracts CO<sub>2</sub> from the atmosphere more rapidly

than weathering of other rock or of basalt under cooler or drier conditions, the increase in weathering due to the increasing area of basalt in the Maritime Continent may have drawn down enough CO<sub>2</sub> from the atmosphere to affect global temperatures. Simple calculations suggest that increased weathering of basalt might have lowered global temperatures by 0.25°C, which is possibly important for the overall cooling.

### Reference

Molnar, P., & Cronin, T. W. (2015). Growth of the Maritime Continent and its possible contribution to recurring Ice Ages. *Paleoceanography*, 30, 196-225. doi: 10.1002/2014PA002752



**Maps of the Maritime Continent showing present-day land (top) and that for 5 Ma (bottom), where submerged terrain is shown in red and islands have been moved to their positions at 5 Ma.** From Molnar and Cronin, 2015



William Neff

## Factors behind Greenland ice surface melting in 2012 and 1889

Recent decades have seen increased melting of the Greenland ice sheet. On 11 July 2012, nearly the entire surface of the ice sheet melted; such rare events last occurred in 1889 and, prior to that, during the Medieval Climate Anomaly. Studies based on data collected during the ICECAPS project for the 2012 event associated the presence of a thin, warm elevated liquid cloud layer with surface temperatures rising above the melting point at Summit Station, some 3212m above sea level.

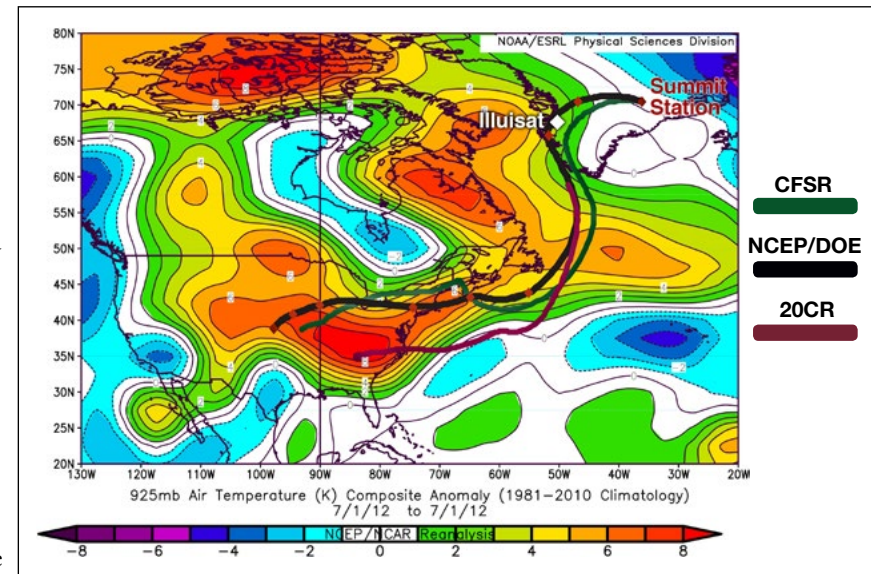
In a recent paper, my colleagues and I explored other potential factors in July 2012 associated with this unusual melting (Neff et al. 2014). These include 1.) warm air originating from a record North American heat wave, 2.) transitions in the state of the Arctic Oscillation, 3.) transport of water vapor via an Atmospheric River (AR) over the Atlantic to Greenland, and 4.) the presence of warm ocean waters south of Greenland.

For the 1889 episode, the Twentieth Century Reanalysis and historical records showed similar factors at work. However, markers of biomass burning were evident in ice cores from 1889, which may reflect another possible factor in these rare events. We suggested that extreme Greenland summer melt episodes, such as those recorded recently and in the late Holocene, could have involved a similar combination of slow climate processes, including prolonged North American droughts or heat waves and

North Atlantic warm oceanic temperature anomalies; together with fast processes, such as excursions of the Arctic Oscillation, and transport of warm, humid air in Atmospheric Rivers to Greenland. It is the fast processes that underlie the rarity of such events and influence their predictability.

A second paper, led by colleagues at the University of Leuven, explored the role of ARs that lead to high precipitation events in Dronning Maud Land, East Antarctica and provided significant contributions to the surface mass balance (Gorodetskaya et al. 2014).

My current research is focused on the extending the study of AR influences in the summer Arctic back to 1871 using the Twentieth Century Reanalysis.



Temperature anomaly (925 hPa) over the US for 1 July from the NCEP/DOE reanalysis. Back-trajectories (700 hPa) are shown: Heavy Black (NCEP/DOE), dark Green (CFSR) and purple (20CR) are averages for the four 6 h trajectories. The 20CR trajectory is not well behaved over the topography of Greenland so that trajectory starts at 60°N, 310E at 700 hPa on a point along the NCEP/DOE reanalysis. The only weather station with daily data recorded for 1889, Ilulissat, is indicated by the white diamond on the plot and lies along the trajectory to Summit Station. From Neff et al. 2014



**R. Steven Nerem**

## The NASA Sea Level Change Team

In 2014, the NASA Sea Level Change Team (N-SLCT) was formed following a call-for-proposals from NASA. The team is comprised of about 20 principal investigators plus their team members; I am the team leader. The objectives of the N-SLCT are to use NASA satellite data and science expertise to:

- improve knowledge and projections of sea level rise and its regional variation,
- improve knowledge and projections of ice mass change,
- develop new sea level datasets for research applications, and
- develop a NASA web portal for sea level change.

At the first meeting of the N-SLCT in October 2014, at Scripps Institution of Oceanography (photograph) we discussed team objectives and developed a NASA sea level roadmap. In addition, the framework for NASA's sea level web portal was discussed. The portal should be live by the end of 2015 (<http://sealevel.nasa.gov>); it is intended to be mainly a tool for the sea level research community, but also aims to educate the public about sea level change and NASA's contributions to our understanding.

Largely because of their global perspective, NASA's satellite missions represent major tools for advancing

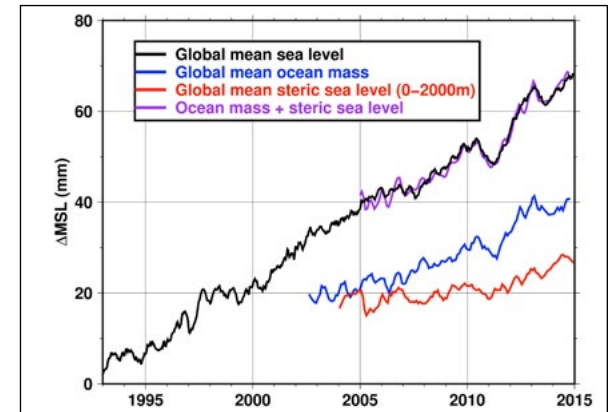


**Participants in the first N-SLCT meeting.**

Courtesy of R. Steven Nerem

our understanding of the continuing evolution of ocean heat content and land ice changes. The figure shows estimates of global mean sea level and its components from a combination of satellite altimeter measurements, satellite gravity measurements, and in situ oceanographic measurements. Together, these data sets can be used to not only measure sea level change, but also parse out the relative contributions from different sources.

Projecting future global and regional sea level change is a major objective of sea level research. Solving this problem requires an understanding of how much heat the ocean will absorb over time, how quickly the ice sheets



**Variation in global mean sea level (black, satellite altimetry), global ocean mass (blue, satellite gravity), and ocean thermal expansion (red, in situ ocean measurements). The sum of global ocean mass and thermal expansion (purple) agrees well with observed variations in global mean sea level.** From Leuliette, E. W. (2015). The Balancing of the Sea-Level Budget. Current Climate Change Reports. Springer

will melt, and a variety of other factors. NASA satellite measurements will be important tools for advancing our state of knowledge in these areas.



**Judith Perlwitz**

## Arctic tropospheric warming: Causes and linkages to lower latitudes

In recent decades, warming global temperatures at the Earth's surface and in the troposphere (the lowest layer of our atmosphere) have been more pronounced in the Arctic, especially during fall and early winter. Because this warming has coincided with receding sea ice, some scientists have theorized that sea ice loss is the first link in a chain in which Arctic changes affect lower latitude weather and climate. Specifically, they suggested that Arctic sea ice loss is the main driver of the observed deep tropospheric warming that caused weaker westerlies in midlatitudes, more persistent and amplified midlatitude waves, and more extreme weather. Through model experimentation, we examined the first step in this chain by quantifying contributions of various physical factors to October–December (OND) mean Arctic tropospheric warming since 1979. Our results indicate that the main factors responsible for Arctic tropospheric warming are recent decadal fluctuations and long-term changes in sea surface temperatures, both located outside the Arctic (Perlwitz et al., 2014). Arctic sea ice decline is the largest contributor to near-surface Arctic temperature increases, but it accounts for only about 20 percent of the magnitude of 1000- to 500-hPa warming. These findings thus disconfirm the hypothesis that deep tropospheric warming in the Arctic during OND has resulted substantially from sea ice loss. Contributions of the same factors to

recent midlatitude climate trends are then examined. We found that pronounced circulation changes over the North Atlantic and North Pacific result mainly from recent decadal ocean fluctuations and internal atmospheric variability, while the effects of sea ice declines are very small. Therefore, our study did not support the hypothesized causal chain of hemisphere-wide connections originating from Arctic sea ice loss.



**Sea ice loss in the Arctic is a major contributor to near-surface temperature increases in the region, but a small contributor to warming at 1000 to 500 hPa.** NOAA



**Roger Pielke Jr.**

## Climate change and the rising costs of disasters

In 2014, the Consortium for Science, Policy & Outcomes of Arizona State University (ASU) released a new title in its “The Rightful Place of Science” book series. The series, edited by author and ASU professor G. Pascal Zachary, explores the complex interactions among science, technology, politics, and society.

In “The Rightful Place of Science: Disasters & Climate Change,” I take a close look at the work of the Intergovernmental Panel on Climate Change (IPCC), the underlying scientific research, and the data to provide the latest science on disasters and climate change. I raise questions about the role of science in political debates, and challenge some conventional wisdom on the possible relationship between human-caused changes in climate and trends in economically costly disasters.

I present a range of peer-reviewed research on disasters and climate change, including research at the global level as well as studies focused on specific phenomena, such as hurricanes, floods, tornadoes, and drought. I also have carefully gone through the IPCC Fifth Assessment Report to integrate the report’s conclusions in my book. I conclude that there is little evidence to support claims that human-caused climate change has made disasters worse, although they may become worse in the future. Either way, I argue, we well-understand the best ways to

reduce vulnerability to future losses and, thus, we hold considerable potential to influence future disasters.

The book provides a cutting edge look at an area of

science that is intrinsically interesting, but also relevant to a wide range of policy decisions and which often finds itself in the middle of heated political debates.



**Streets and pathways are flooded after the passing of Hurricane Tomas in Gonaives, north of Port-au-Prince, Haiti.** Marco Dormino/UNICEF





## Balaji Rajagopalan

# Sub-seasonal variations in spatial signatures of ENSO on the Indian summer monsoon, 1901–2009

with Peter Molnar, Emily Gill

It is received wisdom that the variability and predictability of Indian summer monsoon rainfall hinges on the El Niño Southern Oscillation (ENSO) phenomena. This is based on a large body of research focusing mainly on the relationship between all India summer (June–Sep) monsoon rainfall and indices of ENSO. However, seasonal ENSO alone has not led to skillful successful forecasts of seasonal rainfall and, furthermore, it has been poor at predicting rainfall in space and by sub-season, suggesting a tapestry of ENSO teleconnections in space and time.

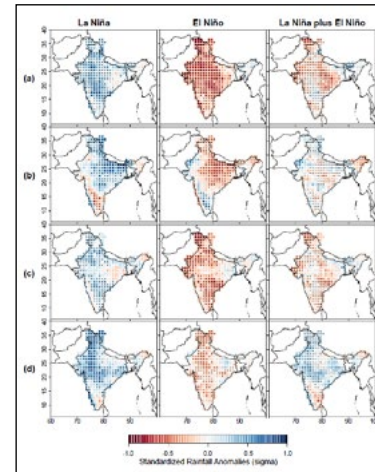
By analyzing high-resolution daily gridded rainfall, Pacific sea-surface temperatures (SSTs), and atmospheric variables, we uncover spatially distinct teleconnections between ENSO and the Indian summer monsoon over the entire monsoons season, as well as over three sub-seasons—early (June), peak (July–August), and late (September). Over the full season, rainfall in western India is more correlated to Pacific SSTs than rainfall in eastern India. This spatial signature shifts as the monsoon progresses through the season. Specifically, we find that a 1°C cooling of the central equatorial Pacific (i.e., La Niña conditions) can result in a ~70–100% increase in precipitation in the north-central and Indo-Gangetic Plains regions during the early season; a ~30–80% increase in peak season precipitation in the south-central and northwestern Rajasthan regions; and a ~60–100% increase in late sea-

son precipitation in northern, northwestern, and central regions of India.

Furthermore, the spatial signatures between La Niña and El Niño are asymmetric in that for a particular location, the enhancement and suppression of rainfall associated with La Niña and El Niño conditions, respectively, are not equal. We find that El Niño suppresses peak season rainfall in the south-central and north-eastern Rajasthan regions more than La Niña enhances it (figure). However, the opposite occurs during the late season in the northern, northwestern, and central regions of India.

Finally, we identify patterns of convergence and divergence consistent with the hypothesis that local Hadley cell circulation affects pressure, and thus the rainfall, during the early season, but that a larger-scale mechanism, such as Walker circulation, may be more responsible for teleconnections during the remainder of the season. These findings indicate that focusing monsoon-forecasting efforts on these regions and on sub-seasonal periods while incorporating ENSO asymmetries will yield useful and skillful forecasts.

This work, in press in the *Journal of Geophysical Research—Atmospheres*, was conducted with CIRES Fellow Peter Molnar and CIRES graduate research assistant Emily Gill, and funded in part by the National Science Foundation and CIRES.



**Composite maps of standardized anomalies of rainfall using Rajeevan et al. (2006) rainfall during strong La Niña and strong El Niño conditions for (a) full, (b) early, (c) middle, and (d) late seasons. The third column is the sum of the first two columns. Linear trends over the entire 109-year period have been removed from each grid cell. Stippling indicates regions where mean rainfall anomalies between La Niña and El Niño are significantly different by at least 95%.**

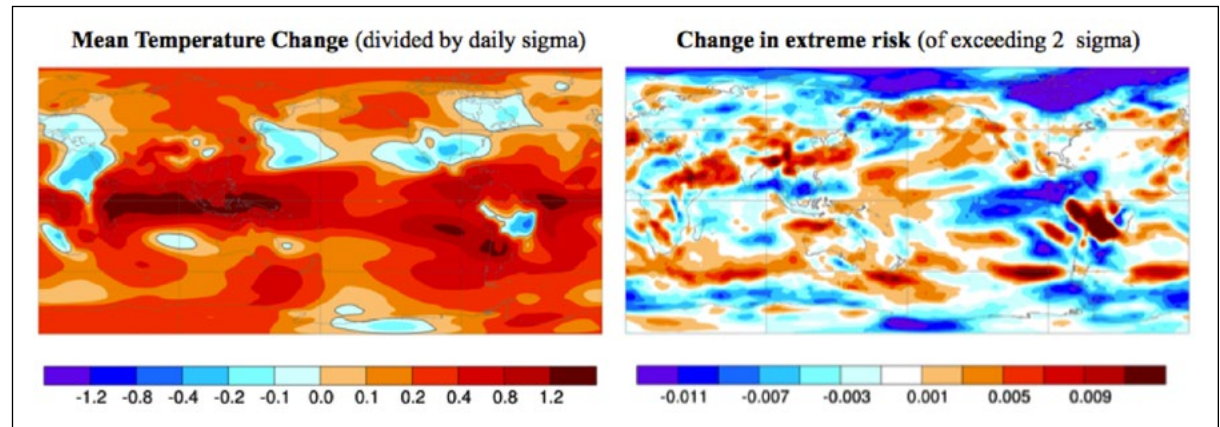


**Prashant Sardeshmukh**

The complex relationship between global warming and extreme daily temperature

Does global warming necessarily imply an increase of extreme warm temperatures and a decrease of extreme cold temperatures around the globe? One might intuitively think so, but such an intuition rests on the assumption that the mean warming is not accompanied by a change in temperature variability. More precisely, it rests on an assumption that the mean shift of the probability distribution of daily temperatures is not accompanied by a change in the width and/or shape of the distribution. But if global warming is not spatially uniform, one can expect the atmospheric circulation, including the upper-level jet streams, to change along with changes in the intensity and locations of storms. Such changes in storminess may locally imply large changes in the width and shape of the daily temperature distribution, with the potential to greatly modify or even reverse the changes in extreme temperature risks expected from the mean warming alone.

We have recently investigated this issue in the context of changes in daily temperature extremes from the early (1901–1925) to the late (1981–2005) 20<sup>th</sup> century. We did this using a long-term global atmospheric “reanalysis” dataset (the Twentieth Century Reanalysis, 20CRv2c). The results, showing the change in risks of extreme warm daily temperatures in the lower troposphere (figure), are revealing. The risks in both periods



**(Left)** The mean change of lower tropospheric (850 hPa) temperature in northern winter (December through February) between 1901–1925 and 1981–2005 in the 20CRv2c reanalysis dataset. The mean change is divided by the standard deviation of the daily temperatures. **(Right)** The change in the probability of the daily temperature being warmer than the mean of the early period by two or more standard deviations. Prashant Sardeshmukh/CIRES

were defined as the probability of the daily temperature being warmer than the mean of the early period by two or more standard deviations. Clearly, the pattern of the change in these risks is very different from the pattern of the mean warming itself. Very similar results were obtained using atmospheric general circulation model simulations of the same periods (not shown here). This

suggests that the changes in extreme temperature risks can indeed not be inferred from the mean warming alone, and that in addition to the mean warming, climate models also need to accurately represent the changes in daily temperature variability to capture the changes in extreme temperature risks. (From Sardeshmukh, Compo, Penland, and McColl, 2015, to be submitted).



**Mark Serreze**

## Extreme precipitation events in the Arctic

As the Arctic loses its sea ice cover, it becomes more accessible to marine transport, tourism, and extraction of energy resources. As the economic and strategic importance of the region grows, so does the need to better understand its weather, particularly extreme weather events. Driven by this recognition, we initiated a project in 2014 to better understand the causes of extreme daily precipitation events in the Arctic, focusing initially on the island on Spitzbergen (Serreze et al., 2015). Spitsbergen, lying between 77° N and 80° N, is the largest island of the Svalbard Archipelago. The region is frequently influenced by low pressure systems associated with the North Atlantic cyclone track. Especially in winter, lows in this area can be very strong, in part because of pronounced horizontal temperature gradients along the sea ice margin.

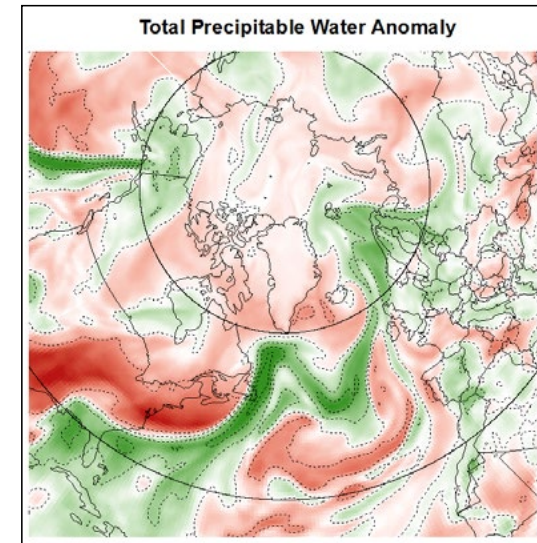
Despite the stronger storm activity in winter, extreme precipitation events at Ny Ålesund, defined as those in the top 1% of the statistical distribution, can occur year-round. Extreme events tend to occur when the region is influenced by a trough of low sea level pressure extending from the southwest, southerly winds extending through a deep layer of the atmosphere, and positive anomalies in water vapor and when there is pronounced upward motion in the middle of the atmosphere.

Upward motion promotes cooling and condensation of moist air parcels. Reflecting local topography, precipitation extremes at Ny Ålesund are typically not well represented at other stations on the island, but there are notable exceptions.

Most of the largest precipitation events at Spitsbergen can be associated with features resembling “atmospheric rivers,” seen as narrow corridors of pronounced positive anomalies in water vapor extending thousands of kilometers south into the tropical Atlantic (figure). For example, the presence of an atmospheric river helps to explain the remarkable precipitation event on Spitsbergen that occurred during late January 2012. This extreme event was accompanied by unusually warm conditions. The event caused a significant increase in permafrost temperatures down to 5 m, induced slush avalanches that damaged infrastructure, and left significant ground ice cover leading to starvation of wild reindeer.

### Reference

Serreze, M. C., Crawford, A. D., & Barrett, A.P. (2015). Extreme daily precipitation events at Spitsbergen, and Arctic island. *International Journal of Climatology*. doi: 10.1002/joc.4308.



**Anomaly field of column-integrated atmospheric water vapor (known as precipitable water) at 0600Z, September 26, 1989, showing an atmospheric river extending from the tropical Atlantic into the Arctic (green shading), linked to an extreme precipitation event over the island of Spitsbergen, east of Greenland.**



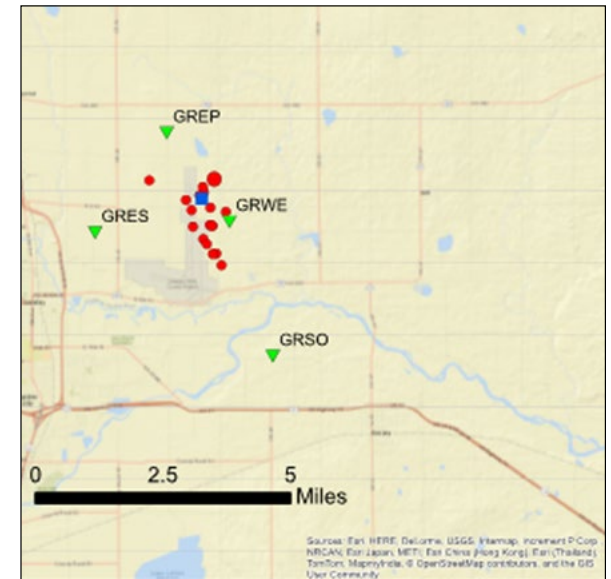
**Anne Sheehan**

## Fluid injection-induced seismicity in Weld County, Colorado

On May 31, 2014, a magnitude 3.2 earthquake occurred east of Greeley, Colorado. Weld County has been the locus of significant oil and gas production in the past decade. It hosts many Class II injection wells, used to dispose of wastewater generated from oil and natural gas production and drilling activities. The May 31 earthquake was widely felt, with reports from Boulder and Golden, over 60 miles away.

The epicenter was close to a deep, high-volume wastewater injection well, extending nearly to crystalline basement rocks more than 10,000 feet below the surface. In response to the earthquake, Sheehan’s research group at CIRES deployed six seismometers beginning three days after the earthquake. Earthquakes were located in a small cluster (~2 km radius), centered near a Class II injection well (NGL Well C4A). The injection company, NGL Energy Partners LP, had been injecting waste fluid into the deepest sedimentary formation of the Denver Basin at rates as high as 360,000 barrels per month for less than a year. The earthquake and subsequent seismicity sequence recorded by our team contributed to the decision by the Colorado Oil and Gas Conservation Commission (COGCC) to recommend a temporary halt to injection at C4A. The well data, drilling logs, and well files were reviewed. The well was drilled into the geologic Fountain Formation, which is in immediate contact with

crystalline basement. A test conducted by the operator indicated that most of the flow was in the highly fractured zone at the bottom of the well. As a result of the test and the recommendation of the COGCC, the operator plugged back the well approximately 458 feet. Injection resumed at 5,000 bpd (barrels per day) on July 19, 2014, with injection increasing to 7,500 bpd in August 2014, and again in October 2014 to 9,500 bpd. The increased injection volumes were allowed by COGCC with review of our seismic monitoring data. Seismicity has decreased significantly since summer 2014, with the exception of a small cluster of events in late December 2014. Current seismic monitoring is ongoing to determine whether the active mitigation of induced seismicity through well modification and staged approach to injection is effective.



**Map showing wastewater disposal injection well (blue square), seismic stations deployed by Sheehan’s group (green triangles), and earthquakes recorded within the first few weeks of the seismic deployment in June 2014 (red circles).**



**Robert Sievers**

## Dry vaccines can be delivered sublingually or into lungs

Aerosols and sublingually delivered vaccines and therapeutics are increasingly effective in improving global health. 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. Vaccine aerosol dry powders can be compressed gently with stabilizers to make wafers, which dissolve under the tongue. The vaccine microparticles can act to stimulate immune responses in mucosa to protect against infectious diseases like measles.

My Global Health Group in CIRES, in collaboration with Aktiv-Dry LLC, Serum Institute of India, Ltd., the Johns Hopkins Bloomberg School of Public Health, and the U.S. Centers for Disease Control and Prevention, 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. The clinical trial success was reported in *Vaccine* in 2014 (Agarkhedkar et al., 2014).

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

Glenn Asakawa/CU-Boulder



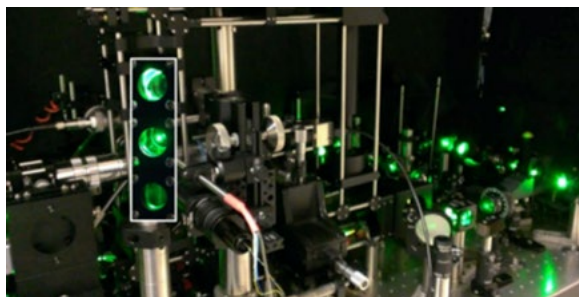
**Margaret Tolbert**

## Optical levitation to probe phase transformations of model atmospheric particles

Research in my group is focused on heterogeneous atmospheric chemistry, specifically on determining the chemical, physical, and optical properties of atmospheric particulate. In particular, the phase of atmospheric particles (solid vs. liquid) is important in determining their role in atmospheric problems such as stratospheric ozone depletion, global climate change, urban smog, and visibility degradation.

We have recently developed a long-working-distance optical trap to probe the phase state of levitated model atmospheric particles in the laboratory. A photograph of the optical trap is shown in the first figure. The bright light in the center of the trapping cell is due to a particle trapped by optical levitation from the lasers.

We study phase transitions by examining the light scattering patterns from the trapped particles. Recent work has focused on a phase transition that has not been previously identified in the atmosphere—contact-induced efflorescence. Efflorescence is the process of salt crystal nucleation from a supersaturated aqueous inorganic solution upon decreasing relative humidity (RH). Most current models of atmospheric particulate assume that inorganic particles remain in the supersaturated aqueous state until extremely low RH. However, we have discovered that particle collisions can cause crystallization at much higher RH, potentially causing

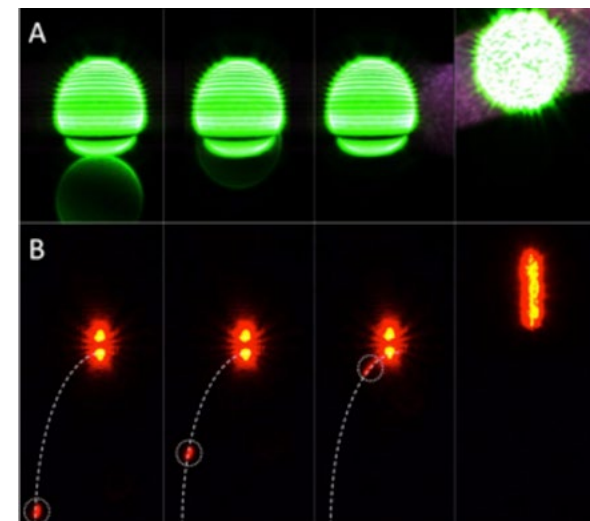


**Optical trap with particle trapping region highlighted.**

Margaret Tolbert/CIRES/CU-Boulder

atmospheric particulate to be solid in the atmosphere more of the time than previously believed. The second figure shows a contact event occurring in our optical cell. Here, an aqueous inorganic droplet was hit by a 500 nm organic particle, causing efflorescence within milliseconds. Ongoing experiments are probing different pairs of droplet and contact nuclei to gain a better fundamental understanding of this process and to evaluate its possible atmospheric significance.

This work is in collaboration with researchers at NOAA and the National Institute of Standards and Technology, and seed funding was provided by the CIRES Innovative Research Program (see page 68).



**Monitoring collisions between a levitated ammonium sulfate droplet and an organic contact nucleus using A) 532 nm far-field imaging and B) 632.8 nm near-field imaging. Contact is observed in frame 3 and the particle has crystallized by frame 4.** Margaret Tolbert/CIRES

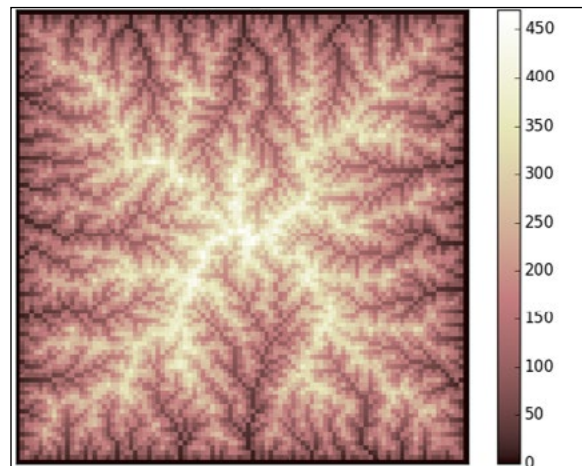


**Greg Tucker**

## Landlab: Simplifying numerical computing in Earth-surface dynamics

The sciences of the Earth's surface are evolving rapidly, and new data, discoveries, and ideas continue to fuel the need for new computational models. Numerical models are crucial to the Earth-science enterprise because they enable us to explore and visualize quantitative hypotheses, and compare hypotheses with data. Yet building, modifying, and maintaining the software behind Earth-surface dynamics models can be daunting. To sustain progress, computational software must be sufficiently flexible and adaptable to promote, rather than impede, the discovery process. To help meet this need, I have been working with a team of colleagues at CIRES, Tulane University, and the University of Washington to begin developing a software library that helps scientists rapidly create, explore, modify, and combine two-dimensional numerical models.

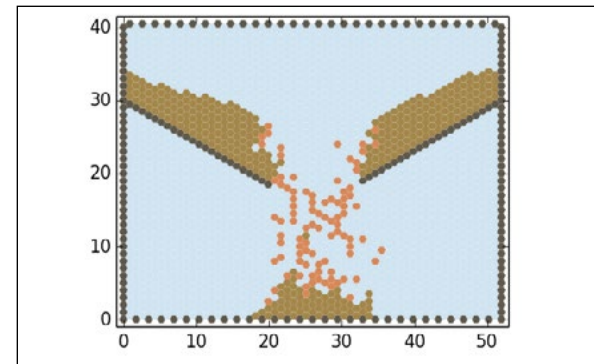
Our goal is to create a support system for model development that 1.) is written in a modern high-level language with a rich set of scientific computing libraries, 2.) takes care of common but labor-intensive tasks, such as grid creation and input/output, with a convenient set of functions and data structures, 3.) packages useful operations and calculations into reusable components, and 4.) provides a simple mechanism for a scientific programmer to combine components. The resulting product—known as Landlab—is written in Python, taking advantage of the rapidly growing popularity of Python as an efficient, high-level



**Elevation output (m) from a simple landform evolution model written in Landlab, showing development of ridges, valleys, and drainage networks in a hypothetical landscape. Color represents terrain height.**

programming language for scientific computing.

Landlab provides a gridding module that allows modelers to create and configure a grid in just one or a few lines of code. Grids may be structured (e.g., raster or hexagonal) or unstructured (Delaunay/Voronoi). State variables and other distributed data can be attached to a grid, and



**2D model of granular material flowing through a hopper, created using Landlab's cellular automaton package. Elements include moving grains (orange), mobile grains (light brown), walls (gray), and air (light blue).**

staggered-grid numerical schemes are easy to implement. Landlab includes a set of process components written by the development team to model a wide variety of processes, for example: incident solar radiation on terrain, evapotranspiration, overland flow, soil creep, stream network erosion, and flexure of the lithosphere. Our hope is that Landlab will foster progress in Earth-surface dynamics by helping modelers focus on their science rather than the computer code behind it.



**Veronica Vaida**

## Multiphase planetary photochemistry including the contemporary and ancient Earth

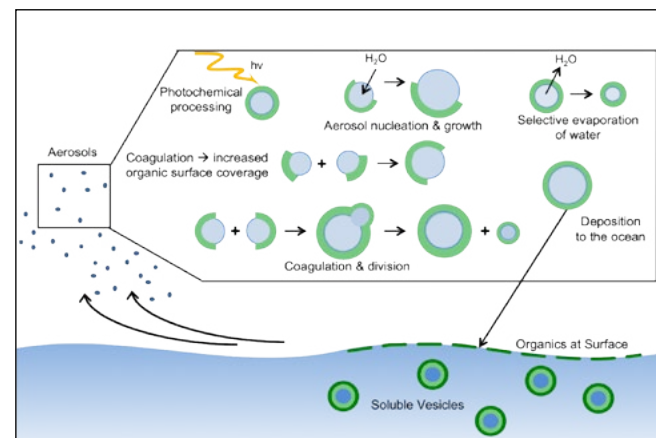
Our program explores water- and sunlight-mediated processes in planetary atmospheres including the contemporary and ancient Earth. Our approach aims to provide new inputs for models of atmospheric chemistry and climate, using fundamental chemical physics to address complex multiphase chemistry. Using solar simulators in laboratory studies, our group has been exploring the importance of water and the environment to the photochemistry of organic and inorganic species.

For example, we recently have focused on pyruvic acid, a small organic molecule found in the atmosphere in both the gas and the aqueous phases and involved in the oxidation of isoprene. We are finding that under atmospheric conditions, chemistry in all phases is different from that observed in laboratory studies. Our group has recently deduced a mechanism for the aqueous-phase photolysis of pyruvic acid. This mechanism is fundamentally different from the gas-phase chemistry and leads to polymer formation. We have shown that these polymers partition to the surface of water. In the environment, such surfaces are found on lakes, oceans, and the vast population of atmospheric aerosols. We study these surface organic films in the lab with surface sensitive methods to learn about the properties of atmospheric aerosols.

Our research aims to scale fundamental experimental laboratory results 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 in collaboration with Professor Jean-François Doussin. By combining these laboratory and chamber studies we hope to connect our understanding of the photochemistry of organic species in aqueous environments to mechanisms for aerosol nucleation and growth.

Our recent results have shown that sunlight can build chemical complexity. We have recently used such chemistry to form lipids, which self-assemble into aggregates. This work is relevant to the contemporary sea-surface microlayer and atmospheric aerosols, as well as the prebiotic evolution of membranes.



**A schematic of aqueous aerosols' life cycle; a connection between the atmosphere and the ocean. Aqueous aerosols generated from sea spray are subject to a variety of processing pathways in the atmosphere before deposition to the ocean. Organic matter (shown in green) partitions to the surface of the sea surface microlayer and of atmospheric aerosols.**

Rebecca Rapf/CIRES





**Rainer Volkamer**

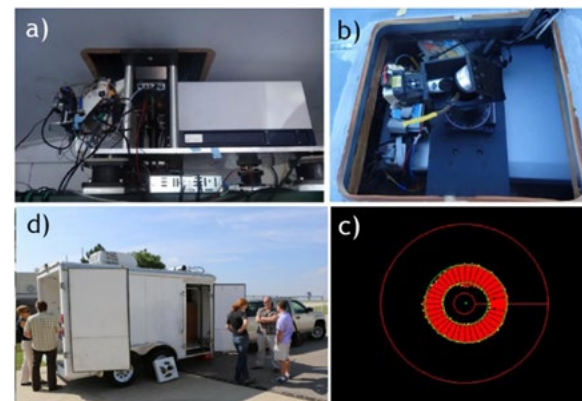
## Photochemistry in Colorado's Front Range: Mobile solar occultation flux

Colorado's Northern Front Range Counties (NFRC) are home to about two-thirds of the state's population. The NFRC have been designated by the Environmental Protection Agency as an Ozone Nonattainment Area for exceeding the primary National Ambient Air Quality Standard for ozone during the summer. Despite a 41% increase in human population between 1990 and 2010 in the NFRC, the concentrations of ozone precursor gases (e.g., nitrogen dioxide,  $\text{NO}_2$ ) in Denver have decreased as a result of effective emission controls. However, ozone mixing ratios from Denver to Boulder have experienced no significant trend. My group has developed a fast solar tracking device for use from a ground-based University of Colorado Boulder mobile laboratory to better quantify and map emissions from oil and natural gas production urban and agricultural sources; and to better quantify the impacts of energy production on the environment.

The mobile solar tracker was developed with support from the CIRES Energy and Environment Initiative. The device consists of two mirrors, stepper motors, transfer optics, a telescope, a screen, an imaging camera, and control electronics. The position of the solar image is determined and used to adjust the mirrors with a high repetition rate; the solar tracker aligns a set of spectrometers with the sun very accurately while the vehicle is in motion. A follow-up project by the Colorado Department of Public Health

facilitated the purchase of a portable Fourier transform spectrometer (FTS). The FTS, coupled to the mobile solar tracker, enables mobile solar occultation flux (mobile SOF) measurements of a large variety of molecules that are precursors for ozone and aerosols.

Mobile SOF selectively detects and quantifies the absorption of trace gas columns between the sun and the sensor. Column observations inherently average over the full boundary layer height, provide access to plumes that often travel decoupled from the ground, and fill a gap between surface- and aircraft-based in situ observations. During the Front Range Air Pollution and Photochemistry Experiment (FRAPPE), we measured mobile columns of ethane (a major component of the fugitive emissions from oil and natural gas production), nitrogen dioxide and formaldehyde (two precursors for photochemical ozone formation), and ammonia from agricultural sources (a precursor for secondary aerosols). These measurements were conducted in collaboration with CIRES researcher Owen Cooper (NOAA/ESRL) and Mike Hannigan (National Center for Atmospheric Research [NCAR]), and were further coordinated with complementary in situ measurements of the above gases aboard a NOAA mobile laboratory, the NCAR C130 and NASA P3 research aircraft.



**The CU-Boulder mobile column laboratory with mobile SOF instrument; a) Rack supporting the solar tracker and EM27 Fourier transform spectrometer, b) imaging solar tracker, c) image of the solar disk indicating good solar tracking, d) CU-Boulder mobile column laboratory at the media day at the Rocky Mountain Metropolitan Airport in Broomfield, Colorado.** Courtesy of Rainer Volkamer/CIRES



**Carol Wessman**

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

With projected increases in frequency and extent of forest disturbances in the Western United States, opportunities for disturbances to overlap and interact will increase substantially and in ways that are unprecedented and, very likely, unpredictable. Our lab studies the potential vulnerabilities of forest ecosystems and their carbon stocks to multiple disturbances and their interactions. We focus on a region of Colorado subalpine forest that has experienced several disturbances over a short period of time—far shorter than the forest recovery time. Based on our field surveys, we modeled the recovery trajectories of these forests under different climate and management scenarios, and their implications for carbon stocks, 100 years into the future.

Carbon stocks were initially more resilient than the coniferous forest; areas with little conifer regeneration recovered carbon at a similar pace due to an influx of deciduous seedlings. In the near term, aspen establishment more than compensated for any loss of coniferous species, to the point where total carbon stocks were similar between areas with zero conifer seedlings and those with ample regeneration. The heterogeneity of recovery across the landscape (domination of conifer seedlings in some areas, deciduous or grasses in others) persisted through the coming century. However, under a changing climate (using Intergovernmental Panel on

Climate Change scenarios), these landscapes transitioned to non-forests. All trees died with warming temperatures and failed regeneration could not sustain the forest. Complete mortality occurred even when forest recovery was assisted with a management strategy that planted local species. Any seedlings of the native conifer species, naturally occurring or planted, could not successfully establish in a warmer climate. However, when actions were taken to plant species more suited to the changed climate (adaptation-oriented management), forest structure and carbon stocks were maintained, albeit at lower densities. In other words, assisted colonization of new tree species preserved the presence of a forest and some ecosystem services (e.g., carbon stocks, forest-type habitat) in the face of subalpine forest failure under climate warming. An important outcome of these modeling studies is the suggestion that disturbances coupled with climate warming are likely to inhibit regeneration of subalpine forest species and may lead to ecosystem change.



**Former graduate student Becky Poore at one of our sites. This is 12 years after the logging of the 1997 Routt National Forest blowdown, showing remains of wind-thrown trees and some regeneration.** Carol Wessman/CIRES



**Paul Ziemann**

## Probing the chemistry and properties of atmospheric organic aerosols

Volatile organic compounds are emitted to the atmosphere from a variety of natural sources and human activities, such as forests, wildfires, vehicles, and industry. In the atmosphere, these compounds undergo complex chemical reactions that are often initiated by sunlight, and which lead to their degradation or conversion into more oxidized, low volatility forms that can condense to create microscopic particles called secondary organic aerosol (SOA). In urban-influenced areas these particles affect human health and visibility, whereas globally they exert a major influence on the 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 SOA particles and the processes that determine their composition and distributions in the atmosphere are still poorly understood.

In the Ziemann group we conduct laboratory experiments in large environmental chambers under simulated atmospheric conditions to investigate fundamental chemical and physical processes by which organic compounds are transformed in the atmosphere to form SOA particles. In the past year, our work has focused primarily on developing and applying new analytical methods to identify and quantify the products of atmospheric oxidation reactions conducted in the laboratory. Studies have involved reactions of OH radicals, the dominant

atmospheric oxidant, with alkanes, an important class of reactive hydrocarbons that are emitted from vehicles. This information has been used to develop chemical mechanisms for these reactions and is now being shared with research groups at the National Center for Atmospheric Research and in France to improve and evaluate computational models for predicting the chemistry of these compounds in the atmosphere and their possible role in SOA formation. We have also been collaborating with research groups at Colorado State University and North Carolina State University to investigate the ability of SOA particles to absorb water, a key process in the formation of clouds. 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.



**Environmental chamber and analytical instruments used to investigate the formation and chemistry of secondary organic aerosol particles under simulated atmospheric conditions.** David Oonk/CIRES

## Center for Limnology

### Nutrient pollution hangover in lakes

The most destructive human impairment of water quality worldwide is nutrient pollution. The problem arises because the nutrients that control growth of aquatic plants, including algae, are relatively scarce under natural conditions, but humans concentrate and mobilize these nutrients.

The two key nutrients that determine abundance of plants in water are nitrogen and phosphorus. Natural concentrations vary widely, but nitrogen often falls between 500 and 1,500 parts per billion (ppb), and phosphorus often is 10 to 100 ppb. In contrast, municipal treated sewage effluent (without advanced treatment) contains ~12,000 ppb nitrogen and ~3,000 ppb phosphorus. Thus, domestic waste may multiply the growth potential of algae by a factor of 100 or more, depending on the amount of dilution that is available for treated wastewater. Other sources, such as fertilizers or livestock, also cause great enrichment of waters with nitrogen and phosphorus.

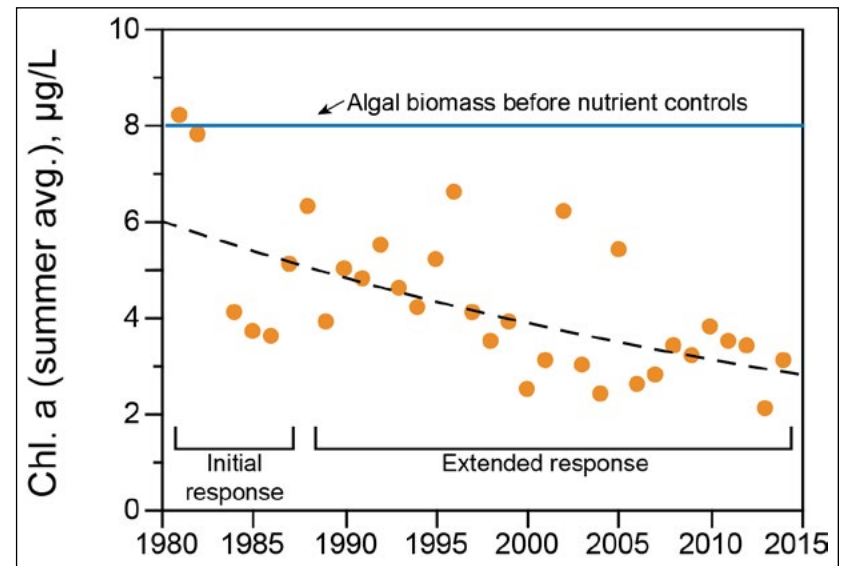
Nuisance growth of algae and other aquatic plants degrades the value of water for recreation, support of aquatic life, and domestic use. Problems associated with nutrient-polluted waters include loss of oxygen, production of tastes and odors, algal-generated toxicity, and low transparency.

Worldwide efforts to curb nutrient pollution are underway, but have made only modest changes in the degree of nutrient pollution thus far. In the United States, nutrient pollution is controlled primarily through the Environmental Protection Agency (EPA) in implementing the federal Clean Water Act (CWA). Colorado implements the CWA under its own statutes. Dillon Reservoir (aka Lake Dillon, photograph) is an early case study for Colorado; it is the largest single water supply for metropolitan Denver and its tributary sources are of

very high quality. An alarming acceleration in development in the 1970s, however, caused the EPA to encourage Colorado to adopt site-specific nutrient regulations for the lake. The Center for Limnology conducted an intensive two-year study of nutrient concentrations, nutrient sources, and nutrient enrichment indicators for the lake and watershed during 1981-1982. The study showed that development within the lake's watershed had caused a doubling of nutrient concentrations in source waters as of 1982, which had in turn increased the growth potential for algae suspended in the lake (phytoplankton). This change, while easily documented with appropriate data on water chemistry, had produced only moderately adverse symptoms in water quality as of 1980. Further enrichment, however, would have resulted in more important and more obvious changes.

In 1984, Summit County and other local government entities occupying the watershed implemented strong controls on nutrient sources, the two most important of which were wastewater treatment plants and septic systems for homes located outside the sanitation districts. The controls halted the increase in release of phosphorus, which was identified as the key nutrient. The controls were effective, as shown by monitoring of phosphorus concentrations in the lake over a period of 34 years by the CIRES

Center for Limnology. Chlorophyll, an index of algal abundance, declined steeply in the lake between 1982 and the mid 1980s (figure), as desired. In addition (and unexpectedly), the lake has continued to show a decline in algal biomass (chlorophyll) through 2014. Thus, nutrient pollution following source control can have impressive results, but these results may develop fully only over decades following implementation of nutrient controls.



Chlorophyll-a concentrations (algal biomass) over the period of record for Lake Dillon (1980-2014). James McCutchan/CIRES

*Problems associated with nutrient-polluted waters include loss of oxygen, production of tastes and odors, algal-generated toxicity, and low transparency.*

**Lake Dillon, Summit County.** Laura Compton



# Center for Science and Technology Policy Research

The Center for Science and Technology Policy Research (CSTPR) was established within CIRES in 2001 as a response to an increase in problem-focused research at the interfaces of environment, technology, and policy, and to the growing demand by public and private decision makers for usable scientific information. Our work is often aimed at understanding the choices that people and institutions make in pursuing goals under uncertainty, be it an uncertain future climate, uncertain outcomes of investments in science and technology, or the uncertain outcomes of a particular environmental policy. One of our goals is enlarging the range of choice considered by policy-makers, by analyzing options in areas such as energy technology, carbon management, science investments, and public lands and ecosystems management.

## Research highlights

CIRES Fellow Lisa Dilling—with Joseph Kasprzyk and Rebecca Smith (CU-Boulder Department of Civil, Environmental, and Architectural Engineering); Imtiaz Rangwala, Kristen Averyt, and Eric Gordon (CIRES/Western Water Assessment); Laurina Kaatz (Denver Water); and Leon Basdekas (Colorado Springs Utility)—received a grant from the NOAA Sectoral Applications Research Program for a project titled “Balancing Severe Decision Conflicts Under Climate Extremes in Water Resource Management.”

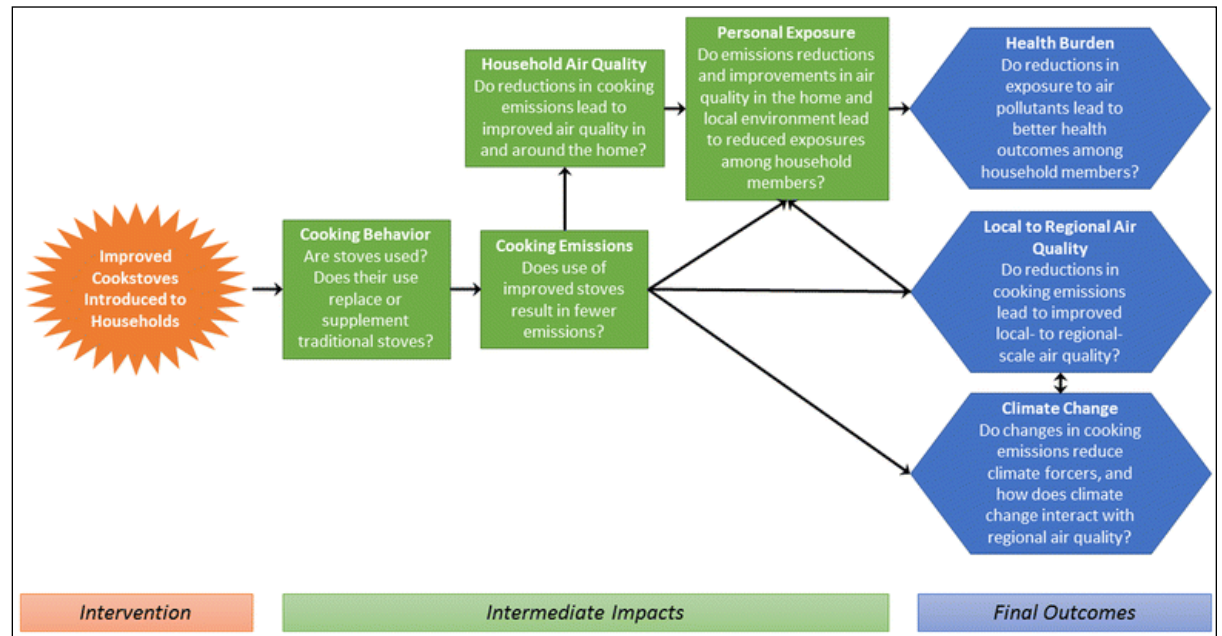
CSTPR’s Deserai Crow (CU-Boulder Environmental Studies Program), with Elizabeth Albright (Duke University), published a study of policy responses to Colorado’s

September 2013 flooding in the CU-Boulder Natural Hazards Center’s Quick Response Research Report #248 (<http://bit.ly/1wx19Rk>).

CIRES Fellow Roger Pielke Jr.’s new book, “The Rightful Place of Science: Disasters and Climate Change” (Pielke 2014, cover below) looks at the work of the Intergovernmental Panel on Climate Change, the underlying scientific research, and the data to provide the latest science on disasters and climate change.

CSTPR’s Katie Dickinson (also UCAR) published a paper describing the study rationale and protocol of her project “Research on Emissions, Air Quality, Climate, and Cooking Technologies in Northern Ghana” (image).

CSTPR’s Bobbie Klein contributed to the “Colorado



Causal pathways linking introduction of clean cookstoves to outcomes of interest. Dickinson et al. (2015).

*One of our goals is enlarging the range of choice considered by policy-makers, by analyzing options in areas such as energy technology, carbon management, science investments and more*

Climate Change Vulnerability Study,” (University of Colorado Boulder and Colorado State University, 2015) which examined climate vulnerability for the state of Colorado and was led by WWA and Colorado State University.

### Outreach

CSTPR’s work is reported via journal articles, books, reports, a newsletter, briefings for decision makers, blogs, talks, a noontime seminar series, workshops, and media interviews. CSTPR’s Ben Hale (Environmental Studies Program and Philosophy Department) was quoted widely in the media and wrote two opinion pieces about the ethical implications of the Ebola epidemic.

### Education highlights

The Red Cross/Red Crescent Climate Centre Internship Program, directed by CIRES Fellow Max Boykoff, placed two graduate students in Uganda, Zambia, and South Africa to work on environmental communication, adaptation decision-making, and disaster prevention and preparedness (photo).

For the second year, CSTPR organized a competition to select two CU-Boulder students to attend the AAAS “Catalyzing Advocacy in Science and Engineering” workshop in Washington, D.C., to learn about Congress, the federal budget process, and effective science communication. Supported by the CU-Boulder Graduate School and Center for STEM Learning. The 2015 winners are from CU-Boulder’s Molecular, Cellular, and Developmental Biology and Computer Science departments.

### Personnel

Steve Vanderheiden joined CSTPR. He is an Associate Professor in the CU-Boulder Department of Political Science; his current research focuses on equity and accountability in adaptation governance, as well as in carbon accounting and informational governance.

### Recognition

CSTPR’s Media and Climate Change Observatory (MeCCO) was one of the winners of CU-Boulder’s “2014 Best Digital Data Management Plans and Practices” competition. MeCCO systematically monitors media coverage of climate change in 50 sources across 25 countries around seven regions of the world. MeCCO participants include CIRES Fellow Max Boykoff, CIRES Visiting Fellow Joanna Boehnert, CIRES graduate students Lucy McAllister, Meaghan Daly, Xi Wang, and Kevin Andrews, and CSTPR’s Ami Nacu-Schmidt.



**Red Cross/Red Crescent  
Climate Centre intern Drew  
Zackary in Karamoja.** John Bosoce

# Earth Science and Observation Center

CIRES' Earth Science and Observation Center (ESOC) provides a focus for the development and application of novel remote-sensing techniques for 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 a global scale. A long-term goal of ESOC research is to advance our understanding of the Earth system and its components through remote sensing observations.

## Cryospheric research

During 2014, our cryospheric research focused on understanding the physical processes of glacier and ice-sheet surfaces. This research included: Quantifying the volume and drainage of supraglacial lakes in Greenland which have significant implications for ice flow rates; determining the characteristics of firn compaction and surface meltwater percolation to interpret satellite and airborne altimetry data; characterizing the distribution and evolution of crevasses on the Greenland ice sheet near the margins (photo); and integrating space-based gravity, altimetry, and visible observations to develop a high spatial resolution estimate of sea level contributions from the Greenland ice sheet, its peripheral glaciers and ice caps, and the Canadian glaciers and ice caps.

## Vegetation and ecosystem studies

We have been studying potential vulnerabilities of forest ecosystems and their carbon stocks to multiple disturbances and their interactions, with a focus on the resilience of carbon stocks and coniferous forest to catastrophic disturbances and climate change. We modeled the recovery and growth of trees under a changing climate (using IPCC scenarios), and demonstrated that under various warming scenarios, forests were unable to survive, even with a mitigative management strategy. To learn more, please see page 48.

## Oceanographic studies

Working in partnership with the Ocean Sciences Department at the University of California Santa Cruz, we have been examining uncertainties in upwelling off the coast of California to better understand the associated heat and carbon exchanges. Upwelling is the process by which pulses in equatorward winds drive warm surface ocean waters offshore to be replaced by nutrient-rich colder waters from depth. The nutrients support phytoplankton blooms and an increase in photosynthesis,

consuming atmospheric carbon dioxide and removing it from its potential role in greenhouse processes that warm the troposphere. By incorporating satellite observations of wind speed into multiple models and comparing the results, we can estimate uncertainty in surface wind measurements, which is essential for understanding the physical processes at the coast, and the resulting uptake of carbon dioxide.



Installing a station in northeastern Greenland, May 2015, to enable interpretation of satellite observations.

Michael MacFerrin/CIRES



*A long-term goal of ESOC research is to advance our understanding of the Earth system and its components through remote-sensing observations.*

### Lidar innovations and discoveries

We have been developing the next-generation lidar technologies to push atmosphere and space science forward with unprecedented observational capabilities. The completion of the Iron Doppler lidar at Table Mountain in Colorado, along with our successful upgrades made at Arecibo Observatory in Puerto Rico and at Cerro Pachon in Chile, have significantly advanced our upper-atmosphere observation capabilities, enabling us to better understand the Earth's upper atmosphere and its couplings to the near-space environment. Through our observation and modeling efforts we have developed

important insights into the structure, movement, chemistry, and electrodynamics of the relatively unexplored regions of our atmosphere from the stratosphere to the middle thermosphere.

### Climate process research

Using state-of-the-art measurements and advanced models developed at ESOC, we have been evaluating how climate changes 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. In partnership with colleagues at other institutions, researchers at ESOC have been working to determine the fraction of evapotranspiration that is attributable to transpiration vs. evaporation, and assess the relative contributions to evaporation from water in soil vs. surface water. By identifying and quantifying the relative moisture sources, we are gaining a better understanding of exchanges of water between the surface and the atmosphere, which ultimately will advance hydrologic and meteorologic forecasting and projections.



**Aurora over Arrival Heights, Antarctica, one site of CIRES/ESOC upper atmospheric lidar research.** Zhibin Yu/CIRES

# 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, 2014, to May 31, 2015, follow.

## Antarctic ice shelves

The Antarctic Peninsula is the most rapidly warming region in the Southern Hemisphere, having warmed roughly three degrees Celsius in the last 60 years. It has lost around 25,000 square kilometers from its ice sheet, with 87 percent of glaciers retreating. In 1995

and in 2002, several of the large floating ice shelves that fringed the peninsula collapsed: In 2002, the Larsen B ice shelf lost 3,250 square kilometers in 35 days. When ice shelves break up, glaciers behind them begin to accelerate. A team led by NSIDC scientist Ted Scambos mapped glacier changes on the Peninsula and were surprised at the extent of the changes.

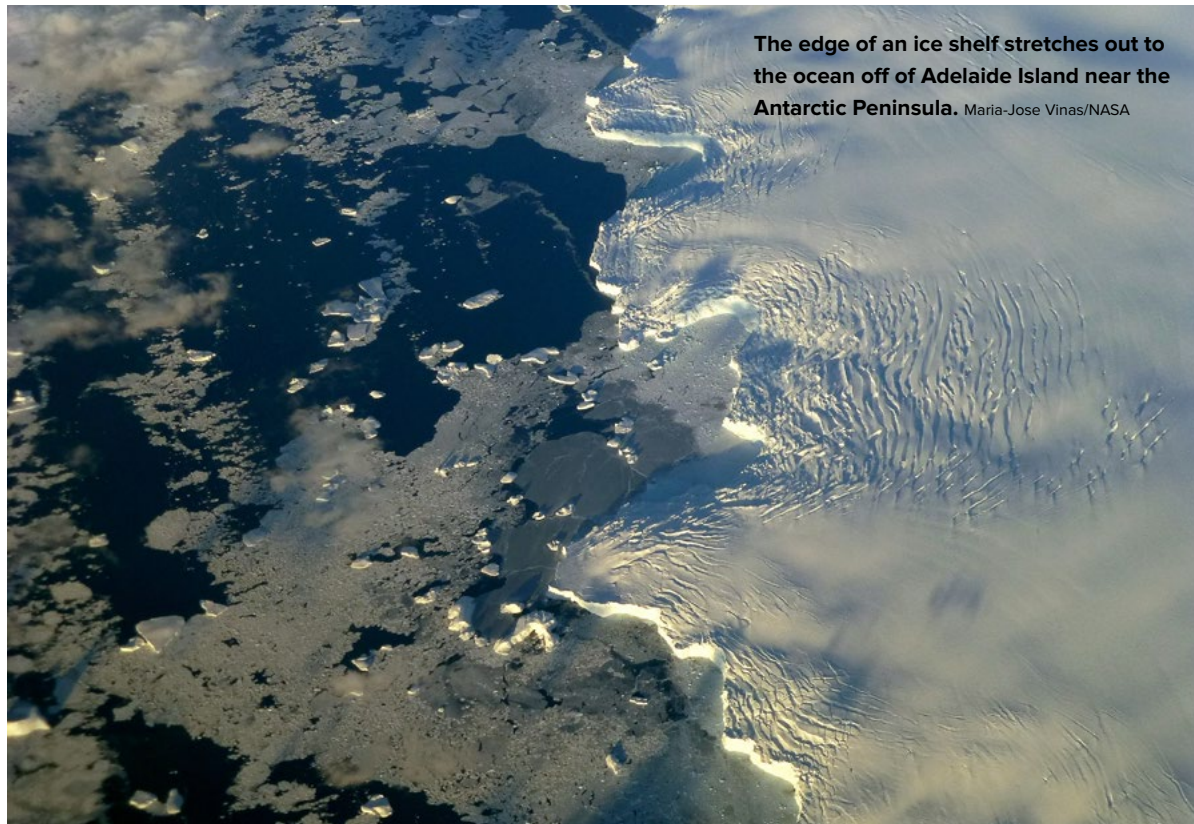
The disturbance from ice shelf breakups slowly extends throughout the mass of ice, taking five to fifteen years to propagate into the upper reaches of the glaciers. Several glaciers feeding the Larsen B Ice Shelf evolved in this manner after its 2002 collapse.

But it was uncertain how the rest of the northern Antarctic Peninsula was changing. The team used satellite data to map ice elevation change for 33 glacier basins, focusing on the 2003 to 2008 period. Surprisingly, they found that the whole area is losing mass. For the entire region to be responding this way means that multiple breakups must have occurred on Peninsula coastlines over the past 100 years.

Peninsula changes are driven primarily by increased air temperatures and greater surface melting, a process only slowly expanding across other areas of Antarctica. Other areas of major importance are changing due to increased warm ocean water being pushed toward the deeper ice-filled basins of the continent.

## Naval ice data made available to researchers

The U.S. Navy Project Birdseye, conducted from 1962 to the mid-1980s, aimed to understand the Arctic Ocean, and, in particular, sea ice. Submarines had the then-unique ability to operate and take measurements regardless of sea ice cover, weather conditions, and time of year. Data from the project may help to extend the satellite record of the Arctic Ocean, which begins in 1979. Although the NOAA at NSIDC program had obtained funds to scan seven of the canisters, no docu-



The edge of an ice shelf stretches out to the ocean off of Adelaide Island near the Antarctic Peninsula. Maria-Jose Vinas/NASA

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.



A graduate student checks a soil moisture gauge for the U.S. Department of Agriculture (USDA). USDA is an early adopter of data from the new Soil Moisture Active Passive (SMAP) mission. SMAP data, archived at NSIDC, will provide global measurements of soil moisture, a boon for the many areas that lack adequate soil gauge coverage. U.S. Department of Agriculture

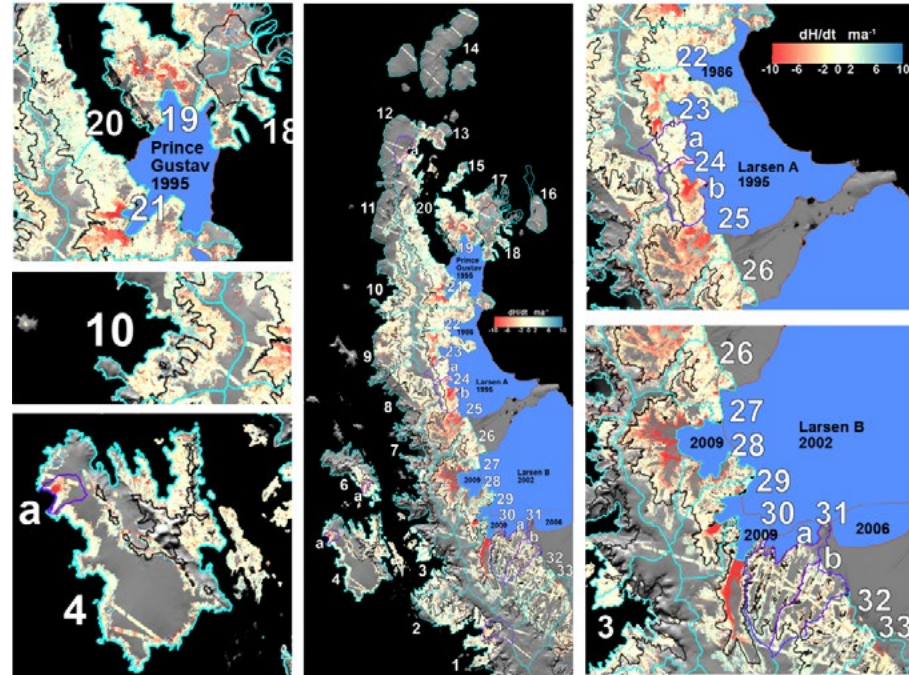
mentation accompanied the photographs until graduate student Brian Zelip from the University of Illinois located 72 reports describing the missions in 2014. As a result, 1,752 images from seven of the 99 canisters are now available online at NSIDC.

### NSIDC to manage NASA soil moisture data

Only about 1 percent of Earth's water moistens the soil, but this small amount plays a large role in processes above ground—growing the crops people eat, determining whether heavy rains will result in flooding, affecting the heat exchange between ground and atmosphere, and influencing cloud formation and weather. Historically, soil moisture records have relied on soil gauges with limited coverage. In January 2015, NASA launched the Soil Moisture Active Passive (SMAP) satellite observatory, which will produce global maps of soil moisture. Data will be distributed by the NASA NSIDC Distributed

Active Archive Center (DAAC). NSIDC DAAC ingested the first preliminary data two weeks after launch. A beta version of the Level 1 products are planned for release in late July 2015.

Typically known for snow and ice products, the NSIDC DAAC was chosen for SMAP because of previous success with soil moisture data from another NASA satellite. The SMAP team at NSIDC DAAC worked with users of soil moisture data, many who have never used satellite data, to understand their needs. As a result, SMAP data are to be distributed in several formats that are common to the hydrology community.



Elevation change rates for major and minor glacier basins or islands in the northern Antarctic Peninsula study area. Cyan outlines the measured study basins and islands. Major ice shelf retreat areas since 1980 are indicated in blue, including the 1995 and 2002 ice shelf major collapse events. Terry Haran/NSIDC

### Polar book wins award

As part of NSIDC researcher Shari Gearheard's work in Clyde River, Nunavut, Canada, a small Inuit hamlet on the northeastern shores of Baffin Island, she and seven other editors documented Inuit knowledge in a book, "The Meaning of Ice: People and Sea Ice in Three Arctic Communities." The book won the 2014 William Mills Prize for Non-Fiction Polar Books, awarded by the Polar Libraries Colloquy.

# 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 climate change. By keeping the needs of decision-makers front and center in designing and conducting research, WWA generates usable and actionable findings and information products.

In FY15, the WWA team worked on both continuing projects and new initiatives that collectively engaged a broad community of federal, state, local, and private-sector stakeholders. Several efforts that produced noteworthy results in the past year are highlighted below.

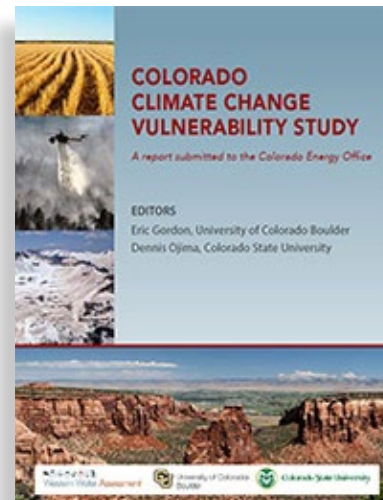
### Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation

Working with the Colorado Water Conservation Board, WWA in August 2014 released an updated and expanded version of its 2008 Climate Change in Colorado report. Like the original, the revised report is an authoritative assessment of the physical science regarding observed and projected climate change for Colorado, describing observed climate trends, the science of climate modeling, and mid-century projections of temperature, precipitation, snowpack, and streamflow for Colorado. The projections are derived from the latest CMIP5 climate model runs. The report leverages the broader findings from the IPCC Fifth Assessment Report and the third National Climate Assessment released in spring 2014 to provide decision-makers in Colorado with crit-

ical state- and basin-specific information. The expanded concluding chapter contains practical guidance for using the report's findings in vulnerability assessments and long-range planning for water resources. The first *Climate Change in Colorado* report has been cited extensively in stakeholder reports and planning documents, as well as the peer-reviewed literature. Likewise, the new report is already informing the climate adaptation and planning for water resources in Colorado and beyond.

### Colorado Climate Change Vulnerability Study

In early 2015, WWA and colleagues at Colorado State University released the *Colorado Climate Change Vulnerability Study*, an overview of key climate change vulnerabilities across the state. Drawing from peer-reviewed research and other existing data, the study summarizes key climate-related challenges facing seven sectors: ecosystems,



*By keeping the needs of decision-makers front and center in designing and conducting research, WWA generates usable and actionable findings and information products.*

water, agriculture, energy, transportation, outdoor recreation and tourism, and public health. It also details the existing adaptive capacity and potential strategies in those sectors to meet future climate challenges. The information in the study was compiled by researchers at CIRES and elsewhere at CU-Boulder, along with colleagues from the Colorado State University, the North Central Climate Science Center, and the National Center for Atmospheric Research. Thirty experts from state offices, consulting groups, and academia reviewed the report, which received wide coverage in the media, including the *Denver Post*, Colorado Public Radio, the *Boulder Daily Camera*, and *ClimateWire*. The findings of the study are intended to inform state and local-level preparedness planning, as well as further sector-specific vulnerability assessments. WWA and CSU received funding from the Colorado Energy Office to conduct this study, which was completed as part of the state's response to House Bill 1293 from 2013.

### **Water in the Western United States: A Massive Open Online Course**

Why is water at the heart of so much conflict in the American West? How have major cities and extensive agricultural systems been able to thrive despite most of the region having an arid or semi-arid climate? How might a warming climate affect the availability and use of water in this fast-growing region? To bring the issues behind these questions to a wide audience and to experiment with new directions in higher education, WWA's Eric Gordon and Anne Gold from the CIRES Education and Outreach program (page 60) co-taught a Massive Open Online Course (MOOC) entitled "Water in the Western United States." Designed as an undergraduate level survey, the course was made available on the Coursera platform in spring 2015 and was free to anyone with an Internet connection. The class consisted of short, 10- to 15-minute lecture videos featuring the course instructors and topic experts, including several CIRES researchers. Brief in-video quizzes, peer-reviewed assignments, and a

final capstone project fostered student engagement. More than 6,000 people registered for the course, with students hailing from 125 different countries.



**Hoover Dam from the air.**  
Pamela McCreight /Wikimedia Commons

# CIRES 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. This year we developed new capacity to reach tribal audiences, to provide online education and data-centered curriculum, and to demonstrate stakeholder satisfaction with scientific products. Some example projects are described below.

## Climate Education

CIRES climate education strives to meet educator needs for current, data-driven, and accurate climate science learning resources. We were honored to be high-

lighted as part of the White House Office of Science and Technology Policy Climate Education and Literacy Initiative. The three CIRES EO projects that were chosen were the award-winning Climate Literacy and Energy Awareness Network (CLEAN) Collection, the Tribe's Eye photography project, and the "Water in the Western United States" online course.

The CLEAN collection ([cleanet.org](http://cleanet.org)) is a peer-reviewed digital repository of climate and energy learning resources for grades 6 through 16. The collection of 630 resources has been reviewed by scientists and educators to ensure the resources are useful, appropriate, and current. The resources are syndicated through NOAA to form the teaching section of the [Climate.gov](http://Climate.gov) portal.

Dozens of tribal college students participated in the Tribe's Eye photography project, wherein students artistically documented environmental change on tribal lands using photography as a medium. CIRES staff and graduate students mentored students in environmental science and photography. The pieces were unveiled at a reception at CIRES, which was attended by students, their faculty mentors, and university personnel.

Building on previous online education efforts, CIRES EO, the Western Water Assessment, and the University of Colorado Boulder offered a free online course, entitled "Water in the Western United States," on the Coursera platform. More than 6,000 students participated in this course, which focused on the complex



**2015 National Ocean Sciences Bowl participants from Standley Lake High School in Westminster, Colorado.** David Oonk/CIRES



**Participating students from Diné college and the CIRES graduate student mentors at the Tribe's Eye photography exhibit. Names (right to left): Lyle Bitsoi, Kalya Hubbard, Mariah Mariano, Wilson Atene, Allison Lee, John Berggren, Margaret Mayer, and Jenny Nakai.**

David Oonk/CIRES

*This year we developed new capacity to reach tribal audiences, to provide online education and data-centered curriculum, and to demonstrate stakeholder satisfaction with scientific products.*

changing climate, policy, and stakeholder landscape affecting water resources in the West. The course received accolades from participants, university administrators, and the Coursera leadership for its scientific and visual excellence.

### Broader Impacts

In collaboration with the summer Front Range Air Pollution and Photochemistry Experiment (FRAPPÉ) and NASA's Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ) field projects, we developed a suite of outreach activities to engage the public in the scientific enterprise. During a series of public citizen science hikes, which we developed in partnership with the city of Boulder's Open Space and Mountain Parks, hikers and volunteers collected air

quality data and learned about Front Range air quality. Summer interns studied air quality in Rocky Mountain National Park. Project partners co-led a workshop for area educators and some large open house events took place. Through another broader impacts grant, the summer data was used to develop a Front Range-focused air quality module for secondary science students (<http://bit.ly/1O96116>).

Building on new data available through the NASA Solar Dynamics Observatory, we developed a suite of student-centered space weather learning resources (<http://bit.ly/1JVCa1k>). These resources are also available through the reviewed NASA Wavelength collection (<http://nasawavelength.org/>). Through partnership with ESRL, the new resources are part of NOAA outreach programming.

### Program and Project Evaluation

At the request of NOAA, we conducted an evaluation study of the Climate.gov web portal. Surveys, usability studies, web analytics, and interviews focused on the extent to which the intended audiences perceive that they have a relationship with Climate.gov team, are aware of Climate.gov's services, and find the website trustworthy, usable, and satisfying. These metrics, known collectively as Quality of Relationship, are based on elements of customer satisfaction and are a measure of performance excellence. The resulting data are being used to inform the next phase of Climate.gov's development.



The Discover AQ campaign hosted many outreach related activities including an open house where members of the public toured the aircraft, met the scientists and learned more about regional air quality issues. David Oonk/CIRES



On a Discover AQ-led citizen science hike, members of the public learned about ozone and air quality issues and collected data for analysis by researchers. David Oonk/CIRES

# International Global Atmospheric Chemistry

The International Global Atmospheric Chemistry (IGAC) Project was formed in 1990 to address growing international concern over rapid changes observed in the Earth's atmosphere. IGAC's mission is to foster atmospheric chemistry research towards a sustainable world. This is achieved through IGAC's foci on building an international network of scientists, capacity building for early career and developing country scientists, and providing the intellectual leadership to address the most pressing global change and sustainability issues through scientific research.

The IGAC International Project Office (IPO) is hosted by CIRES and the IGAC Executive Officer, Megan L. Melamed, is a CIRES Research Scientist. The IGAC

IPO is funded by the U.S. National Science Foundation, NASA, and NOAA. The funding from NOAA is through CIRES' cooperative agreement with the agency.

IGAC builds an international network of scientists through its biennial science conference, which is the primary mechanism for dissemination of scientific information across the IGAC community, and sponsoring focused workshops related to scientific issues and regional coordination. In 2014, along with its sponsor the International Commission on Atmospheric Chemistry and Global Pollution, IGAC held its 13<sup>th</sup> science conference in Natal, Brazil. This was the first time IGAC held its science conference in Latin America and it was a huge success: With approximately 425 participants

from 46 different countries, 169 of the participants were early career scientists. In addition to the 2014 science conference, IGAC sponsored or endorsed 11 workshops in 2014, including topics such as hydroxyl reactivity and climate engineering. Currently the IGAC community comprises 3,000+ scientists from around the world.

IGAC has a strong focus on engaging the next generation of scientists and developing country scientists. Early career scientists are awarded travel grants to attend IGAC-sponsored workshops and the IGAC biennial science conference. In addition, the IGAC biennial science conference also includes an early career program. These scientists join an international network of atmospheric scientists early in their career that will further facilitate



Participants of the IGAC-MANGO Workshop at the Asian Institute of Technology (AIT) in Bangkok, Thailand. Courtesy of Hiroshi Tanimoto and Kim Oahn



The International Global Atmospheric Chemistry Project was formed in 1990 to address growing international concern over rapid changes observed in the Earth's atmosphere.

atmospheric chemistry research at an international level for years to come. For the developing country scientists, IGAC fosters creating a strong, cohesive community of atmospheric scientists in under-represented regions of the world and also connects the scientists to the larger IGAC community to foster international collaborations. An example of such efforts is formation of the IGAC Monsoon Asia and Oceania Networking Group (IGAC-MANGO), which held its first workshop in early 2015 in Bangkok, Thailand (photo, previous page) and brought together scientists from Bangladesh, India, Nepal, Pakistan, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam, Australia, Taiwan, Korea, China, and Japan to determine how to form a more cohesive Asian scientific community and link it to the international IGAC community.

IGAC provides intellectual leadership by identifying current and future areas within atmospheric chemistry that need to be addressed and promoted or that would

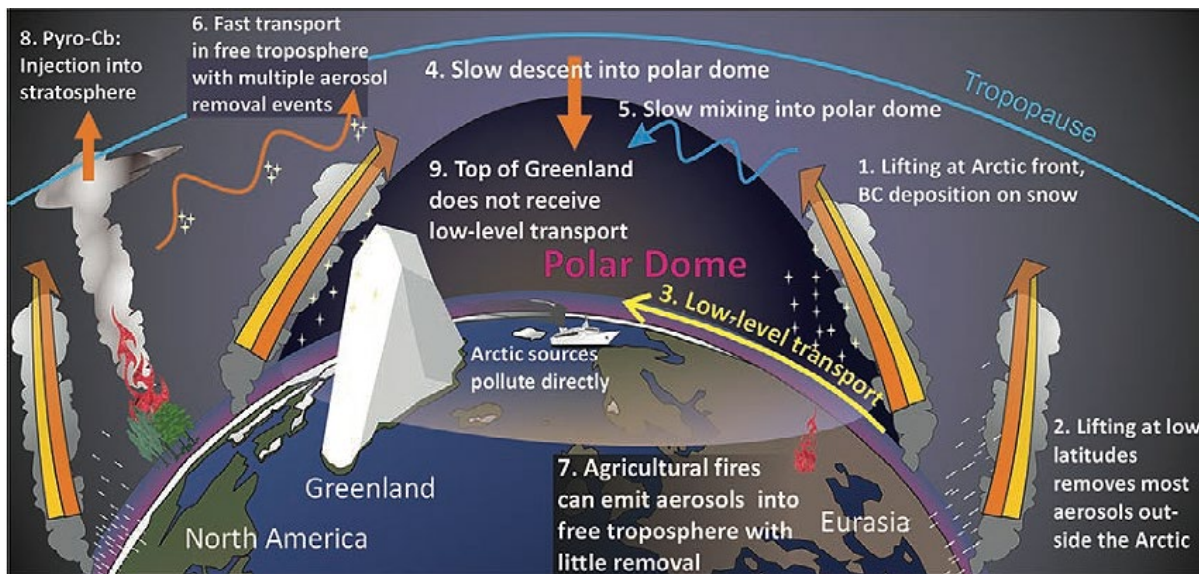
benefit from research across disciplines and/or geographical boundaries. IGAC then fosters scientific collaborations through its activities to promote atmospheric chemistry research in the identified areas. In many cases, these activities result in high-level publications that push the field of atmospheric chemistry. An example of this was a review paper recently published in the *Bulletin of American Meteorological Society* (Law et al., 2014), which highlights findings from the IGAC-sponsored international POLARCAT (Polar Study using Aircraft, Remote Sensing, Surface Measurements and Models, Climate, Chemistry, Aerosols and Transport) Project. The review paper identifies the origins and transport of pollution to the Arctic and identifies areas requiring further investigation. The findings of this review paper have led IGAC to facilitate a new activity on Arctic air pollution that will focus on local air pollution sources and will have social scientists working with local communities on air pollution challenges in the Arctic.

IGAC's priorities and activities are guided by an international volunteer Scientific Steering Committee (SSC). The current IGAC SSC as of January 2015 consists of 19 people from North America, Europe, Asia, Africa and Latin America. The current list of SSC members is available on the IGAC website.

More information can be found at [igacproject.org](http://igacproject.org).

### References

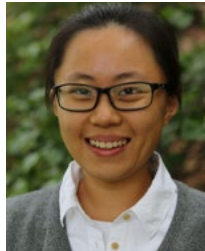
Law, KS, A Stohl, et al. (2014) Arctic Air Pollution: New Insights from POLARCAT-IPY *Bull. Am. Meteorol. Soc.*



Schematic showing pathways for the transport of air pollution into the Arctic. Law et al., 2014

## 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, 325 people have been Visiting Fellows at CIRES, including former CIRES Directors Susan Avery and Konrad Steffen.



### Linyin Cheng

Postdoctoral  
Ph.D., University of California, Irvine  
Project: Frameworks for assessing non-stationary spatio-temporal climactic extremes  
Sponsor: Balaji Rajagopalan

Climate change and variability are likely to affect physical and hydrometeorological conditions and to interact with, and possibly exacerbate, ongoing environmental change. Therefore, there exists a strong need to study extreme weather and climate events across different spatio-temporal scales and to understand their frequency and intensity, which is important for public safety, societal management and policy. My research focuses on analyzing climatic extremes including modeling non-stationarity processes in space and time and modeling concurrent and consecutive extremes and their dependencies.

Current statistical models are designed for modeling the dependence between two sets of extremes that may or may not have occurred at the same time. Furthermore, current models cannot assess joint occurrence of an extreme event with a moderate departure from the mean whose combination could lead to an extreme climatic condition (e.g., extreme heat wave combined with a moderate drought). However, the combination or sequences of climate extreme events may have a significant impact on the ecosystem and society, though the individual events involved may not be severe extremes themselves; developing statistical models, beyond a simple parametric model adjusted for a correlation range and process smoothness, to account for complicated spatial dependence structures. This is important since geophysical processes tend to have a multi-scale character in space.



### Emanuel Gloor

Sabbatical  
Professor, University of Leeds  
Project: Changes of the coupled Amazon carbon and hydrological cycle  
Sponsors: Stanley Benjamin and Stephen Montzka

I collaborated with CIRES Fellows Stan Benjamin and Steve Montzka in the Earth System Research Laboratory, to develop tools and techniques for better understanding and modeling hydrological changes in the Amazon Basin, especially as associated with the carbon cycle.

Specifically, I started an analysis of vertical air-mass transport from the lower troposphere (up to 4.5 km) to the upper troposphere/lower stratosphere. This work is to develop a technique to estimate Amazon Basin greenhouse gas fluxes from vertical profiles of concentration profiles.

I also contributed to establishing a vertical aircraft sampling in Manaus, Brazil, to a height of 8 km using a continuous gas analyzer. I became acquainted with using continuous analyzers, including the measurement of the  $H_2^{18}O$  in water vapor. Our goal is ultimately to install such instruments along a East-West transect in the Amazon.

I am writing a proposal to continue an atmospheric greenhouse gas monitoring program over the Amazon, with CIRES/NOAA/ESRL (John Miller).

I analyzed trends in the hydrological cycle in the Amazon and contributed to manuscripts on methane balance in the Amazon and a 10-year time series at Santarem, Brazil. I also analyzed upper troposphere carbon dioxide data measured by NOAA/ESRL to determine the tropical versus Northern Hemisphere mid- to high-latitude carbon sink.



### Gregory Houseman

Sabbatical  
Professor, University of Leeds  
Project: Structure and Evolution of Continental Lithosphere in Orogenic zones  
Sponsors: Peter Molnar and Craig Jones

Visiting from the University of Leeds, I am undertaking a collaborative study with CIRES Fellows Peter Molnar, Craig Jones and Lang Farmer in the Department of Geological Sciences. We study the mechanism of lithospheric instability in the continents, with special focus on the geological and thermal evolution of the Tibetan Plateau and the western United States. Using numerical calculations that model the long-term (10's of millions of years) and large-scale (1000's of km) deformation of the crust and upper mantle as if it were a viscous fluid, we seek to explain the processes that are responsible for the development of present-day structural variation in the uppermost mantle of the Earth. Both regions have experienced recent (and continuing) deformation, constrained by seismological investigations and geochemical analysis of xenoliths (samples of the upper mantle and lower crust that are delivered to the Earth's surface by violent volcanic explosions): The Tibetan Plateau is the result of continuing continental convergence between India and Eurasia, which has thickened crust and lithosphere. The whole structure is gravitationally unstable, but the question of how it will then evolve is controversial. The western United States now has a relatively thin crust and absent mantle lithosphere but it is thought to have evolved by extension and lithospheric instability from a plateau of thickened crust that was analogous to the present-day Tibetan Plateau. The investigation will use a suite of 2-D and 3-D numerical simulation programs for viscous flow developed by Houseman and collaborators.



### Gesa Luedecke

Postdoctoral  
Ph.D., Leuphana University  
Lueneburg, Germany  
Project: Climate Change Communication and the Media  
Sponsor: Maxwell Boykoff

My aim this year is to empirically and theoretically develop a better understanding of media narratives at the interface of climate change communication and social learning for dealing with climate change. Next to traditional research in terms of written output in peer-reviewed journals as an emphasis of the postdoc fellowship at CIRES, this research would create novel communication approaches, thereby developing effective communication resources in favor of social learning regarding climate change. Next to focusing on environmental psychology and media communication studies, this work would also take up a transdisciplinary perspective by developing and sharing knowledge with multi-stakeholder parties about intentions, beliefs and behaviors of individuals and groups regarding climate change post media consumption. In the fellowship I will work on three respective fields of interest that will support research about media communication of climate change at CIRES CSTPR: collaboration in different projects with CSTPR fellows; transdisciplinary evaluation of communication strategies together with different stakeholders to investigate media communication, media reception, and behavioral intentions post media consumption; and publishing findings from recent work.



### Brian McDonald

Postdoctoral  
Ph.D., University of California,  
Berkeley  
Project: Assessing long-term trends in U.S. air quality and impacts on human health and climate change  
Sponsor: Joost de Gouw

Brian McDonald will be collaborating with Michael Trainer's Regional Chemical Modeling Group. Significant progress has been made in improving U.S. air quality since enactment of the Clean Air Act. However, linking observed air quality changes in the atmosphere to specific policy initiatives has been challenging, primarily due to large uncertainties and errors that exist in emission inventories. It is important to get both air quality and emission models correct so that next generation policies can be designed effectively, to protect human health and mitigate global climate change.

## visiting fellows



### Catrin Mills

Postdoctoral  
Ph.D., University of Illinois  
Project: Arctic meteorology  
and climate  
Sponsor: John Cassano and  
Mark Serreze

Catrin's research focuses on the relationship between day-to-day weather patterns in the Arctic and sea ice variability, using multiple tools, such as a pattern recognition tool called self-organizing maps (SOMs). She is also working with the Cassano research group to study the effects of Arctic change remotely, such as the role of enhanced Arctic sea ice loss on weather systems in the United States. Her research taps into potential predictive capabilities—highly useful for native Arctic communities and stakeholders. She is interested in studying the impacts of extreme weather events on society by using neural networks and other multivariate methods in order to create metrics that augment predictability of atmospheric phenomena and are tailored to user-needs.



### Twila Moon

Postdoctoral  
Ph.D., University of Washington  
Project: Development and appli-  
cation of high-resolution velocity  
records for the Greenland Ice  
Sheet and Antarctic Peninsula  
Sponsor: Mark Serreze

Twila Moon is working with Ted Scambos, Mark Serreze, and others at the National Snow and Ice Data Center to create a new dataset to study how quickly ice is flowing on the Greenland Ice Sheet and the Antarctic Peninsula. Both polar regions have already experienced significant warming from climate change and are contributing to rising sea level around the globe. Warming is expected to continue. Understanding how warming will affect the ice sheets, however, remains difficult, in part because scientists don't have a complete understanding of how quickly ice sheets can change. Moon will be using satellite data and new software to map ice sheet velocity over weeks to months. She will also be using these new datasets to explore how the ice sheets interact with the ocean and sea ice and examine changes in water flow underneath the ice. The data will be a valuable resource for the research community as scientists continue to understand ice sheets in a warming world. Moon is happy to be returning to her roots in Colorado, but even more excited to meet and work with the many researchers in Boulder who are examining ice and climate.



### Hans D. Osthoff

Sabbatical  
Associate Professor  
University of Calgary  
Project: Ozone budgets and  
radical chemistry in unusual  
environments  
Sponsor: Joost de Gouw

Hans Osthoff collaborated with Joost de Gouw's group at NOAA ESRL. The project used a box model based on the Dynamically Simple Model of Atmospheric Chemical Complexity and the Master Chemical Mechanism developed at Leeds University. The model (Edwards et al., 2014) was constructed to simulate a 5-day winter-time ozone pollution event in Utah's Uintah Basin.

Osthoff fine-tuned the model to improve the agreement of predicted and observed concentrations of peroxy-carboxylic nitric anhydride (PANs), byproducts of photochemical ozone production. Their abundances and ratios (e.g., that of peroxypropionic or PPN to PAN) give insight into the contributions of hydrocarbon classes during ozone production. We found a multitude of hydrocarbons contributing to the formation of PAN and PPN. A surprisingly large fraction derived from the oxidation of aromatic VOCs, via methyl and ethyl glyoxal. The model failed to predict the order of magnitude and diurnal profile of peroxyacryloic nitric anhydride (APAN), an oxidation byproduct of cycloalkanes whose chemistry is underrepresented in the model, mainly due to lack of knowledge of relevant kinetic parameters.

Osthoff researched to what extent different classes of volatile organic compounds contribute to ozone production during stagnation events. Formaldehyde, isobutane, and propane had the largest 3-5 day photochemical ozone creation potential (POCP) and m-Xylene had a high POCP on days 1 and 2 of the ozone-production event, but a much lower POCP on the following days, when oxygenated species and radical sources had accumulated.



## Valery A. Yudin

Postdoctoral  
Ph.D., Saint Petersburg University  
Research Scientist  
Project: Gravity Wave Parameterizations in Weather and Climate Models  
Sponsors: Xinzhao Chu and Tim Fuller-Rowell

Valery Yudin is collaborating with researchers in two CIRES divisions: Weather and Climate Dynamics (the space weather research group of Tim Fuller-Rowell) and Environmental Observations, Modeling and Forecasting (the lidar exploration group of Xinzhao Chu) to develop and implement the non-orographic Gravity Wave (GW) physics in the NOAA weather and climate models, such as Global and Climate Forecast Systems (GFS and CFS) and the Whole Atmosphere Model (WAM). In particular, WAM has been accepted as a possible future National Weather Service (NWS) model for long-range weather prediction to link the terrestrial and space weather forecasts. For space weather, WAM is also being coupled to the plasma part of the upper atmosphere and will be used by NOAA's Space Weather Prediction Center for day-to-day ionospheric space weather forecasts driven by lower atmosphere weather. The GW project is designed to improve the non-orographic gravity wave parameterization in WAM and CFS/GFS using recent advances in the theory and observations of GWs and their sources. When WAM was created and the model lid was raised from 60 km (as in GFS) to 600 km, no changes were made to the parameterization to tune the GW physics in the stratosphere, mesosphere, and thermosphere. This project will promise to introduce effects of GWs into the global models. The current GW parameterization used in WAM and GFS/CFS is limited to quasi-stationary orographic waves and in particular,

it doesn't drive the correct zonal wind reversal in the mesosphere and lower thermosphere. We expect the GW forcing in the upper atmosphere for space weather applications will be improved by collaborations among Yudin and the CIRES research groups of Fuller-Rowell and Chu.



**Jakobshavn ice fjord. Icebergs choke the fjord where Jakobshavn glacier flows into the sea off western Greenland. A new analysis shows that the mechanisms that drive the seasonal ebb and flow of some Greenland glaciers are different from those driving longer-term trends like overall retreat of glaciers, and faster flows. Lead author of the *Journal of Geophysical Research* paper, CU-Boulder's Twila Moon, said she hopes it will help scientists better anticipate how a warming Greenland will contribute to sea level rise.** Ian Joughin, University of Washington.

## 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/>

## 2015 Innovative Research Program Awards

### Mapping avalanche starting zone snow depth with a ground-based LiDAR

Jeffrey Deems and Richard Armstrong

### Network theory to understand cloud systems

Graham Feingold and Franziska Glassmeier

### Dynasonde Tomography: Probing the atmosphere with acoustic gravity waves

Oleg Godin and Nikolay Zabolin

### Lidar profiling water temperature in the ocean: A promising new technology to explore the ocean submesoscale variability with a Mach-Zehnder interferometer

Wentao Huang, Xinzhao Chu, Ralfph Milliff, and John Smith

### Modeling of scale-dependent stochastic magnetosphere-ionosphere coupling processes

Tomoko Matsuo and Debashis Paul

### Global inventory of natural gas isotopic and chemical composition for improved atmospheric methane budgeting

John Miller, Stefan Schwietzke, and Owen Sherwood

### Earth remote sensing using signals of opportunity

R. Steven Nerem and Dallas Master

### A low-cost ocean current and temperature sensor for long-term deployment in polar ocean environments

Mark Serreze, Glenn Grant and David Gallaher

### Hydroacoustic monitoring of Antarctic ice shelf collapse

Anne Sheehan, Justin Ball, and Ted Scambos



With help from a 2014 CIRES Innovative Research Program award, scientists and artists collaborated to better understand if the arts, and its realm of metaphors, images, storytelling and emotions, can be an ally for science, and its realm of data, numbers, analysis and intellect. Will Von Dauster/NOAA

## graduate student research awards

CIRES supports a Graduate Student Research Award (GSRA) program to promote student scholarship and research excellence. The goals of the program are to attract the best talent to CIRES at the outset of their graduate careers, and to enable graduating seniors to complete and publish their research results. Any current or prospective Ph.D. student advised by a CIRES Fellow is eligible for this one-time award opportunity. Incoming graduate students must be accepted into a graduate level program at the University of Colorado Boulder to qualify for this fellowship opportunity.

The CIRES GSRA is granted in the form of a Research Assistant position for one or two semesters at 50 percent time. The award includes a monthly salary, fully paid tuition, and a partially paid premium (90 percent) towards the Buff Gold insurance plan. Funding for prospective students may be used in their second year if a Teaching Assistantship covers their first year. Students may receive a 50 percent research award for one or two semesters.

At right are the recipients for this reporting period (June 1, 2014–May 31, 2015).

<http://cires.colorado.edu/education/graduate-student-fellowships/>

## 2015 Graduate Student Research Award Recipients

### **Cao Chen**

Project: Exploration of the mystery of polar wave dynamics with lidar, radar and high-resolution general circulation model.

Advisor: Xinzhao Chu, Aerospace Engineering Sciences

### **Zachary Finewax**

Project: Investigating aerosol and VOC products of biomass burning emissions through HR-CIMS and thermal desorption particle beam mass spectrometry (TD-PBMS).

Advisor: Joost de Gouw, Chemistry and Biochemistry

### **Harrison Gray**

Project: Development and application of luminescence dating as a new means to estimate sediment transport rates.

Advisor: Gregory Tucker, Geological Sciences

### **Catalin Negrea**

Project: Ionospheric physics.

Advisor: Tim Fuller-Rowell, Electrical, Computer, and Energy Engineering

### **Stephanie Redfern**

Project: Global/Regional Climate Modeling and Climate Science Communication.

Advisor: Jen Kay, Atmospheric and Oceanic Sciences

### **Samantha Thompson**

Project: Characterization and Deployment of a soft ionization mass spectrometer for organic aerosol and gas detection.

Advisor: José-Luis Jiménez, Chemistry and Biochemistry

### **Shuichi Ushijima**

Project: Heterogeneous efflorescence of atmospherically relevant salts by mineral dust particles.

Advisor: Margaret Tolbert group, Chemistry and Biochemistry

### **Fnu Yanto**

Project: Space-time variability of Indonesian hydroclimate: Diagnostics, modeling and implications for water resources management.

Advisor: Balaji Rajagopalan group, Civil, Environmental, and Architectural Engineering

## 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 last year are described on these three pages.

### Tribe's Eye

The CIRES Education and Outreach group engaged Navajo youth from Diné College and the Southwest Conservation Corps' Ancestral Lands Program in learning about climate and the local environment through photography. The Navajo Nation has historically been plagued by prolonged drought, experiences little rainfall, and is subject to poor water quality. Climate change is expected to exacerbate future droughts and impacts. Through photography, students communicated their perspectives on how climatic and environmental changes on their reservation affect their lives. In producing compositions, students built knowledge about their topic through interviews with tribal community members and CU-Boulder scientists. Compositions were shared with the public in a gallery event at CIRES in April 2015.

### Southwest Conservation Corps' Ancestral Lands Program group members

The Southwest Conservation Corps produced six compositions as a team, all focused on the work of a crew working long hours in remote locations to remove invasive Russian olive trees by chainsaw. Members: **Rolando Billie, Radeanna Comb, Jared Meyers, and Joe Shayden**

### Diné College group members and compositions

**Wilson Atene** *Wake up Monument Valley*

**Tachena Billie** *First morning of spring*

**Lyle Bitsoi** *Trash pile*

**Elphonso Curley** *Roots*

**Matt Curleyhair** *Alcohol bottle trash, Trash and skull*

**Carl Haskie** *Warning sign*

**Kayla Jackson** *Busy Bee roping company*

**Allison Lee** *Cartoon character on a rock, Cows grazing*

**Ryan Lee** *Illegal dumping*

**Mariah Mariano** *An abandoned house*

**Kyle V. Sorrell** *Graffiti, Evening flight, Vanishing water*

**Darrell Yazzie** *Illegal dumping*

**Kiesha Yazzie** was also a member of the Diné College group, but did not produce compositions for the final show.



*Evening flight.* Kyle V. Sorrell/Diné College



## Research Experience for Community College Students (RECCS)

Following a successful internally funded program in the summer of 2014, the National Science Foundation funded three years of the RECCS program, which gives summer research experiences to undergraduates from underserved communities. With NSF funding, CIRES and the Institute of Arctic and Alpine Research (INSTAAR) offered paid summer research opportunities for 10 Colorado community college students. These research opportunities offer a unique opportunity to conduct research, both field- and laboratory-based; work in a team with scientists; learn basic research, writing, and communication skills; and present research at a science conference. <http://cires.colorado.edu/education/outreach/projects/reccs/>



Community College of Denver student Marianne Blackburn and her instructor Fleur Ferro surveying plots for fire fuel density and pine seedlings. Marianne is working with USGS scientist Jenny Briggs. Lesley Smith/CIRES

## RECCS Students

### Lisa Arvidson

Project: Trends in observed daily summertime maximum temperatures in Colorado

Mentor: Imtiaz Rangwala (CIRES)

### Margaret Baker

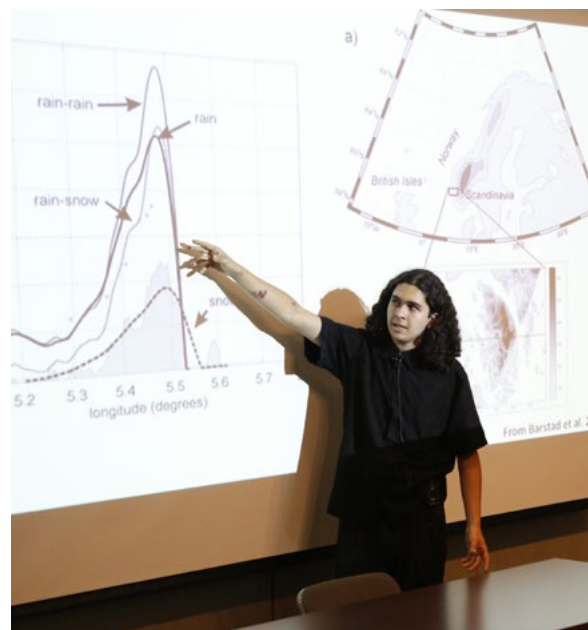
Project: Modeling the effects of acid mine drainage in the Snake River watershed, Summit County, Colorado

Mentor: Diane McKnight (INSTAAR)

### Marianne Blackburn

Project: Changes in surface fuels and regeneration following the mountain pine beetle epidemic in ponderosa pine forests along the Colorado Front Range

Mentor: Jenny Briggs (USGS)



Luca Collins presents his summer's research on the CU-Boulder campus. David Oonk/CIRES

### Savannah Bernal

Project: The effects of nitrogen deposition on biological soil crust in the alpine

Mentor: Nichole Barger (CU-Boulder)

### Luca Collins

Project: Multiple model investigation of atmospheric rivers and Sierra barrier jet controlled precipitation processes

Mentor: Mimi Hughes (CIRES)

### Joseph Gomora

Project: How is stream flow generated between storms: Signature identification of the distribution of flow sources in a headwater mountain stream

Mentor: Michael Gooseff (INSTAAR)



RECCS poster session. Robin L. Strelow/CIRES

## diversity and undergraduate research

### **Moana Sato**

Project: Influence of hillslope steepness on sediment size distribution along rivers draining the Colorado Front Range

Mentor: Greg Tucker (CIRES)

### **Kevin Thirouin**

Project: The influence of soil moisture availability, relative humidity, and tree distance from stream on diurnal fluctuations of leaf water potential in ponderosa pine

Mentor: Holly Barnard (CU-Boulder)

### **Caihong VanderBurgh**

Project: Quantifying the variability in microbial numbers and metabolic activity through a soil profile

Mentor: Noah Fierer (CIRES)

### **Andrea Weber**

Project: Linking hydrology, weather, and earth flow displacements along the Dakota Ridge in the CZO in Boulder, Colorado

Mentor: Bob Anderson (CU-Boulder)

### **PRE-College Internship Program (PRECIP®)**

PRECIP, run by the National Center for Atmospheric Research (NCAR) engages high school students in a six-week project in atmospheric or related sciences, participate in writing workshops, and present a scientific poster summarizing their work at the NCAR student poster session.

#### **PRECIP® Students**

**Paola S. Esteban Pérez** (Colegio San José, Columbia)

Poster: Calibrating the Manus Profiler using TRMM satellite bright band reflectivities

Mentors: Leslie Hartten and Paul Johnston (CIRES)

**Valerie M. Rodríguez Castro** (University of Puerto Rico)

Poster: Calibrating the Manus Island wind profiler by comparing profiler and rain surface measurements

Mentors: Leslie Hartten and Paul Johnston (CIRES)



**PRECIP® students Paola S. Esteban Pérez (left) and Valerie M. Rodríguez (right) with Leslie Hartten.**

Courtesy of Leslie Hartten

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

#### **RESESS Students**

##### **Crystal Burgess**

Poster: Detection of Diagenesis in Paleosol Carbonate Nodules using Optical and Cathodoluminescence Microscopy

CIRES research mentor: Karen Alley

##### **Deanna Metivier**

Poster: Understanding the Use of Climate Information in State Wildlife Action Plans

CIRES research mentor: Heather Yocum

### **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**

##### **Rachel Brinks**

Project: Fighting climate with religion: A look into Judeo-Christian perspectives on climate change

CIRES mentor: Maxwell Boykoff

##### **Jacob Dickerson and Kristen Vaccarello**

Project: Ecological drivers of gut microbiota across a wild neotropical caterpillar community

CIRES Sponsor: Noah Fierer

##### **JohnCarlo Kristofich**

Project: Enzyme evolution across species

CIRES Sponsor: Shelley Copley

##### **Caitlin McShane**

Project: A circumpolar analysis of extreme precipitation events

CIRES Sponsor: Mark Serreze

***First morning of spring***

Tachena Billie/Diné College



# selected 2014 awards

## CIRES Outstanding Performance Awards

The CIRES Outstanding Performance Awards are targeted at projects that are novel, high impact and show remarkable creativity or resourcefulness. In the **Science and Engineering** category, this may involve any work that is related to the scientific process (forming and testing hypotheses to further our understanding of the environmental sciences). In the **Service** category, this may involve any work that facilitates, supports, enhances, or promotes work in the environmental sciences.



Jeff Peischl and Waleed Abdalati David Oonk/CIRES



Waleed Abdalati and Michelle Cash David Oonk/CIRES

## Science and Engineering

**Manoj Nair** (NGDC-NCEI) for geomagnetic innovations involving tsunami detection, crowd sourcing of Earth's magnetic field, and the World Magnetic Model

**Jeff Peischl** (CSD) for extraordinary leadership and innovative research measuring and analyzing greenhouse gases

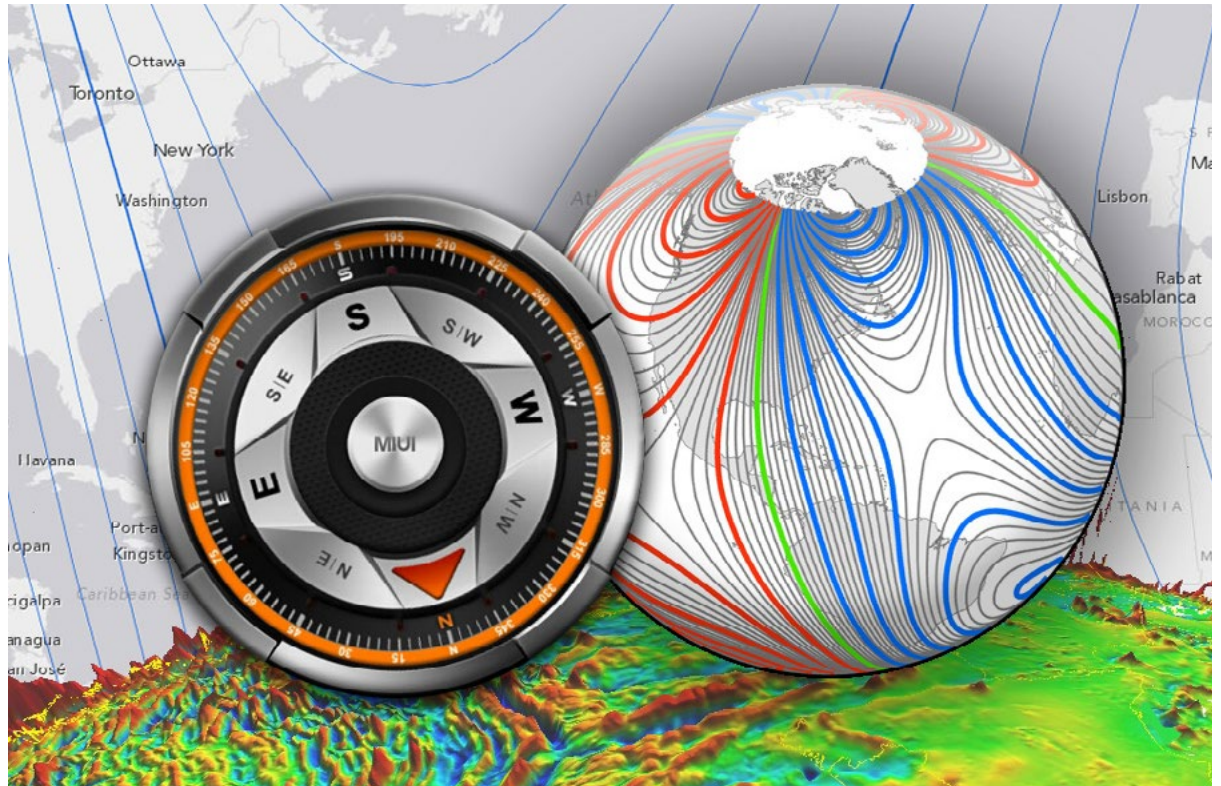
**Takanobu Yamaguchi** (CSD) for his extraordinary work improving modeling and understanding of aerosol-cloud interactions and climate

## Service

**Chris Golden** (GSD) for innovations instrumental to the success of the Hazard Services application for weather forecasters

**Jeff Johnson, Michael Burek, Alysha Reinard, Michele Cash, Tom DeFoor, Richard Grubb,** and **Ratina Dodani** (SWPC) for developing, under budget, a robust and fast ground processing system for NOAA's Deep Space Climate Observatory

**Ann Weickmann** (CSD) for developing innovative software and hardware that enabled great strides in the use of lidar systems for atmospheric science



World Magnetic Model CIRES/NOAA



**Xiao-Wei Quan, Jon Eischeid** David Oonk/CIRES



**Hilary Peddicord, Shilpi Gupta, Beth Russell, and Waleed Abdalati** David Oonk/CIRES

## CIRES medals and more

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. CIRES recognizes their extraordinary achievements with CIRES Silver and Bronze Medals.

### Silver

CIRES Silver Medal for scientific/engineering achievement, 2015

**Xiao-Wei Quan** and **Jon Eischeid**, CIRES scientists in ESRL's Physical Sciences Division, were part of a NOAA team honored with a Department of Commerce Silver Medal for an outstanding scientific assessment of the origins of the 2012 Central Great Plains Drought.

### Bronze

CIRES Bronze Medal for superior performance by federal employees, 2015

**Shilpi Gupta, Hilary Peddicord, and Beth Russell**, CIRES staff in ESRL's Global Systems Division, were part of a NOAA team honored with a Department of Commerce Bronze Medal for achieving the 100<sup>th</sup> worldwide installation of Science On a Sphere®.

## Technology Transfer

CIRES Technology Transfer Award, 2015

**Anna Karion, Tim Newberger, Colm Sweeney, and Sonja Wolter**, CIRES staff in NOAA's Global Monitoring Division, worked with NOAA's Pieter Tans to develop AirCore, for collecting air from 100,000 ft. to the surface with exceptional data resolution, and which won a NOAA Technology Transfer Award.

## Other state, federal and international awards

**Curtis Alexander, Eric James, and Bill Moninger** (with NOAA's **Steve Weygandt, Stan Benjamin, and John Brown**, GSD)

Commendation and thanks from NASA for providing numerical weather model data and modeling support to the new integrated alerting and notification concepts for the Vehicle Systems Safety Technologies project

**Maxwell Boykoff** (CIRES, CU-Boulder)

2014 Green Faculty Award, University of Colorado, Boulder (with Kevin Andrews, Joanna Boehnert, Meaghan Daly, Lauren Gifford, Lucy McAllister, Ami Nacu-Schmidt, and Xi Wang)

**Gijs de Boer** (PSD)

Outstanding poster presentation by an early-career

scientist, given at the 2014 GEWEX 7<sup>th</sup> International Scientific Conference on the Global Water and Energy Cycle at The Hague

**Jeffrey Deems** (NSIDC)

Part of the Airborne Snow Observatory Team, which won a NASA Group Achievement Award

**Thomas Detmer** (CU-Boulder)

Recipient of the the George C. and Joan A. Reid Endowed Scholarship Fund, for intellectual contributions to CIRES and leadership within the broader University of Colorado Boulder community

**Cecelia DeLuca, Ben Koziol, Robert Oehmke, Ryan O'Kuinghtons, Matt Rothstein, Gerhard Theurich, and Silverio Vasquez** (ESRL)

Co-winners of the Federal Laboratory Consortium Tech Transfer Award, for NESII's (NOAA Environmental



**Gijs de Boer releases a ballonsonde while on an atmospheric science mission on Alaska's North Slope.**

Courtesy of Gijs de Boer/CIRES

## selected 2014 awards

Software Infrastructure and Interoperability) contributions to climate data analysis tools

**G Lang Farmer** (CU-Boulder)

2014 Fellow of Geological Society of America

**Shari Fox Gearheard** (NSIDC)

Shared the biennial 2014 William Mills Prize for best non-fiction Arctic or Antarctic book published in the world, for “The Meaning of Ice”

**Anne Gold** (Education and Outreach)

CU-Boulder Chancellor’s Award for Excellence in STEM

**Anne Gold, Amanda Morton, Susan Lynds, David Onk, Lesley Smith, and Susan Sullivan** (Education and Outreach)

Part of a broad team that won two 2014 Webby Awards for the Teaching Climate section of the Climate.gov website—in the juried Green category, and the People’s Choice award

**Mimi Hughes** (PSD)

Outstanding presentation by an early-career scientist, given at the 2014 GEWEX 7<sup>th</sup> International Scientific Conference on the Global Water and Energy Cycle at The Hague

**José-Luis Jiménez** (CU-Boulder)

Seventh Most Cited Scientist worldwide in the Geosciences, from Thomson Reuters; and 2014 College Scholar Award, CU-Boulder College of Arts & Sciences

**José-Luis Jiménez** (CU-Boulder) and **Richard McLaughlin, Eric Ray, and Nicholas Wagner** (CSD)

NASA Group Achievement Award for outstanding accomplishments, Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys (SEAC4RS)

**Anna Karion, John Miller, Eric Moglia, Tim Newberger, Colm Sweeney, and Sonja Wolter** (GMD)

Part of the Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) team, which won a NASA Group Achievement Award for successfully conducting sustained airborne science campaigns to characterize carbon dioxide and methane fluxes from permafrost in arctic and boreal Alaska

**Jordan Krechmer** (CU-Boulder)

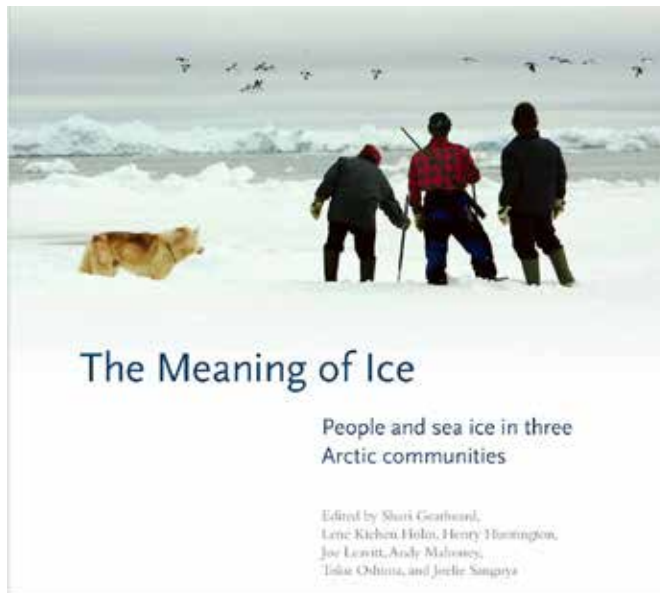
Krechmer, a graduate student working with José-Luis Jiménez, won a 2-year EPA STAR graduate fellowship

**Charles Long** (GMD)

In 2014, the World Meteorological Organization recognized Charles N. (Chuck) Long with the 2012 Professor Dr. Vilho Vaisala Award in Atmospheric Sciences award, given every two years for outstanding scientific papers

**Peter Hale Molnar** (CU-Boulder)

The eminent 2014 Crafoord Prize, awarded in geophysics every four years by the Royal Swedish



**Shari Fox Gearheard (NSIDC)** shared the biennial 2014 William Mills Prize for best non-fiction Arctic or Antarctic non-fiction books published in the world, for “The Meaning of Ice”.



**Education and Outreach team with Webby awards for the Teaching Climate section of Climate.gov website. Left to right: Amanda Morton, Susan Sullivan, David Onk, Anne Gold, and Susan Lynds**

Robin L. Strelow/CIRES

Academy of Sciences, which also gives Nobel Prizes; the City Council of Boulder, Colorado declared that Tuesday, June 3, 2014, was Peter Molnar Day

**Jenny Nakai** (CU-Boulder)

Nakai, a graduate student working with CIRES Fellow Anne Sheehan, won an NSF graduate fellowship

**Steve Nerem** (CU-Boulder)

2014 American Astronautical Society Earth Science and Applications Award

**Brett Palm** (CU-Boulder)

Palm, a graduate student working with José-Luis Jiménez, won a 2-year EPA STAR graduate fellowship

**Gabrielle Pétron** (GMD, with NOAA CSD's Jim Roberts and 63 other scientists in GMD, CSD and PSD)

The Colorado Governor's Award for High-Impact Research, given annually by Colorado Leveraging Assets for Better Science (CO-LABS), for research to understand the atmospheric impacts of rapidly expanding oil and gas development across the West

**Balaji Rajagopalan** (CU-Boulder)

College Research Award, College of Engineering and Applied Sciences, CU-Boulder

**Juan Rodriguez** (NGDC/NCEI)

NOAA Team Member of the Month, for outstanding support of NOAA's space weather mission

**Michon Scott** (NSIDC)

Part of a broad team that won a 2014 Webby Award in the Government category, for Climate.gov

**Mark Serreze** (CU-Boulder)

2014 Fellow of the American Meteorological Society; 2014 Highly Cited Researcher award from Thompson Reuters, ranking among the top 1 percent of researchers in a specific field (climate science)

**Anne Sheehan** (CU-Boulder)

2014 Fellow of the American Geophysical Union; and 2014 College Scholar Award, CU-Boulder College of Arts and Sciences

**Rainer Volkamer** (CU-Boulder)

National Science Foundation Young Investigator (CAREER) award; 2014 Highly Cited Researcher award from Thompson Reuters; 2014 KIT Distinguished International Scientist Award, in recognition of excellence in creative works related to atmospheric chemistry, environmental sustainability and climate

**Jeffrey Weil** (CIRES and NCAR)

American Meteorological Society award, Meteorological Aspects of Air Pollution, given to those who have made a significant contribution to the field of air pollution meteorology over the course of their careers

**Klaus Wolter** (PSD)

2014 *International Journal of Climatology* prize from Wiley-Blackwell

**Valery Zavorotny** (PSD)

Part of a multi-agency team that won the prestigious 2014 Creativity Prize from the Prince Sultan Bin Abdulaziz International Prize for Water



**Peter Hale Molnar,** recipient of the 2014 Crafoord Prize, awarded every four years by Royal Swedish Academy of Sciences.

Victoria Henriksson/Royal Swedish Academy of Sciences



**Anne Sheehan,** 2014 Fellow of the American Geophysical Union and recipient of the 2014 College Scholar Award, CU-Boulder College of Arts and Sciences. Courtesy of Anne Sheehan

# events

CIRES hosts diverse symposiums, seminars, workshops, and other events throughout the year. This year, two highlights were the 70 Seconds of Science communications challenge, and a particularly successful Distinguished Lecture Series, which brought four fascinating researchers to campus.

## Analytical Chemistry Seminars

**Shali Mohleji** How scientists can engage in the policy process (6/14)

**Rainer Volkamer** Group reactive trace gases in tropospheric chemistry and climate (9/14)

**Carl Koval** Research overview of the Joint Center for Artificial Photosynthesis: Development of scalably manufacturable solar-fuels generators (9/14)

**Joost de Gouw** Volatile organic compounds in the atmosphere (9/14)

**Margaret Tolbert** and **Paul Ziemann** A new mechanism for solid formation in the atmosphere: Contact efflorescence; Laboratory studies of the chemistry of secondary organic aerosol formation (9/14)

**Steven Brown** and **Aroob Abdelhamid** Nitrogen oxides and aerosols (NOAA): Some applications of cavity enhance spectroscopy in atmospheric chemistry; Isoprene hydroxynitrates and isoprene carbonylnitrates: kinetics and mechanisms (10/14)

**Zachary Finewax** and **Randall Chiu** Ozonolysis of a polyunsaturated acid and its primary oxidation products; Pond scum and boiling water: Water chemistry at Yellowstone National Park (10/14)

**Miriam Freedman** The structure of atmospheric particles and impacts on atmospheric chemistry and climate (10/14)

**Dan Hickstein** Uncovering the structure and dynamics of a single nanoparticle using the world's shortest laser pulses (11/14)

**Weiwei Hu** and **Zhe Peng** Characterization of a real-time tracer for isoprene epoxydiols-derived secondary organic aerosol (IEPOX-SOA) from aerosol mass spectrometer measurements; Oxidation flow reactors for the study of atmospheric chemistry systematically examined by modeling (11/14)

**Theodore Koenig** Iodine Monoxide observations from CU AMAX-DOAS aboard the NSF NCAR GV research aircraft (11/14)

**Alma Hodzic** Rethinking secondary organic aerosol formation and removal in 3D models based on explicit chemistry (12/14)

**Jay Kroll** Photon and water-mediated sulfur chemistry in planetary atmospheres (2/15)

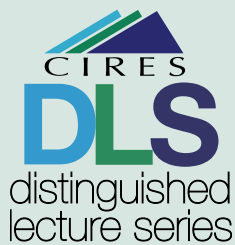
**Jordan Krechmer** Formation of low volatility compounds and SOA from isoprene oxidation without IEPOX uptake (2/15)

**Peter H. McMurry** Chemical nucleation in the atmosphere: Recent discoveries enabled by instrument development (2/15)

**Melissa Ugelow** Optical properties of Titan haze analogs using photoacoustic and cavity ring-down spectroscopy (3/15)

**Shantanu Jathar** Secondary organic aerosol modeling using the statistical oxidation mode (3/15)

CIRES' Distinguished Lecture Series brings in outstanding scientists, historians of science, science policy makers, science journalists, and others, who take imaginative positions on environmental issues and can establish enduring connections after their departure.



**Thomas H. Jordan**  
**University of Southern California**  
The prediction problems of earthquake system science (10/14)



**Gavin Schmidt**  
**NASA GISS**  
Piecing together the climate story (1/15)



**Steve Amstrup**  
**Polar Bears Int.**  
Why should we care about polar bears? (4/15)



**Dan Kahan**  
**Yale University**  
Culture, rationality, and risk perception: The tragedy of the science-communication commons (4/15)



**Elizabeth Stone** Advances in the quantitation of atmospheric organosulfates (3/15)

**Facundo M. Fernández** Forensics, metabolomics and molecular imaging by mass spectrometry (4/15)

**Rebecca Washenfelder** Optical properties of brown carbon aerosol in the near-ultraviolet spectral region (4/15)

### Center for Science and Technology Policy Research Noontime Seminars

**Deserai Crow, Adrienne Kroepsch, Elizabeth Koebele, and Lydia Dixon** Assessing wildfire mitigation outreach strategies in the wildland-urban interface (9/14)

**Leslie Dodson and Drew Zachary** Red Cross/Red Crescent Climate Centre internship program summer 2014 panel discussion (10/14)

**Tanya Heikkila and Chris Weible** Mapping the political landscape of hydraulic fracturing in Colorado (10/14)

**Heather Bailey** The argument for changing the electric utility business model (10/14)

**Jessica Weinkle** Is this (our) risk? The science and politics of catastrophe insurance

**Lucy McAllister** Blind spots: Electronics firms and the social and environmental harms of the electronics commodity chain (11/14)

**Gesa Luedecke** Let's hear from the people: A study on media impact on climate protection and climate adaptation (11/14)

**Kritee Kritee** Climate smart agriculture in Asia: Measurements, implementation strategy, and challenges (11/14)

**Roger Pielke, Jr.** Sugar, spice and everything nice: Science and policy of "sex testing" in sport (1/14)

**Elizabeth McNie** When basic or applied is not enough: Utilizing a typology of research activities and attributes to inform usable science (2/15)

**Marisa McNatt** Mystery of the sea: A study of why the

U.S. has yet to construct an offshore wind farm (3/15)

**Paul Bowman** Ignorance isn't bliss: Why historical emitters owe compensation for climate change (3/15)

**Jordan Kincaid** Fracking in Denton, Texas: Who benefits and why was it banned? (4/15)

**Steven Vanderheiden** Mobilizing individual responsibility through personal carbon budgeting (4/15)

### Cryospheric and Polar Processes Seminar

**Alex Crawford** A new look at the summer Arctic frontal zone (10/14)

**Twila Moon** Seasonal ice dynamics on the Greenland ice sheet (12/14)

**Lewis Brower** Sharing indigenous knowledge and concepts of sea ice among indigenous communities, scientists, and beyond (3/15)

### Education and Outreach Events

**National Ocean Sciences Bowl** Colorado regional competition (2/15)

**Susan Sullivan, Teri Eastburn, and Katya Hafich** Investigating climate change impacts in the Southwest (2/15)

**Anne Gold and Eric Gordon** Free online course: Water in the western U.S. (4/15)

### Reading the IPCC Report: A graduate seminar and lecture series

**Jerry Meehl** Policymakers/Technical summaries (8/14)

**Linda Mearns** Ch. 1– Introduction (9/14)

**Owen Cooper** Ch. 2–Observations: Atmosphere and surface (9/14)

**Mike Alexander** Ch. 3–Observations: Ocean (9/14)

**Bette Otto-Bliesner** Ch. 5–Information from paleoclimate archives (9/14)

**Marika Holland** Ch. 11–Near term climate change (9/14)

**Pieter Tans** Ch. 6–Carbon and other biogeochemical cycles (10/14)

## 70 Seconds of Science

CIRES and NOAA communicators led the third annual 70 Seconds of Science communications challenge in April 2014. Two dozen participants gave quick "elevator speeches" about what they do for NOAA or CIRES, and why it's important. Nearly 100 people attended the two-hour event in the David Skaggs Research Center.



Contest winners **Gopakumar Padmanabhan** in the Global Systems Division, **CIRES Associate Director for Science Kristen Averyt**, and **Michael Scheuerer** in the Physical Sciences Division. David Oonk/CIRES

CIRES' mission 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 communications 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, the American Geophysical Union (AGU), our centers, and colleagues in academic and government institutions around the globe. During the 2015 reporting period (June 1, 2014, to May 31, 2015), communications efforts included 40 news releases (highlights follow), media relations, videos, social media, promotion of CIRES research during the AGU and American Meteorological Society conferences, and more. CIRES scientists and research were highlighted frequently in the media, receiving coverage in, for example: *National Public Radio*, *The Weather Channel*, *Science*, *Nature*, *EOS*, the *New York Times*, the *BBC*, *Discover News*, *The Christian Science Monitor*, the *Los Angeles Times*, UPI, CNN, boingboing and many other local, national, and international media outlets.

## News releases

May 20, 2015

**Colorado's biggest storms can happen anytime, new study finds**

May 13, 2015

**New study shows Antarctic ice shelf is thinning from above and below**

April 23, 2015

**Mountains warming faster, scientists report**

April 7, 2015

**Scientists probe methane emission mystery in Four Corners region**

March 19, 2015

**Arctic sea ice maximum reaches record low extent**

March 11, 2015

**Free online course from CIRES, CU on Water in the West**

March 5, 2015

**Why is Denver a mile high?**

February 18, 2015

**Methane leaks from three large U.S. natural gas fields in line with federal estimates**

February 10, 2015

**Climate intervention techniques are not ready for wide-scale deployment**

February 4, 2015

**Charting Colorado's vulnerability to climate change**

January 14, 2015

**Forecasting and explaining bad air days in Utah's oil and gas fields**

December 15, 2014

**Crowdsourcing Earth's magnetic field**

December 15, 2014

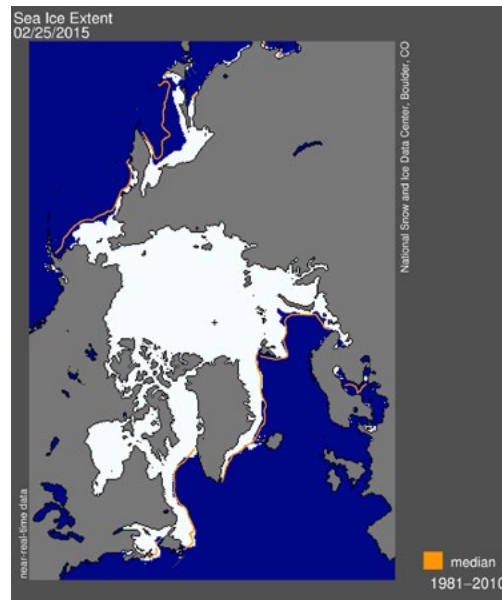
**Surprising findings in Greenland's melt dynamics**

November 24, 2014

**Powdered measles vaccine safe**

October 31, 2014

**New Book: "The Rightful Place of Science: Disasters and Climate Change" by Roger Pielke Jr.**



On February 25, 2015, Arctic sea ice extent appeared to have reached its annual maximum extent, marking the beginning of the sea ice melt season. This year's maximum occurred early and was also the lowest in the satellite record. NSIDC



A helicopter drops water on the Waldo Canyon fire in Colorado Springs, Colorado, June 27, 2012. Wildfires are likely to increase as temperatures in Colorado rise, according to the *Colorado Climate Change Vulnerability Study*. U.S. Air Force photo/Master Sgt. Jeremy Lock

October 28, 2014

**Remapping the New Jersey coast after Hurricane Sandy**

October 17, 2014

**New study pinpoints major sources of air pollutants from oil and gas operations in Utah**

October 1, 2014

**Stunning variety of microbes in Central Park soils mirrors global microbial diversity**

September 30, 2014

**NOAA's weather forecasts go hyper local with next-generation weather model**

September 29, 2014

**Climate change not to blame for 2013 Colorado floods**

August 29, 2014

**Nimbus data rescue: Recovering the past to understand the future**

August 25, 2014

**Air from stratosphere makes it tough for Las Vegas to meet ozone pollution standards**

June 2, 2014

**Reporters using more 'hedging' words in climate change articles, CIRES study finds**

**Webcasts, photos, and social media**

CIRES communications provides web-casting services for institute seminars, workshops, and meetings, with more than 40 webinars broadcast 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>

<https://plus.google.com/106064217201370884632/posts>

**Videos**

[youtube.com/user/ciresvideos](http://youtube.com/user/ciresvideos)

June 2014

**Bright lights in the Bakken**

August 2014

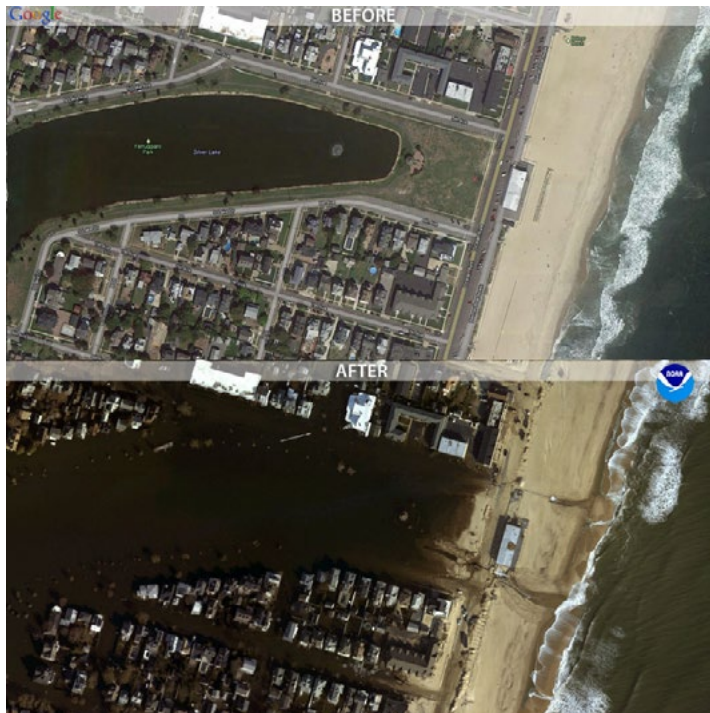
**Nimbus: Recovering the lost years**

November 2014

**The big thaw: Ground-truthing permafrost in Alaska**

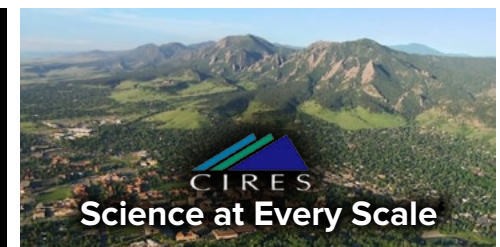
June 2015

**CIRES: Science at every scale**



Aerial views of Belmar, New Jersey before and after Hurricane Sandy.

Google and NOAA's National Geodetic Survey



# project reports

## Project reports by theme

Air Quality in a Changing Climate	83
Climate Forcing, Feedbacks, and Analysis	86
Earth System Dynamics, Variability, and Change	94
Management and Exploitation of Geophysical Data	105
Regional Sciences and Applications	115
Scientific Outreach and Education	117
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Stratospheric Processes and Trends	124
Systems and Prediction Models Development	129

## Key acronyms in this section

<b>CSD</b>	<b>NOAA ESRL Chemical Sciences Division</b>
<b>CU-Boulder</b>	<b>University of Colorado Boulder</b>
<b>ESRL</b>	<b>NOAA Earth System Research Laboratory</b>
<b>GMD</b>	<b>NOAA ESRL Global Monitoring Division</b>
<b>GSD</b>	<b>NOAA ESRL Global Systems Division</b>
<b>NCEI</b>	<b>National Centers for Environmental Information (formerly NGDC)</b>
<b>NGDC</b>	<b>National Geophysical Data Center (now NCEI)</b>
<b>NOAA</b>	<b>National Oceanic and Atmospheric Administration</b>
<b>OAR</b>	<b>NOAA Office of Oceanic and Atmospheric Research</b>
<b>PSD</b>	<b>NOAA ESRL Physical Sciences Division</b>
<b>SWPC</b>	<b>NOAA NWS Space Weather Prediction Center</b>

## Projects, alphabetized

CSD-01	83	GSD-05	131	PSD-03	95
CSD-02	84	GSD-06	132	PSD-04	119
CSD-03	86	GSD-07	133	PSD-05	116
CSD-04	86	NGDC-01	105	PSD-06	96
CSD-05	87	NGDC-02	106	PSD-07	96
CSD-06	89	NGDC-03	107	PSD-08	97
CSD-07	90	NGDC-04	108	PSD-09	99
CSD-08	115	NGDC-05	109	PSD-10	99
CSD-09	124	NGDC-06	120	PSD-11	100
GIP-01	94	NGDC-07	110	PSD-12	134
GMD-01	129	NGDC-08	111	PSD-13	101
GMD-02	124	NGDC-09	111	PSD-14	134
GMD-03	91	NGDC-10	112	PSD-15	102
GMD-04	92	NGDC-11	112	PSD-16	102
GMD-05	127	NGDC-12	113	PSD-17	103
GMD-06	128	NSIDC-01	118	PSD-18	104
GSD-01	130	NSIDC-02	118	SWPC-01	121
GSD-02	117	NSIDC-03	114	SWPC-02	122
GSD-03	130	PSD-01	85	SWPC-03	122
GSD-04	84	PSD-02	92		

■ Office of Oceanic and Atmospheric Research (OAR)

■ National Environmental Satellite, Data, and Information Service (NESDIS)

■ National Weather Service (NWS)

# Air Quality in a Changing Climate

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

■ CIRES Lead: Andy Neuman ■ NOAA Lead: Tom Ryerson

NOAA Theme: Weather-Ready Nation

### Goals & Objective

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

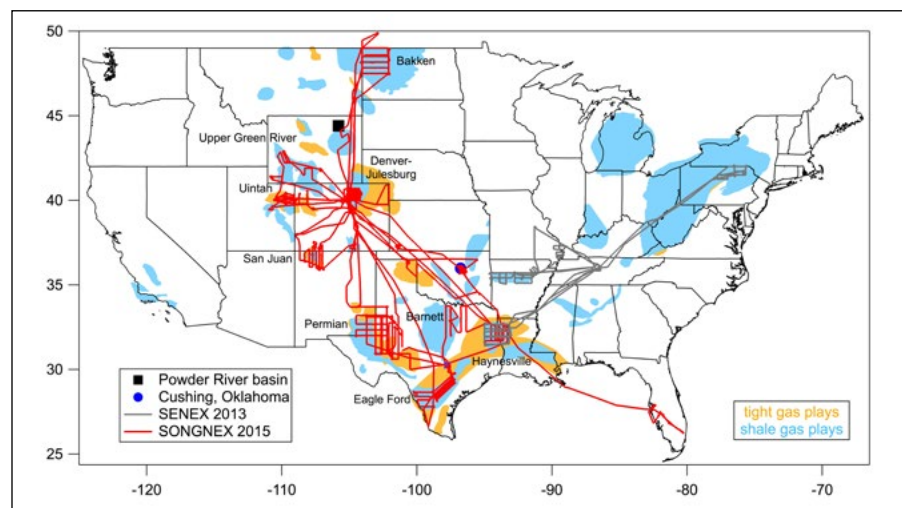
CIRES and NOAA scientists participated in several intensive regional field studies conducted to enhance understanding of air quality and climate. We investigated emissions to the atmosphere and subsequent transport and processing using a variety of measurement platforms. Quantification of emissions improves the ability of models to estimate future climate and air quality. These field studies will provide the scientific understanding of emissions, atmospheric chemistry, and transport to support develop-

ment of effective mitigation strategies. Accomplishments from three of those studies are highlighted here.

We made ground-based measurements at the Boulder Atmospheric Observatory (BAO) and from a newly instrumented mobile van during the DISCOVER-AQ (Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality and and FRAPPÉ (the Front Range Air Pollution and Photochemistry Experiment) studies in the summer of 2014, to assess emissions and processes affecting air quality in the Colorado Front Range. Vertically resolved measurements of reactive nitrogen, ozone, CO, methane, organic acids, and other VOC oxidation products were made using the carriage elevator at the BAO facility. The mobile van focused on quantifying emissions from feedlots in northeast Colorado using measurements of reactive nitrogen, methane, CO<sub>2</sub>, CO, N<sub>2</sub>O, and ammonia.

The WINTER (Wintertime Investigation of Transport, Emissions, and Reactivity) campaign took place in February and March 2015, and included over 100 flight hours and 13 research flights in the mid Atlantic, U.S. Southeast, Ohio River Valley, and over water off of the East Coast. Flights characterized emissions from urban areas, coal fired power plants, and fossil fuel extraction. Measurements included reactive nitrogen (NO<sub>x</sub>, NO<sub>y</sub>, N<sub>2</sub>O<sub>5</sub>, and ClNO<sub>2</sub>), sulfur (SO<sub>2</sub> and sulfate aerosol), organic carbon (VOCs and organic aerosol), O<sub>3</sub> and other trace gases, aerosol, and radiation. These measurements will be used to define the dominant chemical processes occurring in winter and the lifetimes and fates of air pollution during that season.

The SONGNEX (Shale Oil and Natural Gas Nexus) study was conducted March–May 2015 to investigate the atmospheric impacts of oil and natural gas extraction and processing activities. Measurements over nine major basins in Colorado, Utah, North Dakota, Wyoming, and Texas were performed on 18 research flights from the NOAA WP-3 aircraft. Extensive and comprehensive measurements of directly emitted hydrocarbons and VOC oxidation products were obtained from in-situ and canister measurements in order to determine emissions and methane leak rates in each basin. Additionally, measurements of ozone, speciated reactive nitrogen compounds, sulfur dioxide, and ammonia were obtained to facilitate precise source attribution and examine the atmospheric fate of the emissions.



Flight tracks of the NOAA WP-3 aircraft during SONGNEX and SENEX field intensives over regions with extensive oil and natural gas extraction and processing.

# Air Quality in a Changing Climate

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

■ CIRES Lead: Stu McKeen ■ NOAA Lead: Michael Trainer  
NOAA Theme: Climate Adaptation and Mitigation

### Goals & Objective

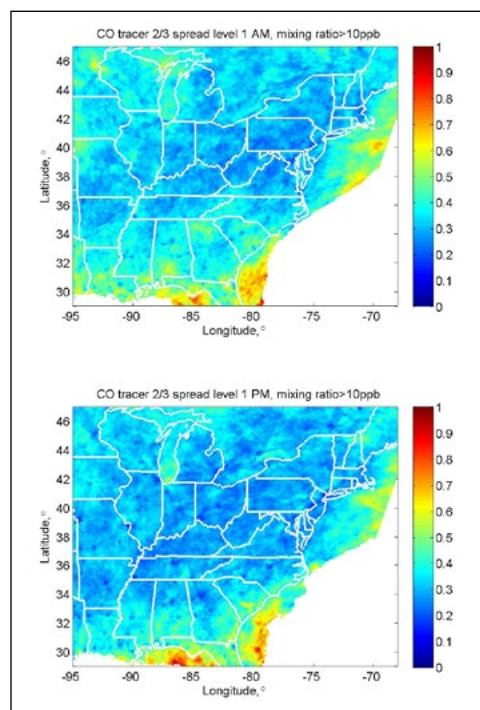
This project will use field observations and laboratory studies to provide better representation of atmospheric chemical, physical, and dynamical processes in numerical models, which will improve predictions and projections of climate and air quality.

### Accomplishments

Understanding how much of important chemical species are emitted by various sources is vital to prediction of air quality and climate change. This project combines meteorological simulations, transport modeling, measurements, and statistical inversion techniques to improve estimates and inventories of carbon monoxide and methane. Carbon monoxide is a tracer for anthropogenic emissions associated with poor air quality. Methane is an important greenhouse gas, and its emissions are poorly known but increasing rapidly because of the boom in natural gas and oil production

from shale formations. We conduct “top-down” emissions estimates using measurements from aircraft campaigns by CSD and others. The measurements are input to a modeling system consisting of the Weather Research and Forecast (WRF) model for meteorological fields, the FLEX-PART Lagrangian particle dispersion model for transport, and inversion methods to correct the emissions inventories. Evaluation of uncertainty and establishment of metrics for the quality of the result are important

**Mean ensemble spread of CO tracer mixing ratio at level 1 (0-100 m AGL). The averages are taken over all 49 days and hours 0400-0600 LST (AM, top) and 1300-1500 LST (PM, bottom). The spread is normalized by the mean mixing ratio at each point.**



goals throughout the process. This work complements estimates of emissions by mass balance techniques from aircraft measurements by allowing the use of data from other platforms and sampling strategies

In 2014-2015, several papers on this work, including emissions estimates for the Los Angeles Basin and evaluation of uncertainty in forward transport simulations due to meteorological uncertainty, were published. Inversions for the Central Valley of California are underway. We collected data from five field campaigns in the Denver-Julesburg Basin of northeastern Colorado, to be used for methane inversions. These data include flight campaigns in 2012 by CIRES and NOAA GSD, in 2014 by NASA and NCAR, and in 2015 by CSD. Data from the Boulder Atmospheric Observatory tower near Erie in 2014 will also be used.

## GSD-04: Improve Regional Air Quality Prediction

■ CIRES Lead: Steven Peckham ■ NOAA Lead: Georg Grell  
NOAA Theme: Science and Technology Enterprise

### Goals & Objective

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

### Accomplishments

Work continued on the development of the Weather Research and Forecasting-Chemistry (WRF-Chem) and Flow-Following Finite-Volume Icosahedral Model (FIM-Chem) models. Several significant improvements were made to the WRF-Chem model this year including the addition of the Carbon-Bond 5 chemical mechanism and improvements to the SAPRC99 chemistry. These numerical packages are commonly used by the regional air quality modeling community and should allow for a closer collaboration with the scientists in the regulatory modeling community. In addition, model developments and results from scientific research were presented at several conferences and workshops. In addition, international outreach by the model development team was made through a WRF-Chem tutorial that was held in Kathmandu, Nepal.

During 2014, 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 (WF-ABBA and MODIS) are included and particles interact with the regional 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 over 380 cities across the lower 48 United States are used to refine the previous 6-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 2014, intensive field studies took place in the Front Range Air Pollution and Photochemistry Experiment. These studies included many national and international scientists and organizations. The WRF-Chem model, using the Rapid Refresh (RAP – <http://rapidrefresh.noaa.gov>) WRF configuration including its North American domain, contributed to this study by proving daily air quality forecasts.. The simulation domain is similar to the operational NOAA/NCEP 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 & Objective

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

### Accomplishments

For 2014-2015, CIRES collected, processed, and distributed observational data such as sodar reflectivity, surface energy balance fluxes and surface meteorological data for the DISCOVERY-AQ project studying ozone pollution along the front range of Colorado. CIRES also helped develop and maintain existing web-interfaces, real-time data monitoring and added enhancements to display capabilities allowing easier user access to the real-time data sets. <http://www.esrl.noaa.gov/psd/data/obs/datadisply/>  
<http://www.esrl.noaa.gov/psd/data/obs/data/>

Site ID	Data Type Name	Start Date	End Date	Active	Realtime	Realtime Directory	Data State	View Data Format
anw	Radar 915MHz-Weber Wuertz	2011-06-01	2012-08-28	N	Y	<a href="#">View</a>	ASCII	<a href="#">View</a>
anw	Wind	2011-06-01	2012-08-28	N	Y	<a href="#">View</a>	ASCII	<a href="#">View</a>
anw	Radar 915MHz-Weber Wuertz	2011-06-01	2012-08-28	N	Y	<a href="#">View</a>	ASCII	<a href="#">View</a>
anw	Temp	2011-06-01	2012-08-28	N	Y	<a href="#">View</a>	ASCII	<a href="#">View</a>
anw	Radar 915MHz Bright Band	2011-06-01	2012-08-28	N	Y	<a href="#">View</a>	ASCII	<a href="#">View</a>
anw	Water Vapor Flux Obs	2011-06-01	2012-08-28	N	Y	<a href="#">View</a>	ASCII	<a href="#">View</a>
anw	Radar 915MHz Wind SNR Plot	2011-06-01	2012-08-28	N	Y	<a href="#">View</a>	Image	<a href="#">View</a>
anw	Radar 915MHz Wind Barb Plot	2011-06-01	2012-08-28	N	Y	<a href="#">View</a>	Image	<a href="#">View</a>
anw	Radar 915MHz Wind Virtual Temp Plot	2011-06-01	2012-08-28	N	Y	<a href="#">View</a>	Image	<a href="#">View</a>
anw	Integrated Water Vapor Flux Plot	2011-06-01	2012-08-28	N	Y	<a href="#">View</a>	Image	<a href="#">View</a>
anw	Radar 915MHz Wind Snow Level	2011-06-01	2012-08-28	N	Y	<a href="#">View</a>	Image	<a href="#">View</a>

New web interface, allowing easy user access to site and instrument metadata for projects.

# Climate Forcing, Feedbacks, and Analysis

## CSD-03: Scientific Assessments for Decision Makers

■ CIRES Lead: Christine Ennis ■ NOAA Lead: David Fahey  
NOAA Theme: Climate Adaptation and Mitigation

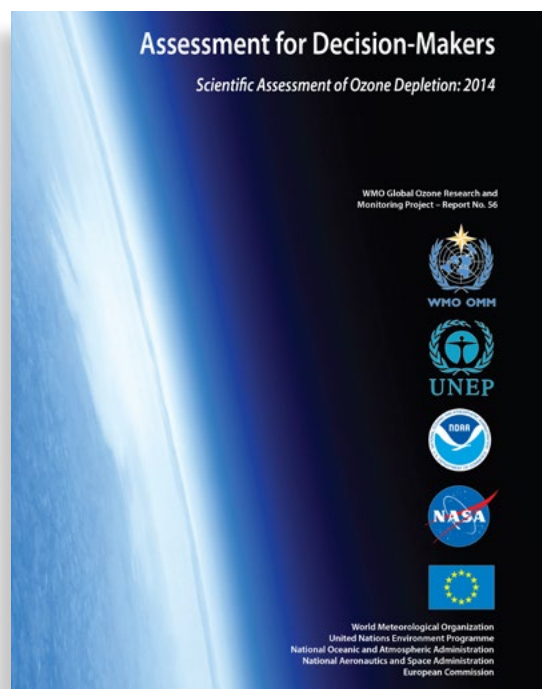
### Goals & Objective

This project addresses adaptation and mitigation.

### Accomplishments

Since the inception in 1987 of the United Nations agreement known as the Montreal Protocol on Substances that Deplete the Ozone Layer, the scientific community has provided policy-relevant scientific information for the Protocol in periodic state-of-understanding assessment reports. These *Ozone Assessment* reports have informed the decisions of the Parties over the past 25 years to amend and adjust the Protocol to further protect the stratospheric ozone layer. In the recently completed *2014 Ozone Assessment*, a new communication product was developed to more effectively convey the complex

**The 2014 Assessment for Decision-Makers document communicates policy-relevant findings of the 2014 Ozone Assessment for the Montreal Protocol, the international agreement that protects Earth's ozone layer. The document has been distributed to all nations of the world.**



scientific information to policymakers. This document, called the *Assessment for Decision-Makers* (ADM), distilled the policy-relevant scientific findings of the full report using new language and new figures especially suited to the intended audience. The ADM was announced and made publicly available in September 2014 at a press conference hosted by the United Nations Environment Programme in New York City. It was distributed to all countries at the Montreal Protocol Open-Ended Working Group Meeting in early 2015. CIRES and the NOAA ESRL Chemical Sciences Division (CSD) contributed leadership, coordination, editing, and communication expertise to the effort of producing the ADM.

The five detailed scientific chapters of the *2014 Ozone Assessment* were also completed. CIRES/CSD led the technical editing, layout, and web distribution of the chapters, which were released in December 2014 and distributed to the Montreal Protocol leadership of all nations.

The *Twenty Questions and Answers About the Ozone Layer* document was also completed, in April 2015. This component of the *2014 Ozone Assessment* answers questions frequently asked by the public, students, and educators. CIRES/CSD led the editing and distribution of this document.

Planning and coordination work was initiated on a first-ever assessment report on ozone in the lower atmosphere.

## CSD-04: Effects of Emissions on Atmospheric Composition

■ CIRES Lead: Joost de Gouw ■ NOAA Lead: Tom Ryerson  
NOAA Theme: Climate Adaptation and Mitigation

### Goals & Objective

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

U.S. production of oil and natural gas has increased over the last decade due to advances in hydraulic fracturing and directional drilling. CIRES scientists are studying the emissions to the atmosphere of trace gases and fine particles that are associated with this industrial activity, and how these emissions affect climate and air quality. We made measurements from ground sites, instrumented vans and two different research aircraft in different oil and gas production basins. Notably, the NOAA WP-3D aircraft was used in the Shale Oil and Natural Gas Nexus (SONGNEX) study to quantify emissions in nine different basins stretching from North Dakota to Texas. Emissions of methane and black carbon aerosol were quantified; these emissions can offset some



of the advantages of natural gas as a lower-carbon fuel relative to coal. The emissions of nitrogen oxides and volatile organic compounds were characterized; these trace gases can react in the sunlit atmosphere to form ozone and fine particles, two major air pollutants regulated by the Environmental Protection Agency. Research is ongoing to explain the variability in observed emissions in terms of the oil and/or natural gas composition, industry practices, and state and federal regulation.

Atmospheric emissions from agriculture are important to air quality and climate, yet their representation in inventories is incomplete. Using an instrumented van, CIRES scientists are studying the emissions of methane, ammonia, nitrous oxide, and other trace species, including bio-aerosol from animal feedlots. Emissions ratios of methane relative to ammonia were measured as a function of the time of day, and in different seasons. These emissions ratios provide important constraints to emissions inventories and the effects of animal feedlots on air quality and climate.

CIRES scientists were involved with the Wintertime Investigation of Transport, Emissions, and Reactivity (WINTER) project in 2015, which involved airborne measurements from the National Science Foundation C-130 research aircraft. Due to the absence of strong photochemistry in the winter, the data are useful to characterize emissions from urban and industrial sources. CIRES scientists measured hydrogen bromide in several power plant plumes throughout the U.S. Northeast. These observations will help improve the understanding of the processes controlling the removal of mer-



Flight crew and scientists that worked on the NOAA Shale Oil and Natural Gas Nexus (SONGNEX) study, which characterized emissions from oil and natural gas production in nine different basins stretching from North Dakota to Texas. David Oonk/CIRES

cury emissions from power plants. Isocyanic acid, a potentially toxic gas and a product of biomass burning, was measured throughout the Southeast, in what is currently the largest dataset available on the abundance and distribution of this species.

## 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 & Objective

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

Lifetimes, ozone depletion potentials (ODPs), and global warming potentials (GWPs) of natural and anthropogenic compounds:

1. **CBrF<sub>3</sub> (Halon 1301): Halon-1301 is a man-made ozone-depleting substance that is a major source of bromine in the Earth's stratosphere.** Halon-1301 is predominantly removed from the atmosphere by ultraviolet (UV) photolysis in the stratosphere at wavelengths between 200 and 225 nm. UV absorption spectrum of Halon-1301 between 195 and 235 nm was measured over the temperature range 210–320 K. An empirical parameterization of the spectrum and its temperature dependence is presented. A global annually averaged lifetime for Halon-1301 of 74.6 years was calculated using a two-dimensional atmospheric model and the present results. In addition, the CBrF<sub>3</sub> ozone depletion potential was calculated using the two-dimensional model to be 18.6 using the UV spectrum and 2σ uncertainty from this work (Bernard et al., 2015).
2. **Temperature Dependence of the Cl Atom Reaction with Deuterated Methanes:** Kinetic isotope effects (KIE) and reaction rate coefficients,  $k_1 - k_4$ , for the gas-phase reaction of Cl atoms with <sup>12</sup>CH<sub>3</sub>D ( $k_1$ ), <sup>12</sup>CH<sub>2</sub>D<sub>2</sub> ( $k_2$ ), <sup>12</sup>CHD<sub>3</sub> ( $k_3$ ), and <sup>12</sup>CD<sub>4</sub> ( $k_4$ ) over the temperature range 223–343 K in 630 Torr of synthetic air are reported. Rate coefficients were measured using a relative rate technique with <sup>12</sup>CH<sub>4</sub> as the primary reference compound. Fourier transform infrared spectroscopy was used to monitor the methane isotopologue loss. A two-dimensional atmospheric chemistry model was used to examine the implications of the present results to the atmospheric lifetime and vertical variation in the loss of the deuterated methane isotopologues. The relative contributions of the reactions of OH, Cl,

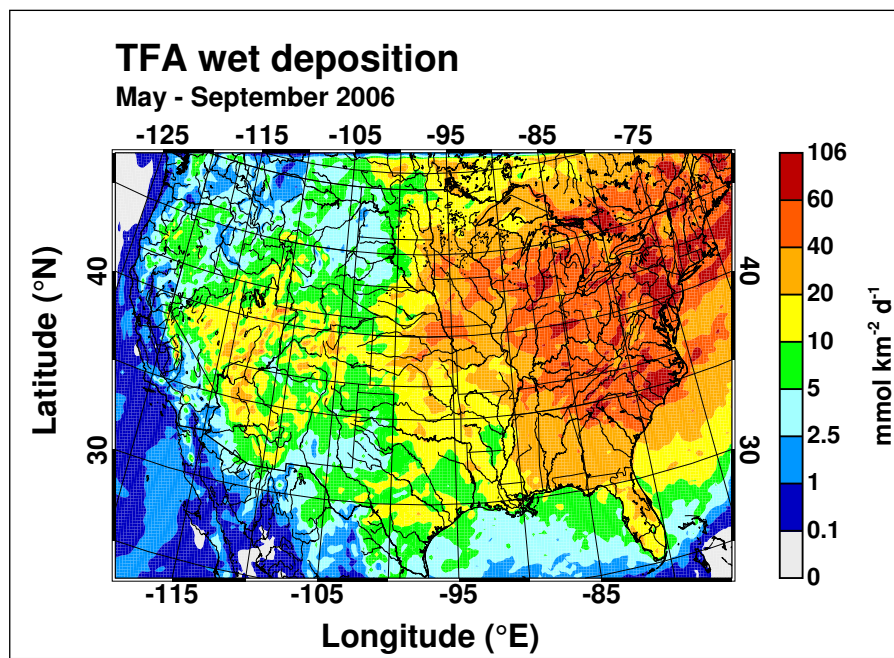
## Climate Forcing, Feedbacks, and Analysis

and O(<sup>1</sup>D) to the loss of the isotopologues in the stratosphere were examined as well (Sauer et al.).

- 3.  $\text{CH}_3\text{CO} + \text{O}_2 \rightarrow \text{OH} + \text{co-products}$ :** The gas-phase  $\text{CH}_3\text{CO} + \text{O}_2$  reaction is known to proceed via a chemical activation mechanism leading to the formation of OH and  $\text{CH}_3\text{C}(\text{O})\text{OO}$  radicals via bimolecular and termolecular reactive channels, respectively. Rate coefficients,  $k$ , for the  $\text{CH}_3\text{CO} + \text{O}_2$  reaction were measured over a range of temperature (241–373 K) and pressure (0.009–600 Torr) with He and  $\text{N}_2$  as the bath gas, and were used to characterize the bi- and termolecular reaction channels. A kinetic mechanism analysis of the combined kinetic data set yielded a zero pressure limit rate coefficient and the kinetic results were used to define the pressure and temperature dependence of the OH radical yield in the  $\text{CH}_3\text{CO} + \text{O}_2$  reaction. Details can be found in the reference (Papadimitriou et al., 2015).
- 4. Nocturnal loss and daytime source of nitrous acid through reactive uptake and displacement:** The nature of daytime sources and nighttime sinks of nitrous

acid is a key uncertainty in understanding atmospheric oxidation and radical cycling. We used flow tube experiments, measurements of acid displacement efficiencies, and field monitoring of nitrous acid and nitrite concentrations to study the exchange of nitrous acid with soils. We showed that nitrous acid can react with carbonates or soil at night and subsequently be displaced from soils during the day by air-to-soil transfer of hydrogen chloride and nitric acid, which are generated photochemically in the atmosphere. We concluded that the acid displacement process could contribute a substantial fraction of daytime nitrous acid emissions in numerous environments, including agricultural, urban, and vegetated regions, and in any location subject to deposition of soil-derived mineral dust.

- 5. Deposition and rainwater concentrations of trifluoroacetic acid in the United States from the use of HFO-1234yf:** Currently, HFC-134a (1,1,1,2-tetrafluoroethane) is the most common refrigerant in automobile air conditioners. This high-global-warming-potential substance (100-year GWP of 1370) will likely be phased out and replaced with HFO-1234yf (2,3,3,3-tetrafluoropropene), which has a 100-year GWP of 4. HFO-1234yf will be oxidized to produce trifluoroacetic acid (TFA) in clouds. TFA, a mildly toxic substance with detrimental effects on some aquatic organisms at high concentrations ( $\geq 100 \mu\text{g L}^{-1}$ ), would be transported by rain to the surface and enter bodies of water. We investigated the dry and wet deposition of TFA from HFO-1234yf over the contiguous United States. The model reproduced well the observed multimonth total sulfate wet deposition and its spatial variability. Predicted average TFA rainwater concentration and the peak values were well below the toxicity threshold (Kazil et al., 2014).



Wet deposition rates of trifluoroacetic acid formed from HFO-1234yf, which is being phased in as the refrigerant for automobile air conditioners. (Kazil et al., 2014)

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

■ CIRES Lead: Barbara Ervens ■ NOAA Lead: Dan Murphy  
NOAA Theme: Climate Adaptation and Mitigation

### Goals & Objective

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

#### Aerosol formation, composition, properties

*Chemical and optical transformation of smoke aerosol during transport and aging:* We have completed a preliminary analysis of chemical and some optical airborne measurements of smoke plumes during the 2013 SEAC4RS (Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys) campaign. A new postdoctoral researcher is performing additional optical aerosol analysis; and a detailed analysis of the Yosemite Rim Fire aging study is ongoing. We are collaborating with colleagues from NASA Goddard, the University of Arizona, NASA Langley, and the University of Colorado Boulder.

*Organosulfate formation:* Organosulfates can be considered a tracer of chemical reactions in aerosol particles. Such processes are not routinely included in chemical aerosol models. We have quantified individual organosulfate compounds in atmospheric aerosol during several airborne field campaigns (Liao et al., 2015).

*Abundance and transport of mineral dust:* We measured mineral dust aerosols from aircraft during several NASA, NOAA, and NCAR campaigns. Identification and quantification of mineral dust is part of an ongoing analysis that mostly involves two North American airborne studies, in 2012 and 2013. We are also investigating the mechanisms for dust vertical transport and its role as ice nucleus (Cziczo and Froyd, 2014; Murphy et al., 2014).

*Secondary organic aerosol (SOA) formation in aerosol water:* SOA comprises a large fraction of ambient particulate matter but its sources are not well understood. Based on laboratory experiments, we developed the first explicit chemical mechanism that describes formation of high-molecular-weight compounds in aerosol from biogenic precursors. Model studies suggest, however, that large (unidentified) amounts of dissolved organic carbon may be needed as SOA precursors to contribute significantly to total SOA burden by this mechanism (Ervens et al., 2014).

*Cloud processing:* Chemical and physical processes in clouds and fogs can significantly modify budgets and properties of trace gases and aerosols. We compiled a comprehensive review that summarizes the model representation of such processes at all scales (Ervens, 2015).

*Future use of HFO-1234yf as a substitute for HFC-134a, and its impact on rainwater composition in the United States:* Currently, HFC-134a is the most common refrigerant in automobile air conditioners. This high-global-warming-potential (GWP) substance is being replaced with HFO-1234yf. HFO-1234yf produces trifluoroacetic acid (TFA) in clouds, which has a low GWP but is a mildly toxic substance with detrimental effects on aquatic organisms. To assess the environmental impact of HFO-1234yf, we investigated the dry and wet deposition of TFA from future HFO-1234yf emissions in the contiguous United States. Average TFA rainwater concentrations for the contiguous United States below the established toxicity threshold were predicted. On time scales shorter than the simulation period, TFA rainwater concentrations reached significantly higher values than the temporal average (figure), especially in dry western locations with very low precipitation and comparably low TFA wet deposition (Kazil et al., 2014a).

#### Representation of clouds in models

*Open-to-closed-cell transitions:* In climate models, the representation of the interaction of marine stratocumulus clouds with the surface fluxes of moisture and heat from the ocean ignores horizontal heterogeneity of the cloud deck, and it does not account for features of the closed- and the open-cell stratocumulus cloud state. We identified fundamental differences in how the closed- and open-cell states interact with the surface fluxes of moisture and heat. A key insight is that in the case of the open-cell stratocumulus state, the interaction extends the lifetime of the cloud state by maintaining turbulence in the boundary layer. We also determined that horizontal heterogeneity in the surface heat fluxes can be ignored in describing the marine boundary layer, in support of the description of surface moisture and heat fluxes currently used in climate models (Kazil et al., 2014b).

Sensitivity studies on aerosol number and surface fluxes show that these parameters determine the transition from open to closed cellular state. This transition can be significantly more difficult than the reverse, pointing to the need to properly represent the meteorological, radiative, and surface flux environment in which these transitions

# Climate Forcing, Feedbacks, and Analysis

occur (Feingold et al., 2015; Yamaguchi and Feingold, 2015).

*Deep convective clouds:* We developed a new technique to investigate the response of mature convective systems to a change in model grid spacing. Compared to traditional studies, the new approach was found to be more computationally effective and provides more robust comparisons between individual model simulations. Using a continental squall line as an example, it was found that there is a distinct shift in several convective characteristics at a grid spacing of ~250 m. Instead of a smooth transition to convergence, we found that the simulations exhibited two resolution-dependent regimes demarcated by 250 m.

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## 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 & Objective

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

Measurements of black carbon (BC) in snow were made using the single particle soot photometer (SP2) for ambient samples and laboratory studies of deposition and removal. Ambient snow samples from North America, the Andes, the Himalayas, and the Antarctic were collected and provided for analysis by collaborators at the Joint Institute for the Study of the Atmosphere and Ocean, the National Center for Atmospheric Research, and the University of Colorado Boulder. SP2 data from flights on

the NOAA Twin Otter in May 2014 to explore BC emissions in North Dakota were finalized and analysis begun. A manuscript describing the development and application of a humidification system for measuring the hygroscopicity of BC containing aerosol with the SP2 was published in the *Journal of Aerosol Science* in March 2015.

Laboratory studies to characterize the response of the Wideband Integrated Bioaerosol Sensor (WIBS) instrument to various types of bioaerosol continued. The WIBS instrument was installed in the NOAA ESRL Chemical Sciences Division van during multiple trips to northeastern Colorado to examine the diurnal and seasonal cycles of feedlot emissions. In March 2015, WIBS measurements were made at the Maito Observatory on Reunion Island in the southern Indian Ocean (map). These observations will be used to constrain modeled bioaerosol loadings in the free troposphere and in tropical marine environments. A manuscript reporting WIBS observations of fluorescent bioaerosol across the southern United States was published in the *Journal of Geophysical Research: Atmospheres* in February 2015.

The Printed Optical Particle Spectrometer (POPS) project reached several milestones, including finalizing the design of all instrument components, producing multiple copies of POPS, integrating POPS onto various platforms, and testing the instrument on these platforms under various conditions. POPS was successfully operated on the Boulder Atmospheric Observatory tower, two different unmanned aircraft system (UAS) platforms, and a high altitude balloon. During April 2015, POPS was deployed on the Pacific Marine Environmental Laboratory Manta UAS in Svalbard, Norway, to measure aerosol concentrations and size distributions in the climate-sensitive Arctic environment.



**A map showing the location of Reunion Island, where the NOAA WIBS instrument was deployed. Reunion is located near a region predicted by a global model to have high climate sensitivity to bio-aerosol concentration.** David Oonk/CIRES

The NOAA Water and UASO<sub>3</sub> instruments were flown on the NASA Global Hawk during February-March 2015. These final flights of the Airborne Tropical Tropopause Experiment (ATTREX) were conducted in collaboration with instrument teams from the U.K. to investigate tropical tropopause layer (TTL) cirrus cloud ice crystal habits and latitudinal gradients in greenhouse gases in the eastern Pacific. Analysis of data from previous ATTREX deployments in 2013 and 2014 continued, with a goal of improving understanding of the microphysics of dehydration in the TTL. The ATTREX data set has also been used to develop a new ice water content (IWC) extinction relationship for TTL cirrus that will improve space-based lidar retrievals of tropical cirrus IWC. A manuscript describing the development and performance of the NOAA Water instrument was published in *Atmospheric Measurement Techniques* in January 2015.

A 2013 CIRES Innovative Research Project grant was used to begin development of a laser-induced fluorescence (LIF) measurement of SO<sub>2</sub> with the goal of measuring SO<sub>2</sub> in the upper troposphere and lower stratosphere in order to constrain the potential contribution of anthropogenic emissions to the radiatively important stratospheric sulfate aerosol layer. During 2014, a new fiber laser source to generate tunable UV light near 217 nm was developed and LIF detection of SO<sub>2</sub> was demonstrated.

### 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 & Objective

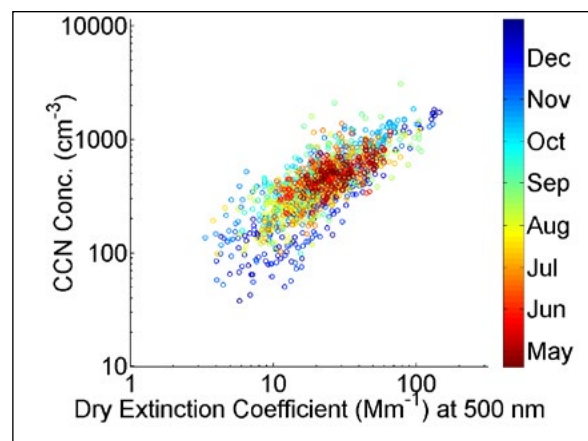
This project makes use of aerosol measurements from long-term monitoring sites and shorter-term deployments to analyze trends in aerosol properties, transport, and aerosol radiative forcing.

#### Accomplishments

A benchmark dataset of in situ aerosol optical properties for six Arctic sites has been developed and is being analyzed to determine similarities and differences in the aerosol climatology across this sensitive region in terms of temporal cycles, systematic relationships among aerosol properties, and radiative forcing effects.

This past year, the historical aethalometer measurements at NOAA baseline stations (going back 30+ years) have been reviewed and finalized and a standard operating procedure for the ongoing deployments has been developed. This accomplishment has already contributed to two submitted manuscripts with several more in progress, including one on a correction scheme for white light aethalometers.

A poster was presented at the Department of Energy Atmospheric Science meeting with results from an uncertainty analysis of long-term aerosol hygroscopic growth measure-



**The Graciosa Island CCN-extinction relationship for Angstrom exponent (0.3-0.5) and supersaturation (0.3-0.5%), color-coded with the time of the year in 2009 and 2010.** NOAA/CIRES

ments. Further analysis and a paper on the topic are in preparation.

A paper with a model comparison of cloud condensation nuclei (CCN) measurements to remote measurements of aerosol optical depth from the Aeronet network was submitted and accepted. The model builds upon an earlier work which used aerosol optical properties to estimate CCN concentrations as a function of supersaturation.

One of the main objectives of GoAmazon is to study the aerosol lifecycle under pristine conditions and evaluate the impact from the Manaus urban plume. Two collaborative projects used the surface CCN measurements: One evaluated cloud droplet formation and a second evaluated aerosol growth and the CCN activated fraction in the urban plume as it crossed the Amazon. The first study was presented at the European Aerosol Conference and the second was a talk at the American Geophysical Union meeting.

# Climate Forcing, Feedbacks, and Analysis

## 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 & Objective

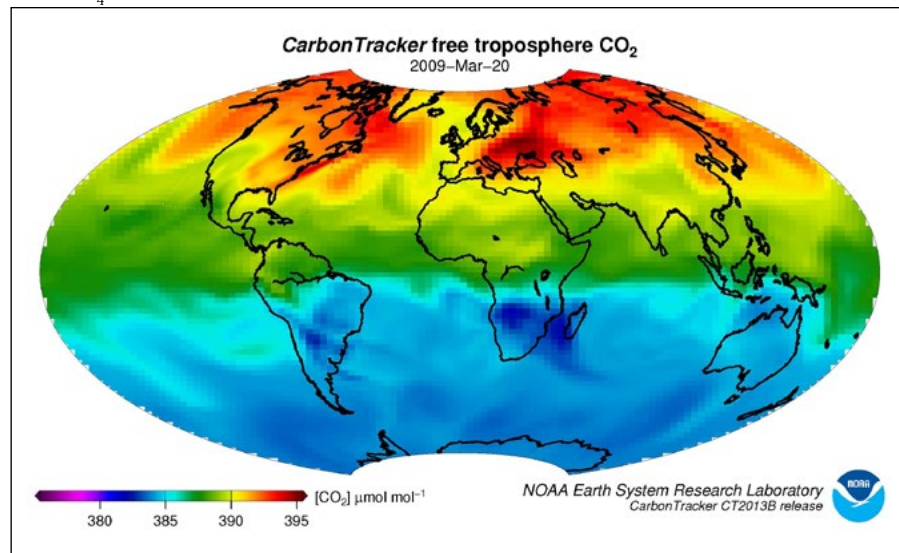
This project focuses on the global distribution of the anthropogenically influenced greenhouse gases: both the major ones ( $\text{CO}_2$ ,  $\text{CH}_4$ , and  $\text{N}_2\text{O}$ ) and the large suite of minor ones (CFCs, HFCs, and HCFCs). In addition to providing an accurate and well-documented 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

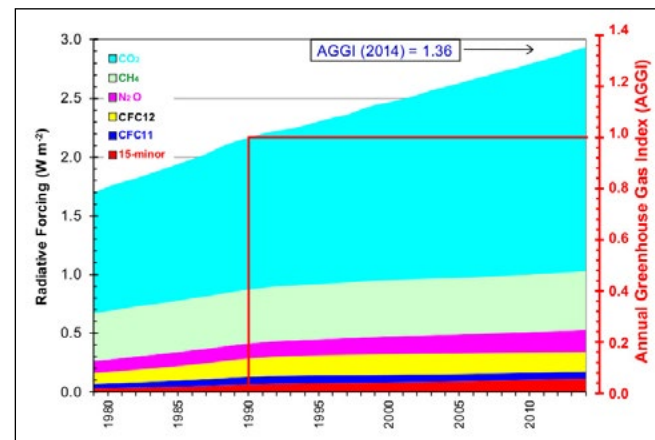
The NOAA Annual Greenhouse Gas Index was updated to include 2014 data on radiative forcing of major and minor greenhouse gases. This is presented on the web at <http://www.esrl.noaa.gov/gmd/aggi/>.

A new system for determination of  $\text{CO}_2$  sources and sinks over North America, “CarbonTracker-Lagrange,” has been developed and tested. During the second half of 2015, the first source/sink estimates using this tool will be calculated.

Although no new CarbonTracker updates were produced during the period,  $\text{CO}_2$  and  $\text{CH}_4$  data from the United States and around the world continued to be collected,



Carbon dioxide weather as modeled by CarbonTracker for March 20, 2009. NOAA/CIRES



Radiative forcing, relative to 1750, of all the long-lived greenhouse gases. The NOAA Annual Greenhouse Gas Index (AGGI), which is indexed to 1 for the year 1990, is shown on the right axis.

NOAA/CIRES

quality-controlled, and analyzed. These data will be inputs to CarbonTracker2015, which will be published by the end of 2015.

## 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 & Objective

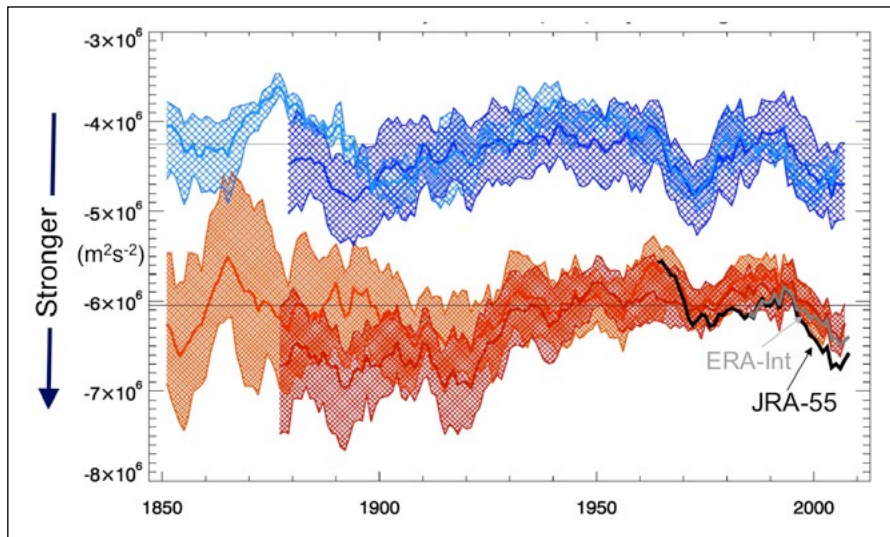
This project will show the relationship between regional climate changes around the globe and ocean-surface-temperature changes. Climate changes may be forced to a large extent by both natural and anthropogenic changes in sea surface temperatures.

### Accomplishments

We have performed a broad investigation of changes in the global overturning atmospheric circulation (including both north-south Hadley-type and east-west Walker-type circulations) over the last 150 years using a combination of the observational NOAA-CIRES reanalysis datasets and model simulations. Specifically, we have investigated the changes in the divergence of horizontal winds averaged over the upper half of the atmosphere. We find that although the divergent circulation defined in this sense has strengthened in recent decades, this strengthening is weak compared to the variations seen over the entire 150-year period, and the overall 150-year trend is also insignificant.

The figure shows changes in an index of the strength of the global divergent circulation in winter (DJF) from 1851 to 2013: A recent strengthening but no clear long-term trend. The red curves are from two different versions of the NOAA-CIRES 20<sup>th</sup> Century Reanalysis dataset. The light and dark grey curves for the more recent period

are from two other reanalysis datasets. The two blue curves are from two different types of model simulations. The red and blue shaded bands indicate the uncertainty in the reanalysis and model-based estimates. Note that although the model-based estimates are generally weaker than the reanalysis estimates, they show similar changes over the 162 year period (From Compo and Sardeshmukh, in preparation).



Changes in an index of the strength of the global divergent circulation in winter (DJF) from 1851 to 2013. NOAA/CIRES

# 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 & Objective

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

### Accomplishments

The NESII group collaboratively develops a range of software infrastructure products for the Earth system sciences. These include model coupling systems, grid remapping, and other utilities, metadata services, data subsetting and reformatting tools, and model inter-comparison and collaboration environments. NESII products are distinguished by their outstanding computational performance and portability, range of features and options, production quality, and level of user support. They can stand alone, but they are also built to work together as a suite to address complex problems.

This fiscal year, we delivered patch release v6.3.0rp1 (July 2014) of the Earth System Modeling Framework (ESMF, <https://www.earthsystemcog.org/projects/esmf/>) and National Unified Operational Prediction Capability Layer software (NUOPC Layer, <https://www.earthsystemcog.org/projects/nuopc/>). This software infrastructure is used for building and coupling climate, weather, and related models. The patch release included a number of fixes to the from-file interpolation weight generation utility called ESMF\_RegridWeight-Gen, and to the metadata handling class, ESMF\_Attributes. However, this year was mainly devoted to development for a next major release, ESMF v7.0, expected late summer 2015. This release will: Enable observational data streams to participate in grid remapping; add a 3D “thick sphere” interpolation option for grid remapping (needed for coupling upper atmosphere to space weather components); introduce GIS formats to be used with grid remapping; and allow for recognition of hardware accelerator resources in the ESMF hardware interface layer.

ESMF continues to be used as infrastructure in research and operational climate and weather codes at the National Weather Service, the Navy, the National Center for Atmospheric Research, NASA, and other sites. The ESMF team shared in the Department of Energy’s (DOE’s) Ultrascale Visualization Climate Data Analysis Tools (UV-CDAT) Federal Laboratory Consortium Technical Transfer Award for its contribution of ESMF grid remapping to the UV-CDAT software. ESMF grid remapping was needed to enable visualization and inter-comparison of many types of gridded data.

Members of the ESMF team also organized and submitted an article to the *Bulletin of the American Meteorological Society* describing the evolution of modeling infrastructure in the

United States and an emerging suite of components based on ESMF/NUOPC conventions, called the Earth System Prediction Suite (ESPS). This article includes about two dozen authors from the agencies cited above and is currently in review. The table shows the models that have adopted these conventions.

Also this last year, in collaboration with the NOAA Environmental Modeling Center

**Table 1. ESPS COUPLED MODELING SYSTEMS**

	NEMS	COAMPS	NavGEM	GEOS-5	ModelE	CESM
<b>Model Driver</b>	●	●	●	●	●	●
<b>ATMOSPHERE MODELS</b>						
GSM	●					
NMMB	●					
CAM						●
FIM	●					
GEOS-5 Atmosphere				●		
ModelE Atmosphere					●	
COAMPS Atmosphere		●				
NavGEM			●			
NEPTUNE			●			
<b>OCEAN MODELS</b>						
MOM5	●			●		
HYCOM	●		●		●	●
NCOM		●				
POP						●
POM	●					
<b>SEA ICE MODELS</b>						
CICE	●		●	●	●	●
KISS	●					
<b>OCEAN WAVE MODELS</b>						
WW3	●	●		●		●
SWAN		●				
<b>LEGEND</b>						
● Components are NUOPC compliant and the technical correctness of data transfers in a coupled system has been validated.						
● Components and coupled systems are partially NUOPC compliant.						

### Abbreviations:

- CAM:** Community Atmosphere Model
- CESM:** Community Earth System Model
- CICE:** Los Alamos Community Ice CodE
- COAMPS:** Coupled Atmosphere-Ocean Mesoscale Prediction System
- FIM:** Flow-Following Finite volume Icosahedral Model
- GEOS-5:** Goddard Earth Observing System Model, Version 5
- GSM:** Global Spectral Model
- HYCOM:** HYbrid Coordinate Ocean Model
- KISS:** Keeping Ice’s Simplicity
- MOM5:** Modular Ocean Model 5
- NavGEM:** Navy Global Environmental Model
- NCOM:** Navy Coastal Ocean Model
- NEMS:** NOAA Environmental Modeling System
- NEPTUNE:** Navy Environmental Prediction sysTem Utilizing the NUMA corE
- NMMB:** Non-hydrostatic Multiscale Model (B grid)
- POM:** Princeton Ocean Model
- POP:** Parallel Ocean Program model
- SWAN:** Simulating Waves Nearshore
- WW3:** WaveWatch III



(EMC) and other partners, the NESII group developed a prototype of the replacement for the Climate Forecast System (CFS) version 2, which is used operationally for seasonal forecasting. This prototype, part of a new “Unified Global Coupled System” or UGCS, includes a three-way coupled Global Spectral Model (GSM) atmosphere, the Modular Ocean Model (MOM)5 ocean, and CICE sea ice model. Wave and alternate ocean and ice components are in the queue to be incorporated into this coupled modeling system as options for applications at other time and spatial scales. The NESII team is also collaboratively developing a version of the UGCS for short-term (0-30 day) forecasts. A parallel effort at EMC involves integrating a separate land model (the Land Information System) and hydrological model (WRF-Hydro) into a regional system at EMC based on the same coupling infrastructure used in the UGCS, called the NOAA Environmental Modeling System or NEMS (<http://cog-esgf.esrl.noaa.gov/projects/coupled-nems/>). The figure shows the planned components of NEMS.

In collaboration with NCAR’s Climate and Global Dynamics Division and others from Florida State University and University of Miami, we developed a NUOPC-compliant version of the Community Earth System Model (CESM). The partnership used this version to couple the Hybrid Coordinate Ocean Model (HYCOM) to other components (atmosphere, land, sea ice) as an alternate ocean model in CESM. This work was funded by the Office of Naval Research.

We released the first version of Cupid, an Integrated Development Environment (IDE) for model development and modeler training (<https://www.earthsystemcog.org/projects/cupid/>). Cupid is a “plug-in” to the widely used Eclipse development environment. This effort was funded by NASA and developed in collaboration with teams from NASA Goddard Institute for Space Studies and the NASA Goddard Space Flight Center. Cupid offers a way to visualize the structure of NUOPC-based modeling systems, modify code and automatically generate compliant code, and compile and run, all within the same view.

This year, NESII also delivered new capabilities and releases of the CoG wiki-based collaboration environment (<http://www.earthsystemcog.org>). The main focus of development this year was merging CoG with the Earth System Grid Federation (ESGF) data distribution facility. ESGF is an international consortium, led by DOE, that manages data dissemination for the Coupled Model Intercomparison Projects (e.g. CMIP3, CMIP5). CoG is now being prepared to be the user interface for CMIP6 and other MIPs. During 2014-2015, CoG supported the High Impact Weather Prediction Project (HIWPP), the MIP for the next weather service atmospheric model dynamical core. There are now CoG nodes at CU-Boulder, NOAA’s ESRL, and NASA’s Jet Propulsion Laboratory. CoG supports about 100 projects in all.

We merged the OpenClimateGIS software, a tool for subsetting, reformatting, and performing calculations on climate data (<https://www.earthsystemcog.org/projects/openclimategis/>), with the Python version of ESMF (called ESMPy). This introduced GIS formats and capabilities such as support for local datums to ESMPy.

## 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 & Objective

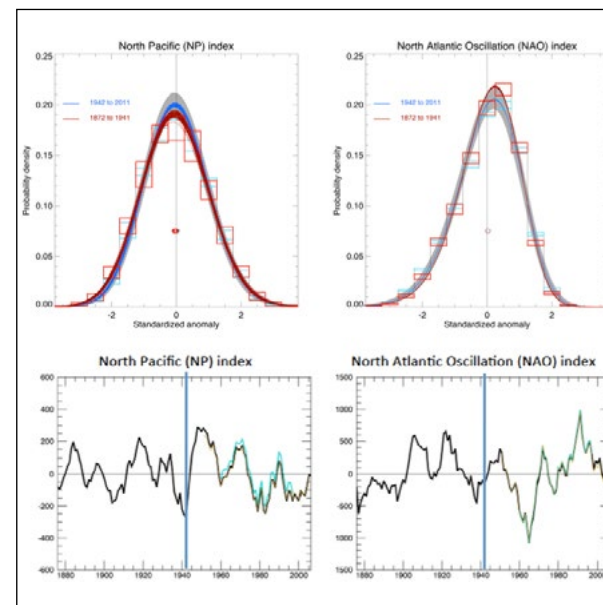
A clearer separation of natural variations from anthropogenic influences in the climate system over the last 140 years will help explain climate variability better and improve the capacity for climate predictions.

### Accomplishments

We completed a study of long-term changes in the near-surface atmospheric circulation and its daily variability using a combination of observational datasets and model simulations. We found that although global warming since the 1870s is unequivocal, the changes in the near-surface circulation are much weaker and harder to establish from relatively short (50-yr) records. We also found little or no change in the probability distributions of daily anomalies of two important indices of atmospheric circulation variability in the Northern Hemisphere, the North Pacific and North Atlantic Oscillation indices. We did find significant changes in some indices of tropical and southern hemispheric circulation variability. The significance of all of these changes was investigated using a general class of so-called

**Probability Density functions (PDFs) of daily indices of the North Pacific and North Atlantic Oscillation in northern winter (Upper Panels), estimated using a 56-member ensemble of NOAA-CIRES atmospheric reanalyses (Compo et al., 2011) of the 1871 to 2011 period.**

Sardeshmukh, Compo, Penland, and McColl, 2015; to be submitted.



# Earth System Dynamics, Variability, and Change

stochastically generated skewed (SGS) probability distributions previously introduced by us. A paper justifying the relevance of SGS distributions in the climate system was published in the physics journal *Chaos*, and another comprehensive paper justifying their particular relevance in the study of climate extremes was submitted for publication.

## PSD-06: Diagnosis and Prediction of Subseasonal Climate Variations

■ CIRES Lead: Prashant Sardeshmukh ■ NOAA Lead: Randall Dole  
NOAA Theme: Science and Technology Enterprise

### Goals & Objective

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

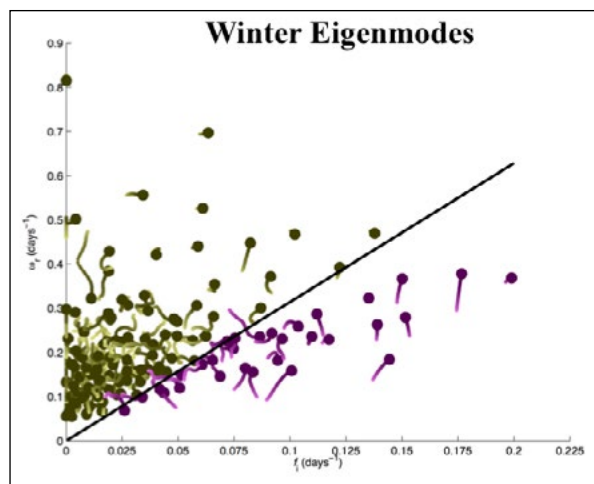
### Accomplishments

We have completed a study that argues for a paradigm shift in understanding internal atmospheric tropical wave dynamics and the Madden-Julian Oscillation (MJO). Most discrepancies between observations and the linear Matsuno-Gill theory of tropical waves are currently attributed to the neglect of coupling between the waves and tropical convection. Although these quantities are undoubtedly related, the extent to which this reflects true coupling versus forcing of one by the other has not adequately been established. Our own observational analysis indicates that the neglect of spatial base state variations is the primary limitation of the Matsuno-Gill theory, whereas the neglect of convective coupling is of sec-

ondary importance. This suggests an updated paradigm in which models that include both effects, but are still linear, would continue to provide a useful framework for interpreting tropical variations.

Our analysis is based on Linear Inverse Modeling (LIM), which deduces the linear evolution operator for tropical anomalies using the time-lag covariances and cross-covariances of the circulation and humidity fields in the ERA-Interim dataset. The eigenmodes of this operator are highly seasonally dependent, consistent with the strong modification of the wave dynamics by the seasonally varying base state. The eigenmodes are also not mutually orthogonal, as they are in the Matsuno-Gill or CCEW paradigm, and this is important for the predictable growth and decay of anomalies. We also show that although the circulation-moisture coupling is overall of secondary importance, it does significantly affect the evolution of some modes and the MJO.

In the figure, filled circles show the frequencies (x-axis) and decay rates (y-axis) of natural wave-like oscillations of the tropical atmosphere, estimated as eigenvalues of the one-day lag regression operator of daily departures (anomalies) of upper and lower tropospheric winds, geopotential height, and moisture from their long-term averages. The purple shading denotes oscillations that are relatively more “wavelike” than damped, and the green shading oscillations that are relatively less “wavelike,” with the diagonal line serving as a demarcation of the two classes. The thin stems emanating from each filled circle show how these frequencies and decay rates are altered by progressively reducing the magnitude of the regression matrix elements representing coupled interactions between the circulation and moisture anomalies to zero. They suggest that the circulation-moisture anomaly coupling has a statistically significant, but relatively minor, effect on the oscillations.



Filled circles show the frequencies (x-axis) and decay rates (y-axis) of natural wave-like oscillations of the tropical atmosphere, as described in Accomplishments.

Sardeshmukh and Newman, 2015; in preparation.

## PSD-07: Sensor and Technique Development

■ CIRES Lead: Andrey Grachev ■ NOAA Lead: Chris Fairall  
NOAA Theme: Science and Technology Enterprise

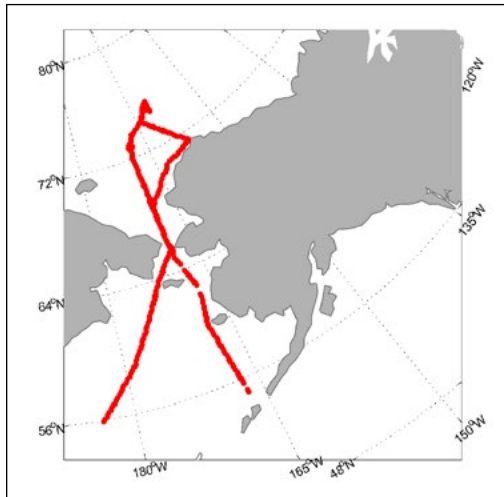
### Goals & Objective

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

The scanning laser altimeter was received and tested on the NOAA ship *Ronald H. Brown* during the CalWater2 cruise (January 2015). The results were excellent with wave profiles measured from the bow of the ship out forward 9 m at 10 Hz. Performance of the sensor was very good in winds exceeding 10 m/s. Heated T/RH sensors have arrived. The fast pressure sensor order has been placed. All sensors will be deployed again on the Office of Naval Research Sea State cruise on *research vessel Sikuliaq* in fall 2015.

A PSD flux system was deployed on *research vessel Mirai* for a cruise in the fall of 2014 (figure). The PSD data have been processed and a report written. The *Mirai* cruise was conducted during the minimum sea ice extent and into the beginning of the fall freeze



**Cruise track of the research vessel *Mirai* for the Arctic cruise, Sept. 5, 2014, to Oct. 7, 2014.**

up period for the Beaufort Sea. Observations were coordinated with the SWERUS2014 cruise on the Swedish icebreaker *Oden* which had CIRES personnel (O. Persson and M. Shupe) aboard.

## 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 & Objective

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

### Accomplishments

CIRES researchers continue to conduct Arctic cloud, aerosol, and atmospheric research using observations and models over Greenland, in the Arctic Ocean, and northern Alaska. Research associated with the Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit (ICECAPS) has examined the temporal variability of surface radiative fluxes using wavelets (Cox et al., 2014), the annual cycle of surface cloud radiative forcing and its dependence on liquid water clouds (Miller et al. 2015), the sensitivity of surface cloud radiative forcing to changes in humidity and temperature (Cox et al., 2015), the annual cycle of snowfall and its dependence on meteorological parameters (Castellani et al., 2015), and the occurrence of trigonal ice crystals (Murray et al., 2014).

Further research examined the role of moisture advection for the summer 2012 Greenland melt event using reanalysis data (Neff et al., 2014), and is using mesoscale models to examine air mass modification that supports clouds over Greenland. Beyond Greenland, research projects documented cloud microphysical properties at Barrow (Shupe et al., 2015a), vertical cloud and atmosphere mixing properties over the Arctic Ocean (Sotiropoulou et al., 2014), a modeling study examining the impact of aerosols on cloud albedo (Kravitz et al., 2014), and a model study suggesting the important role that ice nucleus recycling might play in maintaining cloud ice production in Arctic clouds (Solomon et al., 2015). CIRES researchers also provided a section on clouds and atmospheric radiation for the State of the Climate in 2014 report (Shupe et al. 2015b). On top of this research, CIRES scientists participated in the Arctic Clouds in Summer Experiment (ACSE) research cruise through the Arctic Ocean.



**CIRES scientist Matthew Shupe launches a radiosonde from the deck of icebreaker *Oden* during the Arctic Clouds in Summer Experiment (ACSE) in summer 2014.** Michael

Tjernström

## Climate Forcing, Feedbacks, and Analysis

In addition to Arctic research, CIRES scientists have conducted cloud, aerosol, and precipitation research at mid-latitude locations in California and Colorado. For the later, two studies were conducted related to the Colorado Airborne Multi-Phase Study (CAMPS) aircraft campaign. These examined orographically-forced wave structures and their relation to the spatial organization of clouds and precipitation (Kingsmill et al., 2015) and a statistical characterization of vertical motions, mixed-phase cloud occurrence, and precipitation over the Colorado Park Range (Dorsi et al., 2015). California-based research included developing a 10-year climatology of dust transport (Creamean et al., 2014), examining the chemical properties of insoluble residues in precipitation (Creamean et al., 2014b, Axson et al., 2015), characterizing the impact of interannual variability in aerosols on precipitation (Creamean et al., 2015), and a broader study on precipitation in the Sierra Nevada (White et al., 2015). In addition to these research studies, CIRES scientists played a key role as aerosol forecaster for the CalWater 2 field campaign.

To support these various research objectives into the future, CIRES scientists have worked to develop observational tools and coordinate international networks. Retrieval development used non-spherical ice particle models to develop ice retrievals from polarimetric radar measurements (Matrosov, 2015a), focused on deriving ice water path in ice regions of precipitating clouds (Matrosov, 2015b), and summarizing ground-based remote sensor cloud microphysics retrievals (Shupe et al., 2015c). Work has also targeted the development of unmanned aircraft systems (UAS) by working to incorporate and improve new sensors, and leading a UAS campaign out of Oliktok Point Alaska. An evaluation of UAS dropsonde measurements was published (Intrieri et al., 2014). CIRES scientists have also helped to facilitate international groups studying aerosols and surface radiative fluxes at pan-Arctic research stations associated with the International Arctic Systems for Observing the Atmosphere (IASOA) network. Papers have been written that outline this network and its associated innovative cyber-infrastructure (Uttal et al., 2015; Starkweather and Uttal, 2015).

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## PSD-09: Air-Sea Interactions

■ CIRES Lead: Andrey Grachev ■ NOAA Lead: Jian-Wen Bao  
NOAA Theme: Science and Technology Enterprise

### Goals & Objective

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 upgraded the NOAA/ESRL sea-spray scheme with an important improvement to better represent the wave-breaking mechanism in the parameterized spray generation process according to the prognostic wave state output from a wave model. We sent the updated code of the sea-spray scheme to the NASA Joint Center for Data Assimilation (JCSDA) team for them to further test and evaluate the improvement in their coupled atmosphere-wave-ocean data assimilation system. We also visited the JCSDA team to help them understand the improvement and to optimize the performance of the sea-spray scheme in its interaction with the rest of the air-sea interfacial physics components. Our collaboration with the National Centers for Environmental Prediction and its university partners resulted in a functional representation of the air-sea momentum and enthalpy mediated by sea spray. This functional representation is currently used in the operational Hurricane Weather Research and Forecasting model as part of the improved specification of the air-sea momentum and enthalpy exchange coefficients, which is in better agreement with the CBLAST (Coupled Boulder Layers/Air-Sea Transfer) observations than before.

## 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 & Objective

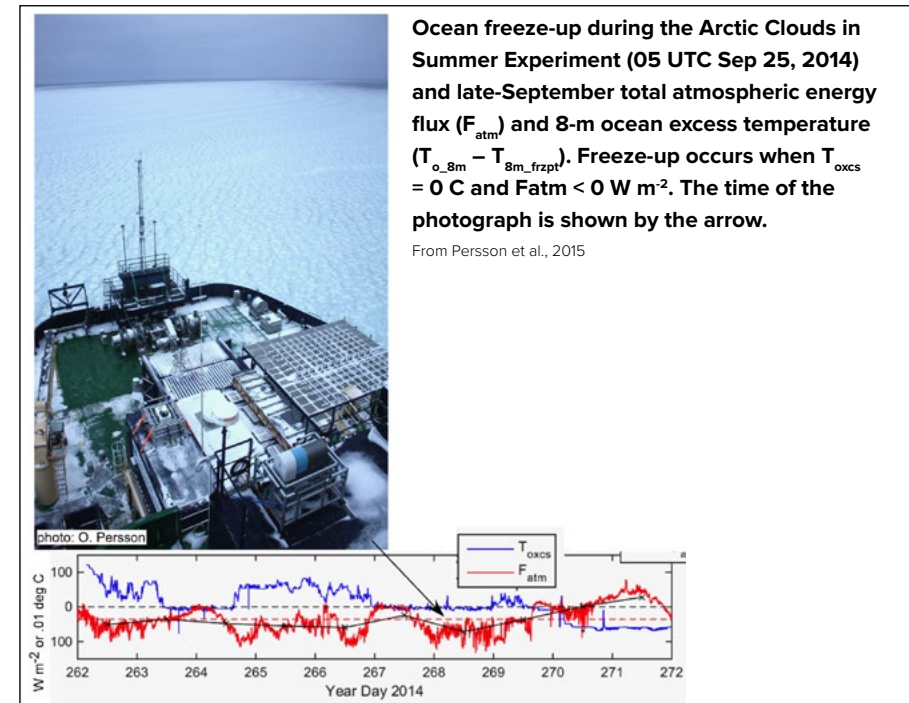
This project provides analysis and modeling of climate-related processes with a focus on those affecting the mass balance of Arctic sea ice and Arctic soil temperatures.

### Accomplishments

We collected turbulent and radiative energy flux and upper-ocean temperature measurements in open water, sea ice, and the marginal ice zone during the latter half of

the 2014 melt season and the first two weeks of autumn freezeup, during two cruises on the *Oden* (shown) and *Mirai*. CIRES participants directly collected wind profiler and w-band cloud radar measurements on the *Oden* and radiative/turbulent surface fluxes on the *Mirai*. The processing of this data has begun, by CIRES participants and international collaborators. Preliminary analyses suggest the importance of total atmosphere-ocean energy fluxes to heat buildup in the upper ocean (not just solar radiation) and for the depletion of the upper-ocean heat content leading to ocean-surface ice formation in late August. The data also suggest that off-ice airflow is important to produce large negative energy fluxes to enhance upper-ocean heat loss. A manuscript of a case study, accepted by *Geophysical Research Letters*, shows that atmospheric synoptic advection of unusually warm continental air over the sea ice, producing thick clouds and fog, coincided with an early-August sharp decrease in ice concentration in the same area as the observations. Several conference presentations on these topics have been given at a variety of international venues.

We also completed the cloud-atmospheric boundary layer-surface study and submit-



# Climate Forcing, Feedbacks, and Analysis

ted a final report submitted to the National Science Foundation. One item completed for this project was a book chapter, titled “The Atmosphere over Sea Ice,” written by O. Persson and T. Vihma, which will be included in the textbook “Introduction to Sea Ice, 3<sup>rd</sup> Edition,” edited by David Thomas.

Surface energy budget analyses at Barrow and Tiksi sites were advanced. An Arctic bulk-flux algorithm was modified and applied to 10 years of data from the North Slope of Alaska Department of Energy Atmospheric Radiation Measurement site. It was validated with approximately 1.5 years of covariance data at this same site. These bulk turbulent fluxes are being used for physical interpretation of total surface energy budgets and surface impacts of cloud microphysical characteristics. This bulk flux scheme is also being applied at other Arctic sites (Tiksi, Eureka, and Summit).

Data for the Earth System Prediction Capability Project study are from the Arctic Clouds in Summer Experiment (ASCE), *Mirai*, and upcoming 2015 SeaState cruises. ACSE data suggest that air-ocean energy fluxes are crucial for both upper-ocean summer heat storage and autumn heat loss, and the importance of off-ice airflow for freeze-up. A coupled atmosphere-sea ice-ocean mixed layer model has been created based on the Regional Arctic System Model, and will be used to simulate atmosphere-ocean and atmosphere-ice energy fluxes and the phase change processes resulting from these fluxes.

## PSD-11: Distributions of Raindrop Size

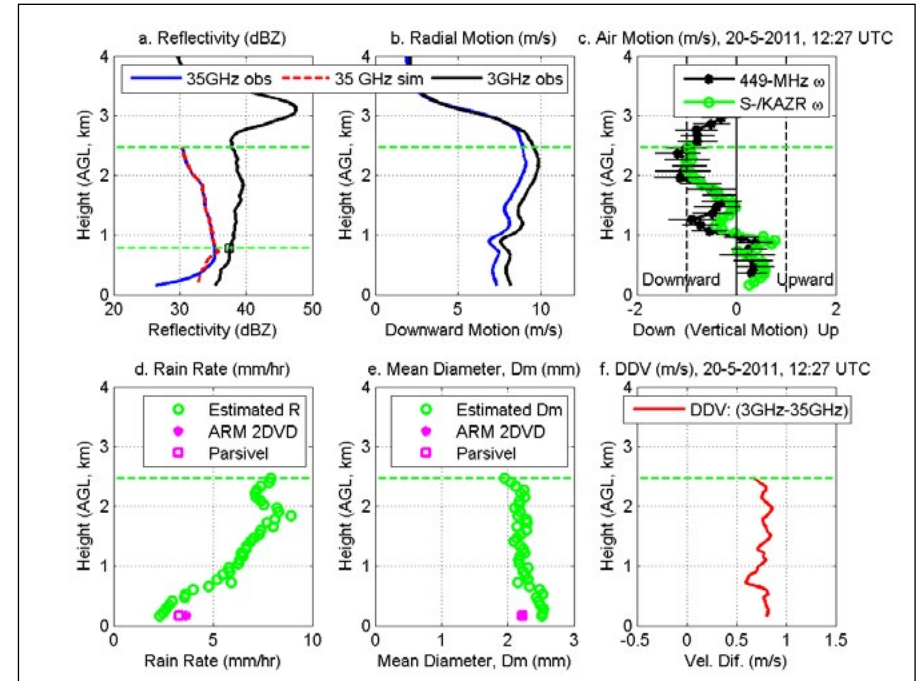
■ CIRES Lead: Christopher Williams ■ NOAA Lead: Rob Cifelli  
NOAA Theme: Science and Technology Enterprise

### Goals & Objective

This project provides basic scientific information on raindrop size, which will support improved accuracy in estimation of rainfall based on cloud characteristics.

### Accomplishments

A raindrop size distribution (DSD) and vertical air motion retrieval method was developed using side-by-side S-band and Ka-band vertically pointing radars deployed at the Department of Energy (DOE) Southern Great Plains central facility during the MC3E field campaign. A key element of the retrieval process is using the differential Doppler velocity (DDV) measured by both radars. The DDV provides information about the DSD and velocity variations observed in both velocities are related to vertical air motions. As an example, the figure shows the retrieval for 20-May-2011 at 12:27 UTC. Note that the difference in velocities shown in 1b have a nearly constant offset with height below the 2.5 km. This difference is related a nearly constant mean raindrop diameter with height shown in 1e. The velocity variations observed by both radars is due to vertical air motions as shown in 1c. The dual-frequency S-/K-band vertical air motion retrievals are verified against Bragg scattering vertical air motions estimated from a collocated 449-MHz (UHF) profiler



**DSD profile retrieval using S-band and KAZR (35 GHz) vertically pointing radars during MC3E on 20-May-2011 at 12:27 UTC. (a) measured reflectivity at S- (black) and Ka-band (blue) with retrieved Ka-band reflectivity (red dash), (b) Doppler downward velocity, (c) retrieved air motions using S- and Ka-band radar (green) and 449-MHz profiler (black), (d) retrieved rain rate, (e) retrieved mean diameter, and (f) Differential Doppler Velocity (DDV).**

shown in 1c.

The retrieval method and results were presented at the IEEE International Geophysical and Remote Sensing Symposium (IGARSS 2014) in Quebec City, Canada, 13-18 July 2014.

## 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 & Objective

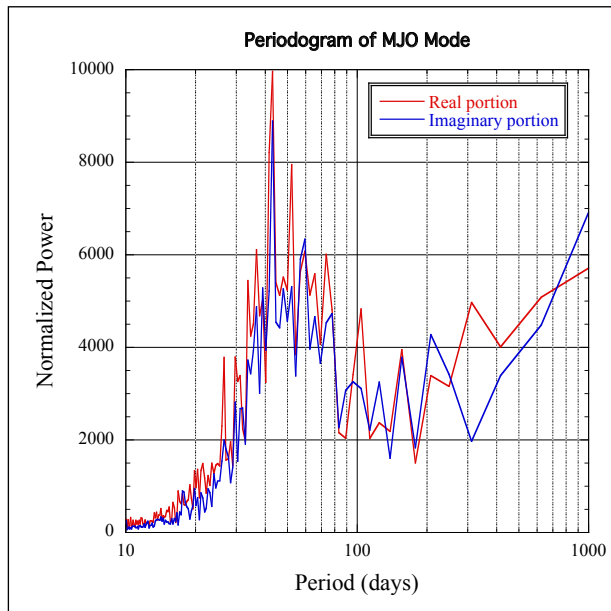
This project will help build a basis for forecasting climate variability associated with the temperature and moisture conditions in and over the tropical oceans, which have effects on climate in large portions of the United States and Central America as well as around the globe.

### Accomplishments

This year we continued research into the air-sea processes involved in the initial stages of a type of organized convection over the tropical Indian Ocean. We also published a paper explaining how the absence of wind profiler data can tell us things about a particular type of atmospheric boundary layer, and experimented with two different methods of calibrating a profiler that had been deployed in the western equatorial Pacific for several years.

Numerical forecast models have difficulty simulating and forecasting the Madden-Julian Oscillation (MJO), especially in its “initiation” phase over the Indian

**Periodogram of the real (red) and imaginary (blue) parts of the MJO mode identified through LIM analysis of long timeseries of 5-day mean tropical subsets of several relevant atmospheric parameters. Both portions have a large and distinct spectral peak between 40 and 50 days.**



Ocean, due in part to model deficiencies such as inadequate subgrid parameterizations. We applied Linear Inverse Modeling (LIM) techniques to a set of basis functions based on 5-day averaged Outgoing Longwave Radiation (OLR), sea level pressure, mid-tropospheric temperature, and upper- and lower-tropospheric zonal winds. One of the resultant modes represented the MJO. It oscillates with a period of 40-50 days, and its geographical features propagate in a manner consistent with known MJO behavior. This is important because the data had not been filtered to remove ENSO or to extract such intraseasonal time scales.

There has been a longstanding desire in the wind-profiling community to extract more atmospheric information from profiling radars than merely winds. Some of this desire could be satisfied by a calibrated profiler, which would enable the calculation of profiles of  $C_n^2$  (the structure function of the index of refraction), which is related to turbulence, and  $Z_e$  (the equivalent reflectivity), which is reported by precipitation radars. We have used two different methods to calibrate the 915-MHz profiler which was deployed at Manus, Papua New Guinea from 1992 to 2001. One method iteratively determines the calibration constant required to match reflectivities during two separate stratiform rain events with the rainfall measured by a tipping bucket located near the profiler. The other method determines the calibration constant required to match long-term statistics of bright-band reflectivities measured by the Manus profiler with similar statistics measured by the TRMM satellite. The two calibrations are very close (1.5 dB). These results serve as a proof of concept, providing encouragement to calibrate several other profilers which were deployed as part of the Tropical Pacific Profiling Network (TPPN) in the 1990s and 2000s. These calibrated tropical profiler data are useful for long-term detailed studies of atmospheric structures and turbulence, and of interest to the communications industry.

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# Climate Forcing, Feedbacks, and Analysis

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

■ CIRES Lead: Kathy Pegion ■ NOAA Lead: Martin Hoerling  
NOAA Theme: Climate Adaptation and Mitigation

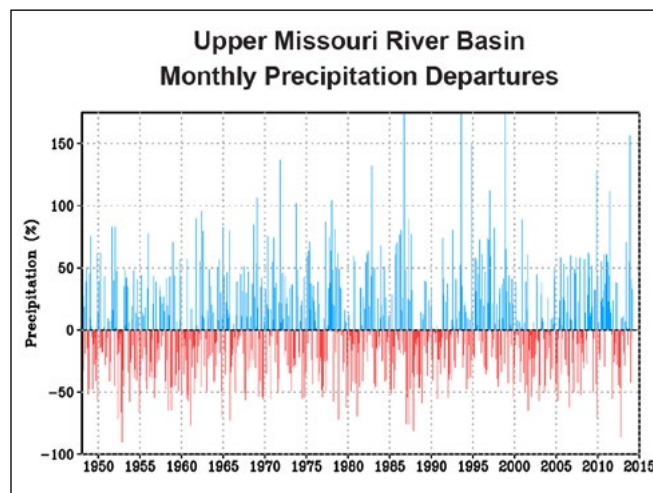
### Goals & Objective

This project will provide decision-makers with a better understanding of the skill and reliability of regional climate information.

### Accomplishments

In August, 2014, we completed an assessment report, joint with the U.S. Army Corps of Engineers, on the 2011 flooding in the Upper Missouri River. Monthly and seasonal precipitation in the Upper Basin, in the Lower Basin, and entire Missouri River Basin is highly variable (figure), with standard deviations averaging close to 30 percent of the long-term average. The upper Missouri River Basin received approximately 70 percent more precipitation in May 2011 than would be considered normal based on the monthly climatology. In contrast, during September 2012, rainfall in the upper Missouri River Basin was more than 80% below normal for the month, as part of a prolonged dry period lasting from June-September 2012.

The lower Missouri River Basin experienced similar wet (2011) and dry (2012) periods to those observed for the Upper Basin, but the precipitation values were not as extreme relative to the monthly long-term averages.



Monthly precipitation departures from the long-term monthly averages for 1948 to present illustrating high month-to-month variability within the Upper Basin

NOAA/CIRES

Comparisons of model versus observed precipitation showed similar patterns of wet and dry conditions. However, the forecasts did not provide consistently skillful and reliable predictions of the amplitude and duration of conditions leading to the 2011 flooding and 2012 drought.

The only potentially useful forecast skill was for short lead predictions in the Lower Basin during El Niño events.

We conclude that the meteorological factors leading to the 2011 flood or the 2012 drought are not accurately predicted at seasonal lead times by current state-of-the-art, operational and experimental forecast systems. For the lead times and for the times of year of interest, in separate analyses made using all years, only ENSO neutral years, or only La Niña years, the three metrics used to quantify forecast skill in the Missouri River Basin indicate no useful skill in precipitation forecasts for the Upper Basin, for the Lower Basin, or for the entire Missouri River Basin. While perhaps not useful to manage basin-wide flood and water supply risks, there is potential skill for predictions of precipitation at short lead times during El Niño events in the unregulated lower part of the basin below the mainstem dams.

The link between El Niño and precipitation in the Lower Basin may potentially be of value in the Lower Basin to inform a broad range of regional to local regulatory and management practices.

More information can be found here: [www.esrl.noaa.gov/psd/csi/factsheets/pdf/noaa-mrb-fcst-skill-assessment-summary.pdf](http://www.esrl.noaa.gov/psd/csi/factsheets/pdf/noaa-mrb-fcst-skill-assessment-summary.pdf)

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

■ CIRES Lead: Xiaowei Quan ■ NOAA Lead: Martin Hoerling  
NOAA Theme: Climate Adaptation and Mitigation

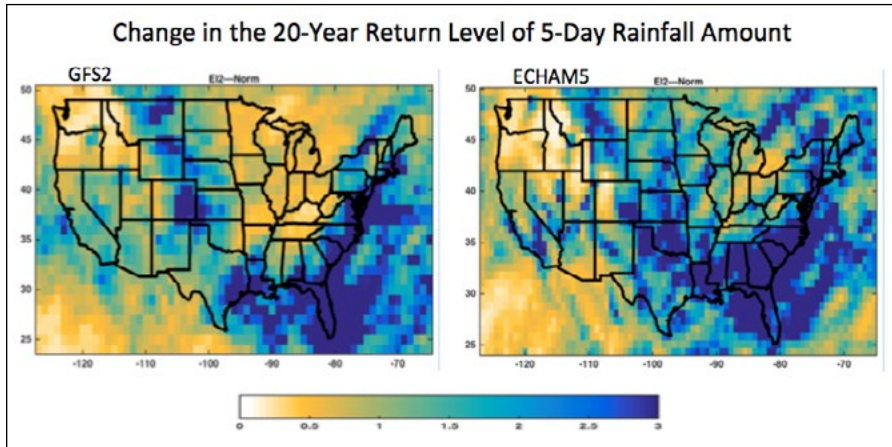
### Goals & Objective

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

Outputs of these model simulations are analyzed to examine the behavior of heavy rain events. Currently we are focusing on the question of how El Niño and La Niña affect extreme 5-day rainfall events. Our preliminary results indicate detectable signals of the impact of strong El Niño that increases frequency of winter to early spring heavy rain events over the upper Missouri River Basin and in the east/northeast regions in Texas. The attached figure shows the spatial pattern of changes in the 20-year return value of 5-day heavy rainfall





Changes in the 20-year return value of 5-day total rainfall amount for the months of November to April during the two strong (i.e. 1982-83 and 1997-98) El Niño events as simulated by two climate models (GFSv2 of NOAA NCEP and the ECHAM5 of ECMWF and MPIM) forced with the observed temporal evolution of global sea surface temperature, sea ice, and radiative forcings. NOAA/CIRES

events during the months of November of onset year of two strong El Niño events (1982-83 and 1997-98) to the April of following year related to the 20-year return values of the 1981-2010 climate mean conditions. The signal of increased risks of heavy rain occurrence in these regions during the years of strong El Niño, as indicated by the increased 20-year return values, is consistent in the ensemble simulations of both the climate models we have accomplished this year.

## PSD-17: Understanding How Tropical SSTs Influence Atmospheric Variability

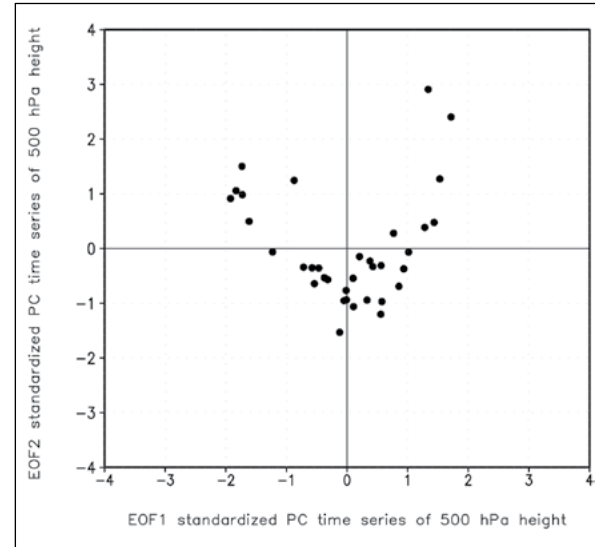
■ CIRES Lead: Tao Zhang ■ NOAA Lead: Martin Hoerling  
NOAA Theme: Climate Adaptation and Mitigation

### Goals & Objective

This project will promote more accurate prediction of North American climate variability beyond a simple linear response to El Niño Southern Oscillation (ENSO) forcing.

### Accomplishments

We have finished a 50-member Arctic sea ice run from 1979-2013 using the Global Forecast System version 2 model. In this configuration, the sea surface temperature (SST)/ice variability is the same as those in AMIP run over the arctic region, but the climatological values are used



The scatter relationship between PC1 index and PC2 index based on the EOF analysis of GFSv2 simulated 50-member ensemble mean winter (DJF) season 500-hectopascal heights. The analysis is computed over 20 degrees north latitude to 90 degrees north latitude for 1979/80 through 2013/14. The ordinate of the PC time series is of the standardized departure.

outside of arctic region. The results may be useful for the Arctic study.

In a study of forced atmospheric teleconnections during the recent period, three primary modes of forced variability are identified using empirical orthogonal function (EOF) analysis of the ensemble mean wintertime 500-hPa heights. The key findings are that we show for the first time the second mode is associated with quite different manifestation of tropical SST variability (see figure). In its positive polarity, this second mode is an expression of the asymmetry in atmospheric teleconnections between ENSO's extreme opposite phases. In its negative polarity, this second mode expresses the atmospheric sensitivity to an SST pattern resembling the precursor for subsequent El Niño development. Such a negative phase of the second forced mode was especially prominent during 2013-14 and explains key features of the California drought and heat wave.

### Reference

Zhang, T., M. P. Hoerling, J. Perlwitz, and T. Xu. (2015). Forced Atmospheric Teleconnections During 1979-2014. *J. Climate* (submitted)

# Climate Forcing, Feedbacks, and Analysis

## 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 & Objective

This work is to explain to decision-makers what climate variables are potentially responsible for different water-resource-management outcomes.

### Accomplishments

Here we have focused on the California drought issue and have explored how climate change has affected the risk of severe sustained drought over the state. The analysis is ongoing, and has led in early 2015 to a manuscript which is now under review at the *Journal of Climate*.

### Reference

Cheng Linyin, Martin Hoerling, Amir AghaKouchak, Ben Livneh, and Xiao-Wei Quan (2015). Current Effects of Human-induced Climate Change on California Drought. *Journal of Climate*, submitted. A draft manuscript can be found at: [http://www.esrl.noaa.gov/psd/csi/pubs/docs/Cheng\\_submitted\\_ScienceAdvances.pdf](http://www.esrl.noaa.gov/psd/csi/pubs/docs/Cheng_submitted_ScienceAdvances.pdf)



**The 2011-2014 California drought cast a burden on statewide agriculture and water resources, and especially high temperatures have brought into question the role of long-term climate change. New model simulations show that climate change since the late 19<sup>th</sup> Century induces increased annual precipitation and increased surface temperature across California. (Cheng et al., 2015).** California Department of Natural Resources

# 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 & Objective

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

Under the Enhancing Data Management Systems and Web-Based Data Access project, CIRES personnel made significant contributions in support of NOAA's mission. These contributions were a direct result of a team-based agile software development process that

has matured over the last three years. Using our agile process, we delivered a diverse set of software solutions that facilitate the ingest, discovery, and access of scientific data sets. Specific accomplishments are detailed below.

Initially, the team worked on a Hurricane Sandy recovery project, producing a map and data retrieval solution. This tool provides data on ocean bathymetry and hydrographic survey data relevant in both recovery and mitigation efforts.

During the fall of 2014, the team focused on adding a data stream to our ingest software supporting the National Tsunami Warning Center. The water-level tide gauge data ingest streams include a new capability for archiving data using a NetCDF file format and this code has a high probability of reuse in future efforts.

Our work then transitioned to focus on a significant rewrite of software in support of the the Extended Continental Shelf (ECS) Information Management System. This system provides web accessible tools for multi-agency collaborations whose goals are to determine and define the extent of the U.S. Continental Shelf beyond 200 nautical

The screenshot shows a web browser window displaying the NOAA National Geophysical Data Center interface. The page title is "Request Bathymetric Data". The URL is "www.ngdc.noaa.gov/next-web/orders/create#/Multibeam". The NOAA logo and "NATIONAL GEOPHYSICAL DATA CENTER" are visible at the top. Below the logo, there are tabs for "Request Summary" and "Multibeam Surveys 12". A search criteria panel on the left lists: Cruise IDs: EX1201, EX1204, E...; Start Year: 2012; End Year: Present; Platforms: All. A central map shows green survey tracks over a blue ocean area. To the right of the map is a "Survey & File Statistics" panel showing: Filesize (approximate): 27.5 GB; Files: 2858; File Data Types: Bathymetry, Geomtry, Metadata, Supporting Images. Below the map and statistics is a table of available data.

Data Available	Cruise ID	Year	Platform (Ship)	Instrument	
➤	EX1201	2012	Okeanos Explorer	Simrad EM302	☑
➤	EX1204	2012	Okeanos Explorer	Simrad EM302	☑
➤	EX1205L2	2012	Okeanos Explorer	Kongsberg EM302	☑
➤	EX1301	2013	Okeanos Explorer	Kongsberg EM302	☑
➤	EX1302	2013	Okeanos Explorer	Kongsberg EM302	☑
➤	EX1304L.en1	2013	Okeanos Explorer	Kongsberg EM302	☑

**Web application developed in support of Hurricane Sandy recovery and mitigation.** CIRES/NOAA

# Management and Exploitation of Geophysical Data

miles (nm). The software is now in use by the ECS project team to assemble a boundary extension submission to the United Nations, tracking datasets, analysis, documentation and other arguments in support of the official request.

In the spring of 2015, the team worked on a satellite product analysis and distribution enterprise system, and at the same time completed final testing, operations, and maintenance of software supporting the DSCOVER (Deep Space Climate Observatory) satellite which launched February 11, 2015. DSCOVER is currently entering its L1 monitoring position. Once the data flow begins, products from the DSCOVER mission will be ingested to ensure data access, long term stewardship and archival of the satellite data.

In the coming year, CIRES personnel will continue to focus on a researching technologies that support data ingest, discovery, and access. New efforts will include work on a Crowd-Sourced Bathymetry project, Big Earth Data Initiatives, and increased partnerships within the new NCEI organizational structure.

## NGDC-02: Enhancing Marine Geophysical Data Stewardship

■ CIRES Lead: Jennifer Jencks ■ NOAA Lead: Susan McLean  
NOAA Theme: Science and Technology Enterprise

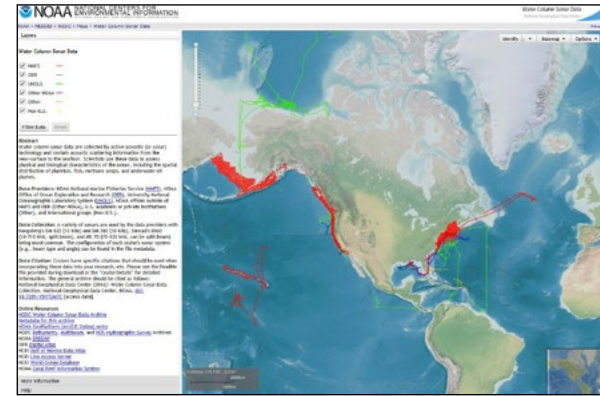
### Goals & Objective

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.

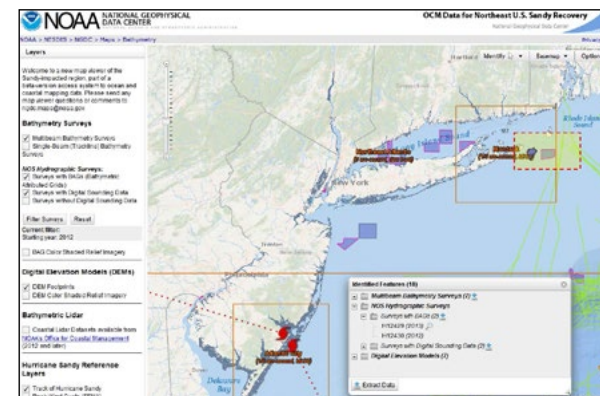
### Accomplishments

Both national and international organizations contribute to and retrieve marine geophysical and geological data from the National Centers for Environmental Information (NCEI) (formerly NGDC) interactive databases. NCEI 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 2014, 156 multibeam swath sonar surveys (175,650 nautical miles) and 56 trackline (single-beam bathymetry, magnetics, gravity, subbottom, and seismic reflection) surveys (285,155 nautical miles) conducted throughout the world's oceans have been added to NCEI's global marine geophysical archives by NCEI and CIRES data managers.

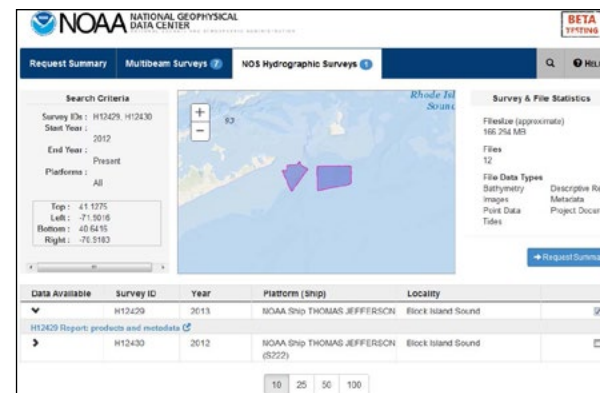
Water column sonar data image the volume of water between the ship and the seafloor, and are used to map schools of fish and other marine organisms, characterize habitat, map natural gas seeps, and monitor undersea oil spills. In partnership with and supported by NOAA Fisheries, CIRES and NCEI staff hardened the data ingest pipeline and extended it to five out of the six NOAA Fisheries Science Centers located around the nation. These efforts resulted in the archive of over 15 terabytes of water column sonar data. Over 60



interactive Water Column Sonar Data Viewer. CIRES/NOAA



Web map viewer of ocean and coastal mapping data in the Northeast, showing the path of Hurricane Sandy and its coastal inundation zone. CIRES/NOAA



Web data extract client for data request refinement. The tool allows a user to select their data choices (e.g., only survey H12429 in this example). The estimated download request summary (i.e., file size and number of files) updates automatically. CIRES/NOAA

DOIs were minted for the general archive and for individual cruises within the archive, each providing a permanent citation of the associated dataset. Improvements were made to the functionality and performance of the project's data access web page ([http://maps.ngdc.noaa.gov/viewers/water\\_column\\_sonar/](http://maps.ngdc.noaa.gov/viewers/water_column_sonar/)) to enable researchers and the public to query, discover, and request these data. Benefits of this publicly accessible central repository include increased collaboration across institutions and the ability for researchers to address cross-cutting scientific questions to advance the field of marine ecosystem acoustics.

In 2014, a pilot project was initiated to establish the framework for stewarding NOAA Fisheries passive acoustic data, another large-volume data set. These data are used to monitor ambient noise within the ocean, which contains sounds produced by marine mammals, fish, and invertebrates as well as anthropogenic sources of noise including shipping traffic and energy exploration surveys. Efforts are underway to develop a pipeline for well-documented data to flow from the data providers to the recently built database.

Marine geophysical data archived at and delivered by NCEI currently support two specific, ongoing U.S. mapping efforts: the Extended Continental Shelf (ECS) project and the Integrated Ocean and Coastal Mapping (IOCM) program. One of the key data management tasks of the ECS project is the requirement to track the exacting provenance and quality requirements required under international law. To achieve this goal, NCEI and CIRES staff have continued to improve upon a relational, geospatial database called the Information Management System (IMS). The IMS contains the primary ECS data, products, associated metadata, analyses, documents, etc., and enables consistent data management by the multi-agency project team members. The IMS utilizes web map services built on top of spatially enabled databases, which underlie a browser-based JavaScript web mapping application to view and interact with the data.

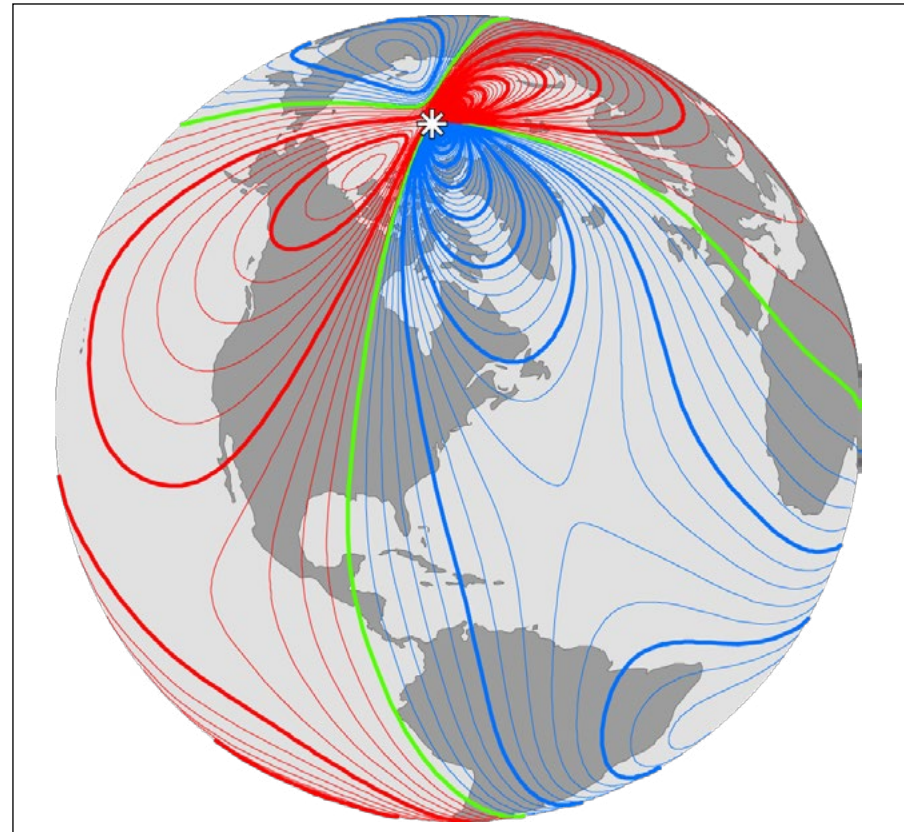
CIRES staff also developed tools for easy discovery and robust, sustainable, and bundled delivery of ocean and coastal mapping (OCM) data in the Northeast region that was impacted by Hurricane Sandy in October 2012. A web map viewer of the region (top figure, previous page) utilizes web services of NCEI and the NOAA Office for Coastal Management (formerly NOAA Coastal Services Center) to depict the footprints of publicly available bathymetric data disseminated by NOAA, as well as Federal Emergency Management Agency (FEMA) web services, to show the extent of its coastal inundation in New York and New Jersey. The viewer launches a web data extract client that disseminates bundled multibeam bathymetry and NOS soundings via NCEI's extract service (NEXT). This custom-designed and developed graphical interface (bottom figure previous page) allows users to refine their data request by selecting their specific data of interest. Links within the client to National Ocean Service (NOS) sounding product pages are available on a per-survey basis. Additional OCM data types archived at NCEI (e.g., trackline bathymetry, water-column sonar) will be included in the future, each of which will have its own tabs for refined data selection.

## 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 & Objective

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.



**Magnetic declination (angle between magnetic north and true north) at the Earth's surface on January 1, 2015, from the World Magnetic Model. CIRES/NCEI/NGDC**

# Management and Exploitation of Geophysical Data

## Accomplishments

The CIRES geomagnetism team developed and released a new version of the World Magnetic Model (WMM), valid for 2015-2019. The WMM is the standard model for navigation, attitude, and heading referencing systems used by several civilian and military organizations, including the U.S. Department of Defense, the U.K. Ministry of Defence, the North Atlantic Treaty Organization (NATO) and the International Hydrographic Organization (IHO). It is also used widely in civilian navigation and heading systems, including more than a billion smartphones. The model, associated software, and documentation are distributed by NOAA on behalf of the National Geospatial Intelligence Agency (NGA). The current model was calculated from magnetic measurements provided by the European Space Agency (ESA) Swarm satellite mission, launched in November 2013, and from additional measurements provided by the Danish Ørsted satellite and the worldwide network of magnetic observatories. Swarm is the latest and most sophisticated dedicated magnetic satellite mission ever flown. It comprises three satellites in near-polar orbits at around 500 km altitude, including two satellites flying side-by-side to provide gradient measurements of the crustal magnetic field anomalies. CIRES scientists actively participated in the calibration and validation of Swarm data, as part of the international calibrate and validate team set up by ESA.

Some applications require higher spatial resolutions than that of the WMM for accurate geomagnetic referencing. Based on Swarm magnetic measurements, the CIRES geomagnetism team developed and released new versions of the Enhanced Magnetic Model (EMM) and the High Definition Geomagnetic Model (HDGM). These advanced models are derived from satellite, marine, aeromagnetic, and ground magnetic surveys and describe magnetic fields not included in the WMM, such as crustal field anomalies and variations generated by electric fields outside the Earth. The current EMM is valid until 2020; the HDGM is updated every year.

As part of an international team under the auspices of the International Association of Geomagnetism and Aeronomy, CIRES scientists contributed to the development and validation of the twelfth generation International Geomagnetic Reference Field (IGRF). The IGRF is updated every five years and is widely used by the scientific community. Unlike the WMM, the IGRF is not an operational model and is built from a number of candidate models provided by various groups of modelers.

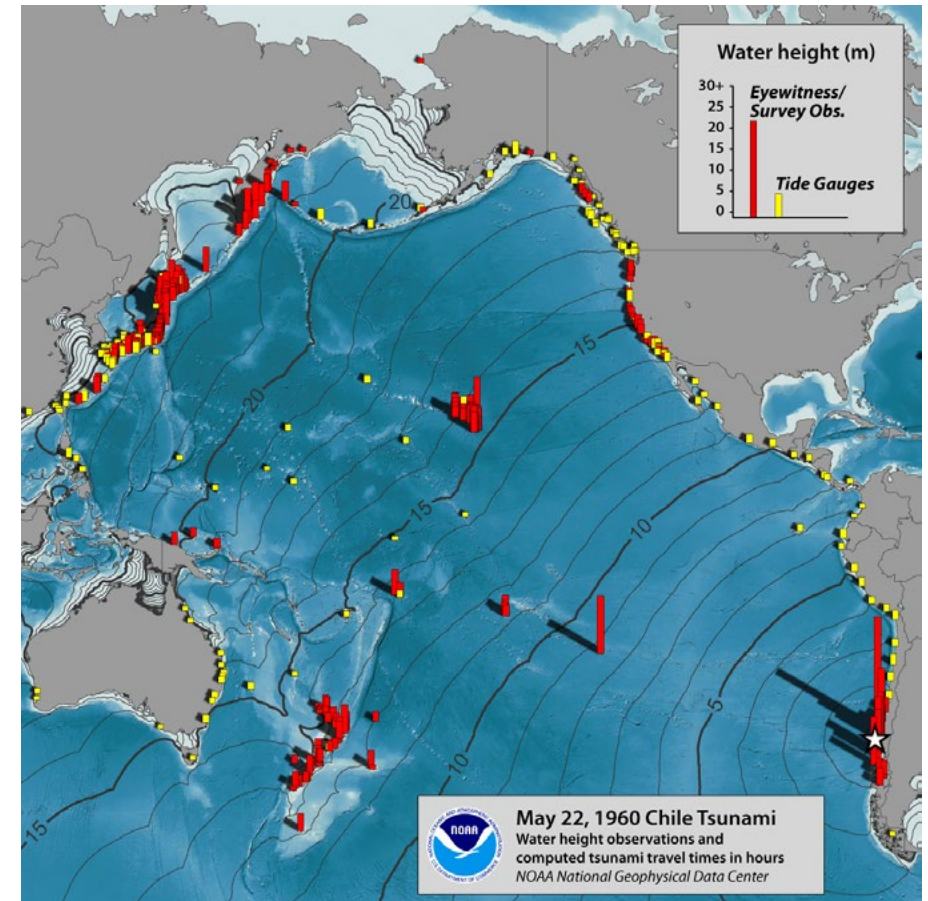
## NGDC-04: Enhanced Coastal Data Services, Integration, and Modeling

■ CIRES Lead: Kelly Stroker ■ NOAA Lead: Susan McLean  
NOAA Theme: Science and Technology Enterprise

### Goals & Objective

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.



**May 22, 1960, tsunami water heights from eyewitness accounts, field surveys, and tide gauges and estimated tsunami travel times plotted at one-hour intervals (black lines) using the earthquake epicenter (star) as a point source.**

*Pacific Tsunami Warning System, A Half-Century of Protecting the Pacific, 1965-2015. Varner/NCEI*

## Accomplishments

CIRES staff at the National Centers for Environmental Information (NCEI) developed five 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.

With funding provided through the Disaster Relief Appropriations Act of 2013, CIRES staff at NCEI, in collaboration with the U.S. Geological Survey (USGS) Earth Resources Observation and Science Center, have developed a framework for the creation of an accurate, consistent, and seamless depiction of merged bathymetry and topography in the U.S. coastal zone. In 2014–2015, a suite of digital elevation models (DEMs) of the U.S. Atlantic Coast impacted by Hurricane Sandy in October 2012 was built for the New Jersey coast and Delaware Bay. Lower resolution DEMs, using only bathymetry data, were also built for offshore areas of the affected region. The DEMs are tiled to enable targeted, rapid updates as new data become available. The DEMs telescope from the deep ocean floor to the coastal zone in three, one, one-third, and one-ninth arc-second cell sizes. The one-ninth arc-second DEMs integrate both bathymetric and topographic data at the coast, while the offshore DEMs map bathymetry only. This framework, specific to square-cell “raster” models, enables shared development of coastal DEMs that are freely available for public use, such that users can seamlessly integrate public coastal DEMs built by different federal agencies, academia, and the private sector. ([http://www.ngdc.noaa.gov/mgg/inundation/sandy/sandy\\_geoc.html](http://www.ngdc.noaa.gov/mgg/inundation/sandy/sandy_geoc.html))

A variety of tasks to further standardize lidar data holdings in the archive were also completed during the last year. Most notably, all data in the archive were converted to a lossless compressed version of the lidar-specific .las format (.laz format). In total, over 100 surveys were re-processed/submitted and re-archived. This work resulted in a reduction in total volume of the lidar data archive by nearly half (~20 terabytes to ~10 terabytes), all while maintaining the data integrity. Additionally, we worked with the data provider to standardize naming conventions of data submissions and also include more robust documentation. We archived 6.8 terabytes total, ingested from June 1, 2014, to May 30, 2015; of that, ~2.9 terabytes were new data.

A crucial element to plan for many coastal natural hazards impacts is water-level data. CIRES staff at NCEI ingest, process, and archive tide gauge data and deep ocean-bottom pressure recorder data from several NOAA agencies. These data are then made available via online tools for researchers and modelers. In 2014, there were three tsunami events that were investigated, documented, and included in our tsunami database: A small meteo-tsunami observed on March 10 along the West Coast; a local but strong

meteo-tsunami observed on March 28 at Panama City, Florida; and a tsunami generated by the April 1, 2014, magnitude 6.9 Chilean earthquake. For each of these events, there were urgent data requests for Deep-ocean Assessment and Reporting of Tsunami (DART) and coastal tide-gauge data.

We reestablished the flow of water level data from eight tide gauge stations operated by the National Tsunami Warning Center (NTWC) and transformed the data into a more useable netCDF format, aggregated by station per week. We added an additional team member to manage water level data and reestablish connections with NOAA's National Data Buoy Center, National Ocean Service, Tsunami Warning Centers, and Pacific Marine Environmental Laboratory. We also hired an undergraduate student to complete the effort to archive digitally scanned images of paper tide gauge records, thus completing the archive of over 3,000 scanned records. May 2015 marked 50 years of tsunami warning in the Pacific and the establishment of the Pacific Tsunami Warning System (PTWS). To recognize the achievements of the PTWS over the last 50 years, and with funding support from NOAA, the International Tsunami Information Center and NCEI staff have published the commemorative historical book, “Pacific Tsunami Warning System, A Half-Century of Protecting the Pacific, 1965–2015.”

Water column sonar data, archived and distributed at NCEI, 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. Since the archive's completion in 2013, over 15 terabytes of data and associated metadata have been ingested and made available to the public through a data access Web page, [http://maps.ngdc.noaa.gov/viewers/water\\_column\\_sonar/](http://maps.ngdc.noaa.gov/viewers/water_column_sonar/).

## NGDC-05: Enhanced Stewardship of Space Weather Data

■ CIRES Lead: Justin Mabie ■ NOAA Lead: William Denig  
NOAA Theme: Science and Technology Enterprise

### Goals & Objective

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

## Accomplishments

Data ingest has continued and is up to date. A new ionosonde was installed in Antarctica and high quality data are being collected. Results from three field experiments have been analyzed and three publications are being drafted. The data center consolidation had merged the National Geophysical Data Center (NGDC), the National Oceanic Data Center (NODC) and the National Climatic Data Center (NCDC)

# Management and Exploitation of Geophysical Data



**Digging through continuous permafrost to install towers that were part of the new isospheric research radar in Antarctica.** Justin Mabie/CIRES

into a single organization, the National Centers for Environmental Information (NCEI). This data center consolidation will change the focus of data management activities in the coming years and ongoing efforts are being made to preserve data and ensure continuous data access to the public. The works of Charles Anthony Schott titled “Notes on Terrestrial Magnetism” were digitized and cover all aspects of the field of geomagnetism during the pioneer years from 1852 through 1891.

## NGDC-07: Remote Sensing of Anthropogenic Signals

■ CIRES Lead: Kimberly Baugh ■ NOAA Lead: Chris Elvidge  
NOAA Theme: Science and Technology Enterprise

### Goals & Objective

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

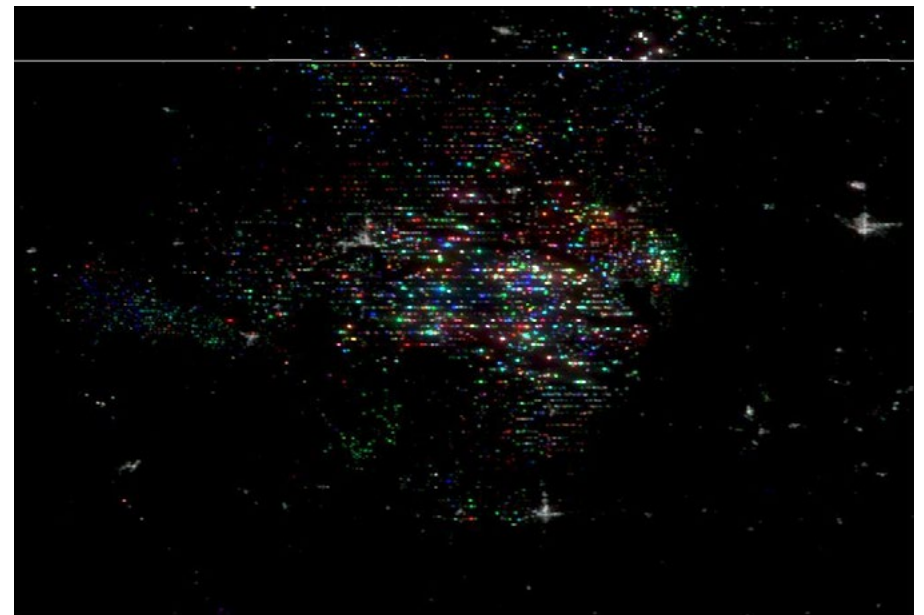
### Accomplishments

During the past year, CIRES staff collaborated with NOAA scientists to complete

development on Version 1 of a VIIRS Boat Detection (VBD) algorithm. This algorithm is designed to detect brightly lit fishing boats as seen in the nighttime data from the VIIRS Day-Night Band. VBD version 1 works only in the dark half of the lunar cycle and is currently operational over Indonesia. CIRES staff is working on algorithm development to address the large number of false detections that occur due to moonlit clouds. This new version will enable the VBD product to be generated under all lunar conditions.

This year CIRES staff has pulled from the NOAA CLASS archive and processed 23 months of VIIRS Nighttime data. This effort has resulted in a time-series of monthly cloud-free composites of nighttime lights and Nightfire combustion source detections. Active algorithm development continues with the goal of separating ephemeral and persistent light sources, as well as separating lights from non-light areas. Algorithm development and production of these monthly composites will continue through 2016.

CIRES staff also worked on refining calibration for estimating flared gas volumes



**Nighttime lights RGB color composite showing temporal behavior of gas flaring in the Bakken region of North Dakota. This image was made by layering 3 months of nighttime lights composites: May 2014 is red, September 2014 is green, and October 2014 is blue.**



using the VIIRS Nightfire product. Flare locations were identified using global Nightfire composites. A preliminary calibration coefficient was obtained by regressing the reported gas flaring volumes for regional areas against the Nightfire-derived radiant heat values for those same areas. This coefficient was then used to obtain preliminary country-level estimates of gas flaring volumes for 2014.

## 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 & Objective

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

Accomplishments for the GOES-R (Geostationary Operational Environmental Satellite series-R) effort include:

- Completed delivery of Level 2+ product algorithm theoretical basis documents for the GOES-R space weather products.
- Delivered a total of 29 algorithms to the GOES-R Program Office. These algorithms define the higher-level data products that customers frequently use to analyze space weather.
- Identified and coordinated development of the tools which NGDC/STP (NGDC/Solar-Terrestrial Physics) will use to support Post-Launch Test (PLT) and Post-Launch Product Test (PLPT) activities.
- Provided substantive support to Mission Operations Support Team for GOES-R PLT planning activities.
- Provided extensive responses to an independent peer review of PLT and PLPT plans for the GOES-R space weather instruments.
- Developed requirements and functional architecture for the NGDC Satellite Product Analysis and Distribution Enterprise System (SPADES). SPADES is a demonstration software system that will serve as a prototype for the operational system the National Weather Service will ultimately implement. SPADES will generate the Level 2+ space weather products.
- Completed a successful Program Design Review (PDR) for SPADES. Preliminary Design Review preparations included a risk-reduction effort to prototype the core SPADES system. Interfaced extensively with the National Weather Service team responsible for operational implementation of the Level 2+ space weather products.

- Completed development of the SPADES Storage Segment, Processing Segment, and first part of Ingest Segment (interface to the GOES-R Product Distribution and Access system). Prepared and presented a successful critical design review for SPADES.
- Evaluated instrument vendor plans and test results for space weather instruments.
- Worked with space weather instrument vendors to define the software tools and analysis tasks that will be needed for the PLT period.
- Participated in meetings of the GOES-R Product Working Group to help ensure that the space weather instrument concerns are addressed at a Program level.
- Identified major interface issues that would adversely impact NGDC's ability to execute PLT activities and successfully archive quality GOES-R data.
- Identified outstanding issues with GOES-R L1b products and reported these to the GOES-R Program.
- Provided technical input during discussions about instrument waivers. Created mitigation plans to reduce risks associated with the underlying issues that prompted these waivers.

## NGDC-09: Enhanced Ionosonde Data Access and Stewardship

■ CIRES Lead: Terry Bullett ■ NOAA Lead: Rob Redmon  
NOAA Theme: Science and Technology Enterprise

### Goals & Objective

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

### Accomplishments

The hallmark accomplishment for this period is the successful installation of an advanced research ionosonde at the new Korean Jang Bogo Antarctic Research station (74 degrees 37 minutes south latitude and 164 degrees 12 minutes east longitude). The instrument is a Dynasonde Vertical Incidence Pulsed Ionospheric Radar (VIPIR) and is the largest and most capable instrument of its type in the world. CIRES members Terry Bullett and Justin Mabie spent more than three months installing this instrument, overcoming numerous technical and logistical difficulties. The instrument is sponsored by the Korean Polar Research Institute (KOPRI). Preliminary data indicate the system performance is phenomenal and far exceeds expectations. This instrument will reveal new insights in ionospheric physics and the coupling of the sun to the Earth through the Earth's magnetosphere.

The study of energy transport from the oceans into space has obtained some of its first published results. Under the direction of principle investigator Nikolay Zabolotin, there is experimental proof that deep ocean waves consistently create low frequency

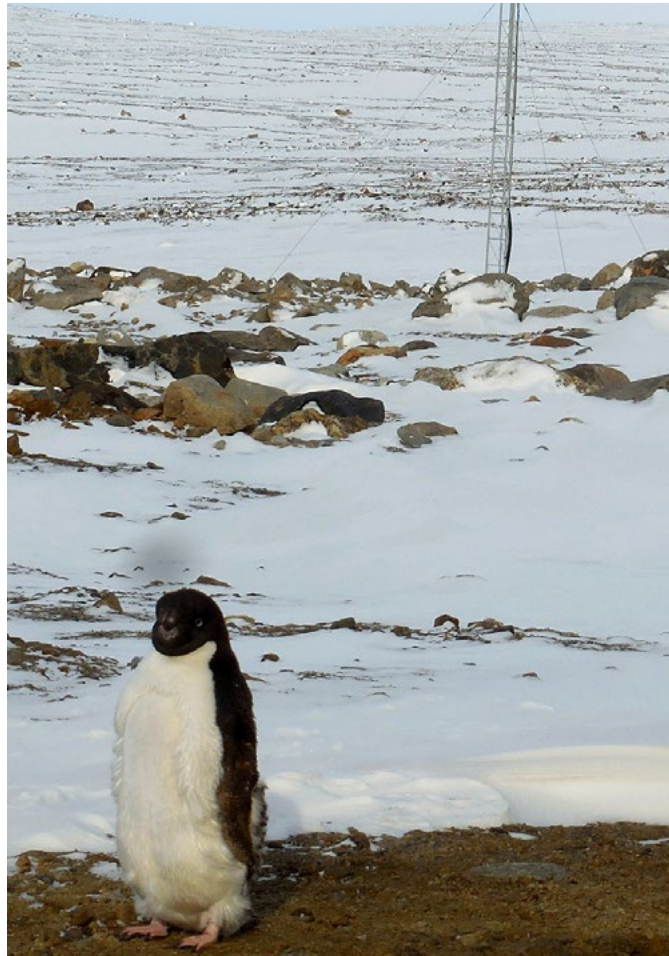
# Management and Exploitation of Geophysical Data

pressure waves in the lower atmosphere, and that these waves propagate up into space to at least 400 km altitude. This project provided the space environment data. The energy from these waves could play a role in forecasting both terrestrial and space weather, and may play a role in planetary energy balance and climate.

Real-time global ionosonde data collection and dissemination has improved to about 80 real-time stations around the world, and a larger variety of instrument and data types is now being supported. Through the efforts of CIRES's Jim Manley, the real-time data holdings have been improved, not only in numbers of stations, but with

**A curious penguin visits the Jang Bogo Antarctic Research Station in February 2015. In the background is one of the receiving antennas for the Jang Bogo Dynasonde.**

Terry Bullet/CIRES



improved quality, uniformity, and utility. These data are an important part of real-time space weather applications such as ionosphere specification and forecast, and predicting high frequency radio propagation for radio amateurs and emergency services.

## NGDC-10: Enhanced CORS Data Access and Stewardship

■ CIRES Lead: Francine Coloma ■ NOAA Lead: William Denig  
NOAA Theme: Science and Technology Enterprise

### Goals & Objective

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

### Accomplishments

We have completed enhancement of access to the National Geodetic Survey's Continuously Operating Reference Station (NGS CORS) data set by incorporating CORS data into NOAA's enterprise data archive platform, the Comprehensive Large-Array Data Stewardship System IT infrastructure, as part of NGDC's Annual Operating Plan. CORS data are used as input into NOAA's space weather model for the US-Total Electron Content and the tropospheric model for GPS-meteorology.

This project is now complete and is closed.

## 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 & Objective

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

### Accomplishments

The efforts of CIRES staff this year doubled the metadata holdings at the NOAA-Paleoclimatology World Data Service (WDS) for Paleoclimatology, adding nearly 1,000 borehole temperature records along with their data; almost 11,000 pollen records; and around 700 records of paleoclimate-relevant software and data repositories. Notably, the expansion of pollen metadata results from a new partnership with the Neotoma pollen database project and marks the start of incorporating this collection into NOAA's archive for long-term preservation. Users of the NOAA-Paleoclimatology WDS services can now search seamlessly across both WDS and Neotoma holdings. These pollen records are widely used to reconstruct past temperature and precipitation conditions, and to observe the impacts of past climate change on ecosystems.

**Pollen records reveal climate-related changes through time in many plant ecosystems, including coastal redwood forests.**

National Park Service



We also developed an initial working version of controlled vocabularies to more completely and precisely describe the measurements we archive for seven of the most commonly-contributed paleoclimate data types. A classic example of the “long tail of science,” paleoclimate data consist of many, small studies completed by individual investigators in separate laboratories using a multitude of methods and techniques. This heterogeneity is one of the biggest barriers to the development of accumulated data products and access capabilities, and to the use of paleo data beyond the community of paleoclimate specialists. Our work completes a first step of a longer-term project of interacting with paleoclimate scientists to develop standard formats and improved access capabilities for paleoclimate variables.

We completed a multi-year applied research project using paleoclimate data to test how well state-of-the-art climate models are able to simulate climate changes resulting from melting of high-latitude ice sheets into the ocean. This project culminated with a publication in the journal *Paleoceanography* and was chosen for a presentation at the NOAA Science Days in Silver Spring, Maryland, followed by a briefing to NOAA leadership. This paleo event highlights the possibility of non-linearities in ice sheet melting and the potentially significant climate impacts that could result from future changes in ocean circulation.

### **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 & Objective**

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

#### **Accomplishments**

Preparations accelerated for the next major delayed-mode International Comprehensive Ocean-Atmosphere Data Set (ICOADS) update, Release 3.0 (R3.0)—now planned for completion around early 2016—including continued refinement of the workplan and ongoing discussions with our international partners to coordinate input data contributions and deliverables.

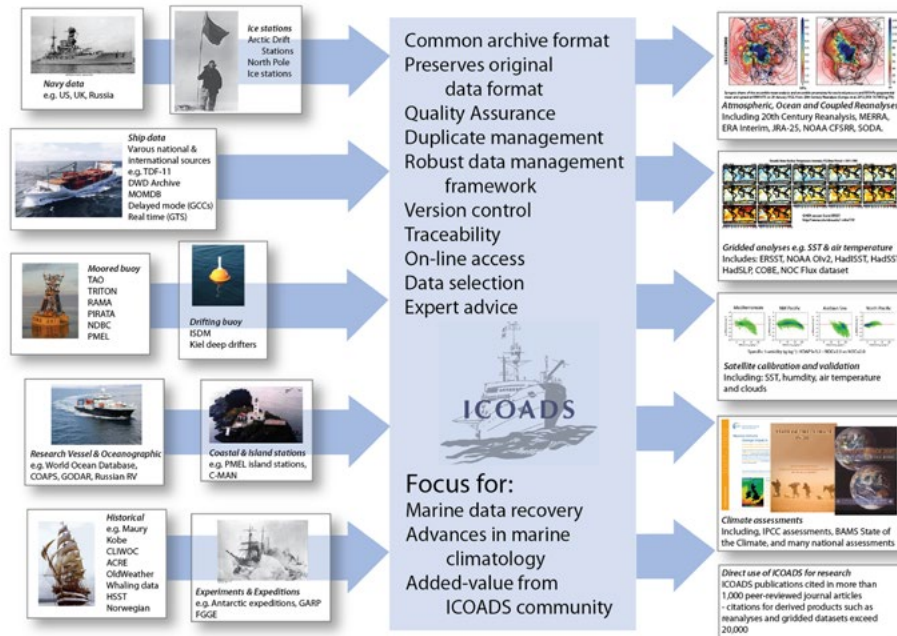
Under one major workplan element, we continued to refine the next version of the International Maritime Meteorological Archive format (IMMA1), which, together with its access software, is enhancing ICOADS data stewardship and access, and is also serving as a foundation for the associated ICOADS Value-Added Database (IVAD) project.

Under another major workplan element, we continued implementation of our new merged Global Telecommunication System (GTS) product. This combines GTS data from NOAA’s National Centers for Environmental Information (NCEI) and Environmental Prediction (NCEP), and, once fully operational, will provide ICOADS users with enhanced near-real-time “preliminary” monthly updates extending beyond the ending date of the latest delayed-mode update, presently release 2.5, covering 1662–2007.

Woodruff continued membership on the Expert Team on Marine Climatology (of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM)) and related groups.

He also participated in several international meetings: The 30<sup>th</sup> Session of the Data Buoy Cooperation Panel (October 27–31, 2014, in Weihai, China); led a JCOMM delegation to the National Marine Data and Information Service (NMDIS) (November 3–5, 2014, in Tianjin, China) to review China’s trial WMO-IOC (World Meteorological Organization-Intergovernmental Oceanographic Commission) Centre for Marine-meteorological and Oceanographic Climate Data (CMOC/China); and gave an invited presentation on ICOADS at a special U.K. Royal Meteorological Society seminar on “The Observational Legacy of Matthew Fontaine Maury for Climate

# Management and Exploitation of Geophysical Data



## The International Comprehensive Ocean-Atmosphere Data Set (ICADS)

Change and Variability” (April 15, 2015, in London, U.K.).

As a scientific organizing committee member, Woodruff was heavily involved in the Fourth JCOMM Workshop on Advances in Marine Climatology (CLIMAR-IV; June 9–12, 2014) Workshop, and First IVAD (June 13, 2014) Workshop, both held in Asheville, North Carolina.

## 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 & Objective

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

### Accomplishments

Three new data collections were published, and several others were updated, most notably, a sea ice concentration product for operational ice forecasting. This product meets a need for greater accuracy and higher resolution in ice concentration fields that are used

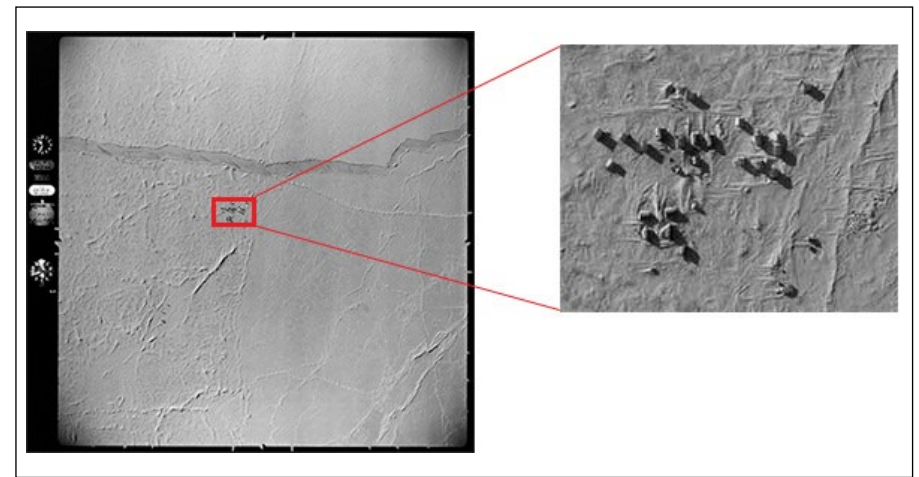
to initialize an operational sea ice forecast model. ([MASAM2: Daily 4 km Arctic Sea Ice Concentration, 2012–2014](#))

The Navy’s Project Birdseye reports and aerial photographs were published. From the early 1960s through the mid 1980s, the U.S. Naval Oceanographic Office and later the Naval Research Laboratory conducted approximately nine missions per year over arctic sea ice. These data document an Arctic sea ice cover very different than the one we have today. The collection is the subject of an [NSIDC Highlight story](#). ([Project Birdseye Aerial Photograph Collection: Digital and Analog Materials](#))

A historical data set of Canadian surface-climate observations was published. These data include solar time, wind speed, wind direction, dry-bulb, wet-bulb, and vapor pressure at 24 sites. NOAA@NSIDC is making the data available as part of an effort to help ensure the preservation of small data collections that are not part of a larger funded program, and that may receive wider use through documentation and distribution online. The data were prepared by a student at the University of Illinois Urbana-Champaign Graduate School of Library and Information Science as part of a course on the Foundations of Data Curation taught by NSIDC’s Ruth Duerr. (ClimoBase: Rouse Canadian Surface Observations of Weather, Climate, and Hydrological Variables, 1984–1998)

The Sea Ice Index data set has been updated with a reduced Arctic pole hole and improved Northern Hemisphere masks for removing spurious ice caused by residual weather effects. ([Sea Ice Index](#)).

More information can be found at <http://nsidc.org/noaa/news.html>,



Photograph from the Birdseye collection canister eighty-seven, frame twenty-seven shows an AIDJEX Camp on March 23, 1971. NSIDC

# 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 & Objective

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, observe the wind and turbulence structure in the atmospheric boundary layer, and investigate Arctic ocean plankton layers and harmful algae blooms.

We used the Tunable Optical Profiler for Aerosol and Ozone (TOPAZ) ozone lidar and the High Resolution Doppler Lidar (HRDL) lidar to characterize the vertical distribution and transport of ozone and to observe the boundary layer structure, including wind speed and direction profiles, turbulence, and boundary layer heights, during the Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ) and the Front Range Air



**NOAA Twin Otter airplane, with the downward-looking oceanographic lidar onboard, to study plankton layers in the Beaufort Sea north of Barrow, Alaska.**

Richard Marchbanks/CIRES

Pollution and Photochemistry Experiment (FRAPPÉ) studies in the Colorado Front Range. We analyzed the lidar data from the Colorado studies as well as the 2013 DISCOVER-AQ experiment in Houston, TX, and presented our findings at the American Geophysical Union fall meeting. One of the main objectives of the series of DISCOVER-AQ studies is to assess how well surface concentrations of air-quality-relevant atmospheric constituents can be measured from space using integrated column observations from satellites. To address this goal, we compared TOPAZ ozone lidar profiles that were vertically averaged over the lowest 1.5 km of the atmosphere with surface ozone observations. We found that column ozone observations were similar to the surface concentrations when the boundary layer was well mixed, generally from late morning through mid-afternoon. However, in the early morning and late afternoon, column ozone values were often significantly higher than those at the surface because of titration and deposition of ozone in the surface layer in the morning and the frequent advection of clean air in a shallow layer in the afternoon by the land-sea breeze or thunderstorm outflows.

Commercially available, autonomous Doppler wind lidars are becoming more widely used to probe the atmospheric boundary layer. However, a rigorous study of the error characteristics of wind lidars has been lacking. To fill this gap, we conceived and lead the Lidar Uncertainty Measurement Experiment (LUMEX). The HRDL lidar and several commercially bought Doppler wind lidars were deployed at the Boulder Atmospheric Observatory. We compared their observations and thoroughly characterized their uncertainty due to measurement errors and atmospheric variability. This experiment was followed up by the Experimental Planetary boundary layer Instrumentation Assessment (XPJA) to study single and multiple Doppler lidars' wind retrievals for measuring complex flows in and around wind farms.

The oceanographic lidar was deployed on a NOAA Twin Otter aircraft and flown out of Barrow, Alaska, to study plankton layers in the fresh water-salt water zone of the Beaufort Sea. Plankton layers play an important role in controlling many biological and biogeochemical processes in the oceans. Our observations provided new insights into the structure and dynamics of these arctic plankton layers. The oceanographic lidar was also flown over Lake Erie to characterize the extent and intensity of harmful algae blooms. Regional water district managers need this information because these algae blooms can force cities along Lake Erie to shut down water treatment plants.

# Regional Sciences and Application

## PSD-05: Prediction of Extreme Regional Precipitation and Flooding

■ CIRES Lead: David Kingsmill ■ NOAA Lead: Allen White  
 NOAA Theme: Climate Adaptation and Mitigation

### Goals & Objective

This project specifically addresses regional climate predictions.

### Accomplishments

Several research activities associated with this project were undertaken over the last year, which led to some interesting new findings. Precipitation forecasts from simulations of non-tropical storms over the southeastern United States were evaluated quantitatively. The results of this analysis suggest that the best forecasts occur in association with events having a relatively small amount of precipitation, a relatively small amount of conditional instability, and a relatively large amount of horizontal water-vapor transport.

In addition, southern Sierra orographic precipitation output from two different Weather Research and Forecasting (WRF) model simulations (one run continuously for 13 years and one run in discrete five-day simulations) were verified with results indicating that precipitation output from the discrete five-day simulations did not improve on the one-time initialized simulation.

Finally, parameterizations of cloud and precipitation microphysics in WRF simulations of a winter storm making landfall in northern California were evaluated. Output from simulations using the microphysics scheme employed operationally by the National Weather Service produces a spatial pattern of precipitation characterized by unrealistically large horizontal gradients.

The project also engaged in the development of tools to advance knowledge of extreme regional precipitation and flooding. Displays of hydrometeorological data were enhanced by adding a new web interface for advanced querying capabilities of observations collected by ESRL's PSD (figure). Additionally, the Hydrology Laboratory-Research Distributed Hydrologic Model was integrated with the Community Hydrologic Prediction System-Flood Early Warning System for the Russian and Napa River watersheds. This system can now automatically retrieve various forecasts, such as precipitation, river discharge, and soil moisture.

The screenshot shows the ESRL PSD web interface. At the top, it displays the NOAA logo and the text 'U.S. Department of Commerce | National Oceanic & Atmospheric Administration | NOAA Research'. Below this is the 'Earth System Research Laboratory Physical Sciences Division' header. The main content area is divided into several sections: 'Image Products', 'Data and Image Archive', 'Data and Image Downloads', 'Site Information', and 'Instruments'. A central map of the United States shows various sites marked with red dots. To the right of the map is a list of instrument categories with a search bar. Below the map is a table with columns for Site ID, Data Type, Name, Start Date, End Date, Active, Realtime, Realtime Directory, Data Date, and View/Format. The table lists several sites, including 'Radar 915MHz-Weber Wuertz' and 'Radar 915MHz-Bright Band'. Annotations with red arrows point to the filtering options on the right and the table below the map.

Screen capture of the web interface for display of data from observations collected by ESRL/PSD.

# Scientific Outreach and Education

## GSD-02: Science Education and Outreach, Science On a Sphere®

■ CIRES Lead: Elizabeth Russell ■ NOAA Lead: John Schneider  
NOAA Theme: NOAA Engagement Enterprise

### Goals & Objective

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

### Accomplishments

The year started off with a Science on a Sphere® (SOS) Users Collaborative Network Workshop at the Science Museum of Minnesota. The SOS team introduced the workshop attendees to new features that had been recently released, including usage statistics and live streaming picture-in-a-picture for use with SphereCasting, and

unveiled a flatscreen version of SOS for the classroom in active development. The SOS team left the workshop with many ideas for their next software release. After many months of work, including a data catalog reorganization, major updates to the iPad app, implementation of automated alignment, and many enhancements, a new version of the SOS software was released in March 2015.

An ongoing goal of the SOS team is to broaden the reach of the program through new

installations and traveling exhibits. During the last year, SOS was installed in 12 new locations, including six new countries! The traveling SOS was part of three exhibits, including the Our Ocean conference hosted by the U.S. State Department. Floorplans for different configurations were also developed to allow SOS to fit into more spaces. We also conducted quarterly SOS Education Forum webinar meetings between network educators to promote more creative use of the sphere in museum education.

The second annual SOS teachers' workshop was held in July 2014 for elementary school teachers. At the workshop, they were introduced to a desktop version of SOS called SOS Explorer and were able to create lessons with it and provide valuable feedback for future development. Teachers at conferences throughout the year were also introduced to the SOS Explorer (i.e., the National Science Teacher's Association national conference in Chicago, Illinois, and the Colorado Science Conference in Denver, Colorado). Feedback on the necessary features of SOS Explorer was solicited through the NOAA Education and Climate Stewards Education Project teacher networks as well.

TerraViz has been focused on improving and stabilizing existing feature-sets as it matures from a research project to a licensed and distributed software application. NEIS was released for the High Impact Weather Prediction Project pilot program this year. New capabilities developed in TerraViz are a new intuitive user interface, improved search capabilities, display of multiple globes and data visualizations at once, algorithm processing to compare models, real-time point observations, seamless high-resolution (64k) map tiles, and an improved annotation tool.



**Hilary Peddicord, SOS Education Specialist, talks to Boulder middle school students about the Colorado Floods of 2013 using the new classroom tool, SOS Explorer.**

Anthony Arena/Casey Middle School

# Scientific Outreach and Education

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

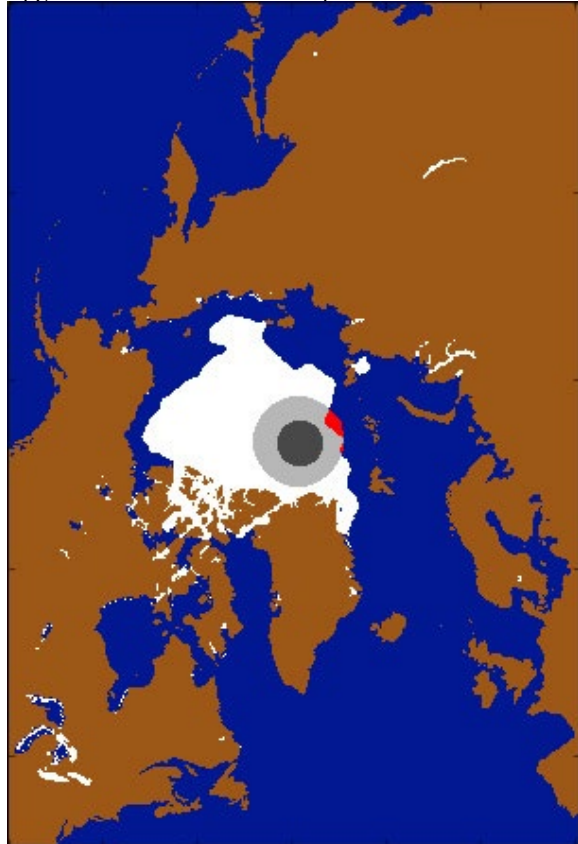
■ CIRES Lead: Florence Fetterer ■ NOAA Lead: Eric Kihn  
NOAA Theme: NOAA Engagement Enterprise

### Goals & Objective

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

### Accomplishments

While we were not able to move to daily updates for the NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration, we were able to update and upgrade the code base for this product, which was a necessary first step. We also updated



the code and documentation for the new Special Sensor Microwave Imager/Sounder (SSMIS) pole hole and for new northern National Ice Center Valid Ice masks.

An image from the Sea Ice Index online documentation illustrates the change in the pole hole. The red area shows where open water has crept into the boundary for the old pole hole (light grey circle) for September 22, 2009, whereas the new pole hole (dark grey) is small enough to not cut off this open water. NSIDC

## NSIDC-02: Update and Maintain Education Resources for the Cryosphere

■ CIRES Lead: Florence Fetterer ■ NOAA Lead: Eric Kihn  
NOAA Theme: NOAA Engagement Enterprise

### Goals & Objective

This project brings unique reference materials to educators and researchers.

### Accomplishments

With Jack Maness (Associate Professor and Director of Science Libraries at the University of Colorado Boulder), we submitted a proposal titled “Revealing Our Melting Past: Providing an Sustainable Future” for the Roger G. Barry National Snow and Ice Data Center Archives to the Council on Library and Information Resources. Unfortunately it was not funded, so we will try again.

The Glacier Photograph Collection is an important part of our archive. With the help of an intern from the World Glacier Monitoring Service in Zurich, Switzerland, we added glacier photographs and corrected metadata for the online portion of the collection.



One of the glacier photographs, this one from the Langtang Valley, Nepal, that will be added to the online Glacier Photograph Collection through the work of the World Glacier Monitoring Service intern. Pascal Buri/CIRES



## 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 & Objective

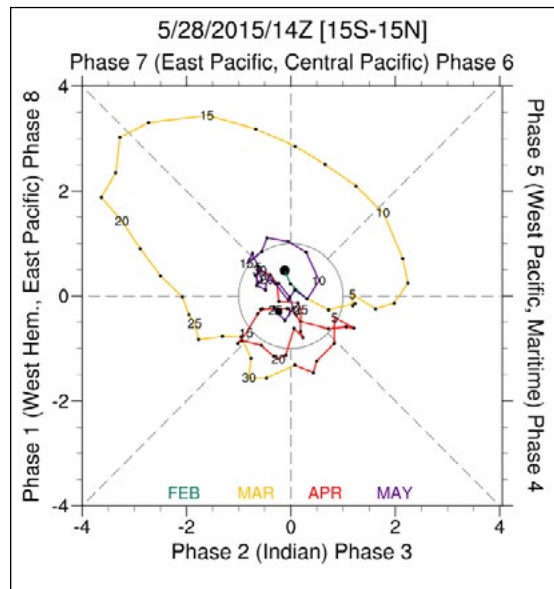
This project addresses regional use of climate information.

### Accomplishments

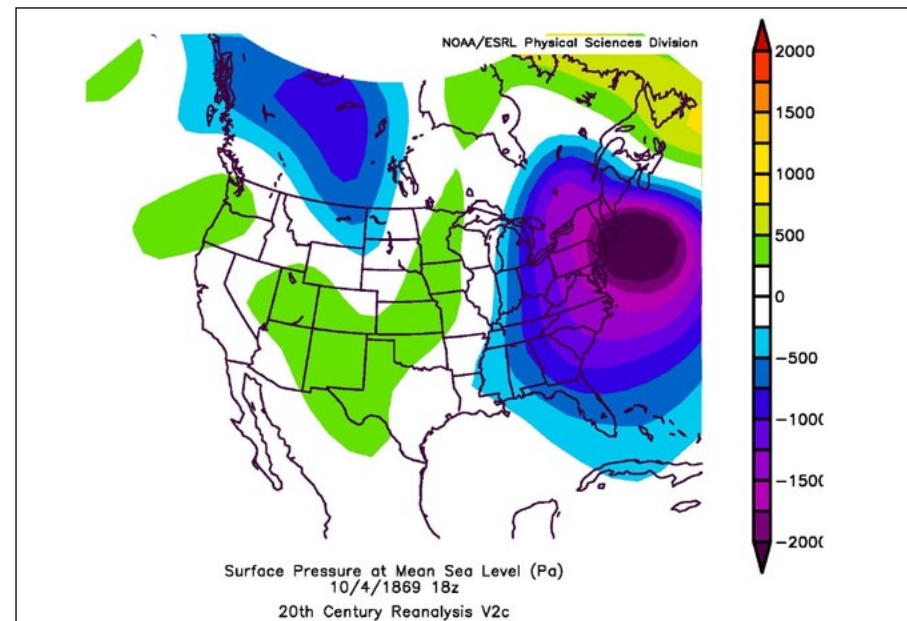
We have created a set of Madden-Julian Oscillation (MJO) time series that quantifies current and historic MJO activity. The indices include a historic Outgoing Longwave Radiation (OLR) MJO Index (OMI) and an updated Real-time OLR MJO Index (ROMI). These use the new NOAA Outgoing Longwave Radiation-Daily Climate

Data Record (OLR-Daily CDR) analyzed 1979–2013 dataset, combined with current OLR data. The current phase of the MJO is shown in figure 1. The webpage is <http://www.esrl.noaa.gov/psd/mjo/mjoindex/>

The 20<sup>th</sup> Century Reanalysis dataset has been updated to version V2c. Our plotting and analysis web tools are able to access this version. V2c starts in 1851 and includes improved sea surface temperature and ice boundary conditions and more input observations. In figure 2, the famous “Saxby Gale” of 1869 is illustrated with the surface pressure anomaly map for that time. CIRES has hourly, daily, and monthly climatologies available and users can use OPeNDAP (Open-source Project for a Network Data Access Protocol) to access the data in addition to the web tools and the FTP-able files.



**Figure 1. A phase diagram of the February–May 2015 MJO index. The color of the line indicates the date and the position of the point indicates the relative contributions of the two EOFs (empirical orthogonal functions), indicating what phase the MJO is in.** Courtesy of Catherine Smith/CIRES



**Figure 2. Surface pressure anomaly during the famous “Saxby” Gale October 4, 1869, a tropical storm which caused much devastation along coastal New Brunswick, Canada.**

Courtesy of Catherine Smith/CIRES

# Space Weather Understanding and Prediction

## NGDC-06: Satellite Anomaly Information Support

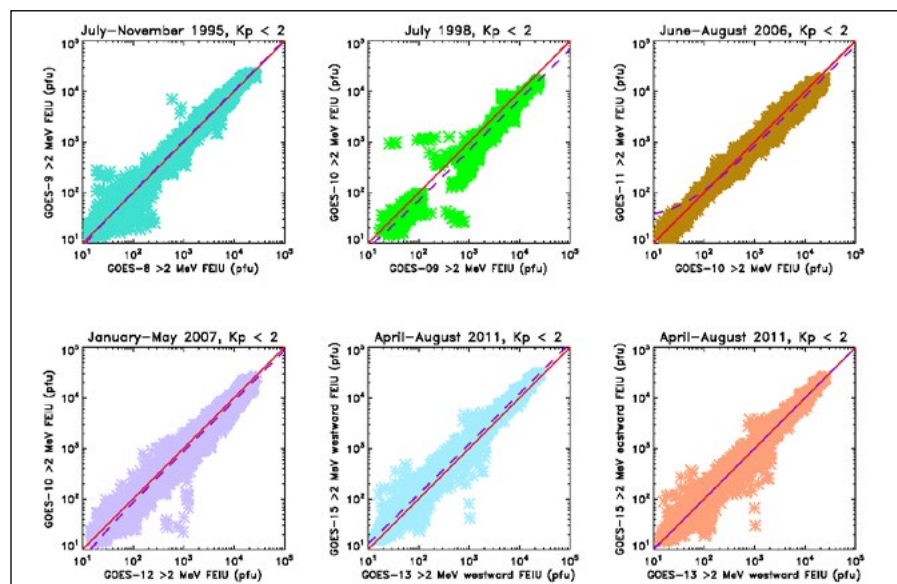
■ CIRES Lead: Juan Rodriguez ■ NOAA Lead: Bill Denig  
NOAA Theme: Science and Technology Enterprise

### Goals & Objective

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 (SAIS) project involves the development of products and services that provide situational awareness for satellite operators and that support improved space weather and space climate models. NOAA has monitored radiation belt electrons as an important space weather hazard at geostationary orbit and in polar orbit since the 1970s. Charge can build up to dangerous levels on



**On-orbit cross-calibrations of GOES >2 MeV electron measurements, taking advantage of opportunities when two satellites were separated by an hour in local time or less. The geophysical scatter in the comparisons is reduced during periods of low geomagnetic activity (here, represented by the index  $K_p < 2$ ).** Juan Rodriguez/CIRES

satellites that are exposed to elevated mega-electron-volt (MeV) electron fluxes. The resulting discharges can cause satellite anomalies including false signals and physical damage. During this year, the work by CIRES on SAIS focused on the reprocessing and validation of long-term radiation belt electron data from NOAA's geosynchronous and polar-orbiting satellites.

Since 1995, the Geostationary Operational Environmental Satellites (GOES) have measured radiation belt electrons using a series of instruments of the same design. This year, CIRES reprocessed the >0.8 and >2 MeV electron channels using the same calibration coefficients and dead-time corrections. The reprocessing included the calculation of error bars and flagging of excess contamination. This and other space weather data sets reprocessed by NGDC/NCEI were highlighted in an article in *Space Weather* (Redmon et al., 2015).

The reprocessed data were used in an extreme value analysis of nearly 20 years of >2 MeV radiation belt electron fluxes (January 1, 1995 to June 30, 2014), led by the British Antarctic Survey (Meredith et al., 2015). The primary purpose of this work was to estimate the 1-in-10, 1-in-50, 1-in-100, and 1-in-150 year daily averaged >2 MeV electron fluxes at the GOES East and GOES West locations. It found that the largest flux observed during this period was a 1-in-50 year event. An essential part of this study was a cross-calibration by CIRES of the reprocessed data from several GOES satellites, which found that they agreed to within 30 percent, a negligible error in the context of the >5 orders of magnitude variability in the >2 MeV radiation belt fluxes.

In collaboration with the CU-Boulder Laboratory for Atmospheric and Space Physics, CIRES and NGDC/NCEI achieved a major advance in the reprocessing of MEPED (Medium Energy Proton/Electron Detectors) data from five NOAA POES (Polar-orbiting Operational Environmental Satellites) and two EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites) MetOp satellites (Peck et al., 2015). While MEPED measures radiation belt electron fluxes in four integral energy channels, the scientific community increasingly needs estimates of the differential flux energy spectrum. The method of Peck et al. (2015) corrects the electron measurements for proton contamination and estimates the spectrum and associated error bars using a non-linear least squares minimization technique. The reprocessed data set starts in 1998 with the launch of NOAA 15.

### References

Meredith, N. P., Horne, R. B., Isles, J. D., & Rodriguez, J. V. (2015). Extreme relativistic electron fluxes at geosynchronous orbit: Analysis of GOES E>2 MeV electrons. *Space Weather*, 13, 170–184. doi: 10.1002/2014SW001143

Peck, E. D., Randall, C. E., Green, J. C., Rodriguez, J. V., & Rodger, C. J. (2015). POES MEPED differential flux retrievals and electron channel contamination correction, *Journal of Geophysical Research Space Physics*, 120. doi:10.1002/2014JA020817

Redmon, R. J., Rodriguez, J. V., Green, J. C., Ober, D., Wilson, G., Knipp, D., Kilcommons, L., & McGuire, R. (2015). Improved polar and geosynchronous satellite data sets available in Common Data Format at the Coordinated Data Analysis Web, *Space Weather*, 13, 254-256. doi: 10.1002/2015SW001176

### SWPC-01: Space Weather Information Technology and Data Systems

■ CIRES Lead: David Stone ■ NOAA Lead: Steven Hill  
NOAA Theme: Science and Technology Enterprise

#### Goals & Objective

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.

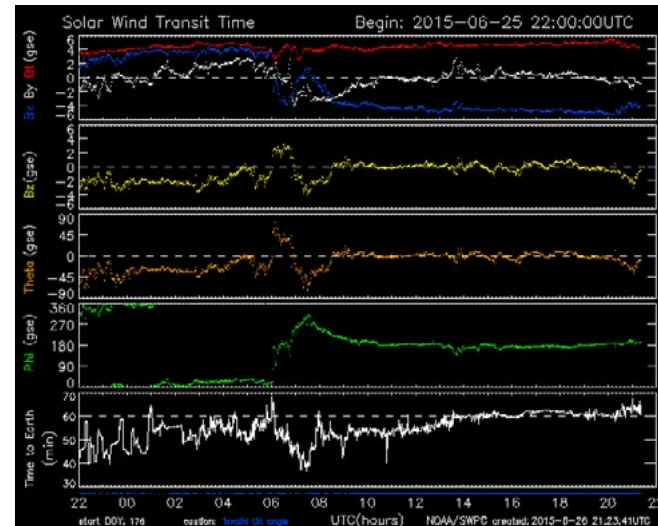
#### Accomplishments

CIRES staff in the Space Weather Prediction Center (SWPC) successfully managed a half-dozen developers through the operational release of SWPC's new public website. This new website required the completion of numerous new space weather product pages, major style and navigation improvements, data delivery service upgrades, and extensive Web Operations Center (WOC) coordination. The new site averages 500,000 users and more than 1.5 million page views per month.

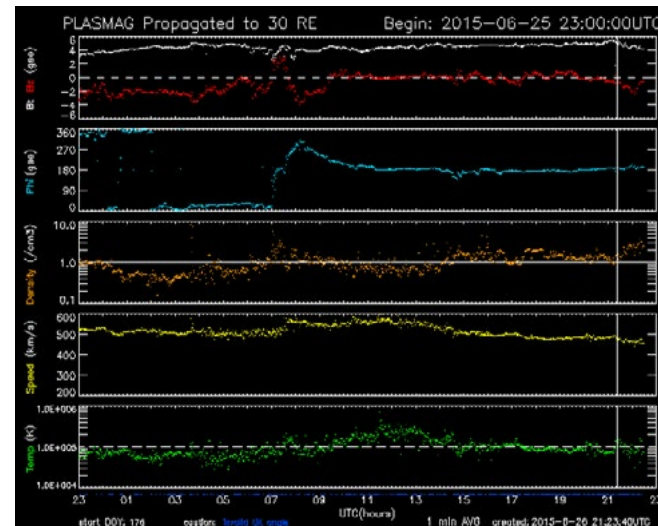
We also supervised multiple full tests of the new Alternate Processing Site (APS) for SWPC's Continuity of Operations (COOP) plan. These tests included the take-down of all operational processing here at SWPC's Boulder campus, and relocating the processing to a facility in Washington, D.C., within two hours. Further, the tests required us to maintain all space weather prediction capacity while remaining in APS mode for extended periods.

We successfully delivered the Deep Space Climate Observatory (DSCOVR) ground system into operations. We supported the launch and early operations of the DSCOVR mission. We provided test support, bug fixes, and enhancements to the system as required, through delivery of the satellite into L1 orbit. We released three new web data plots to support the transition of solar wind data from the aging Advanced Composition Explorer (ACE) satellite to the DSCOVR satellite: Predicted Solar Wind at Earth, Real Time Solar Wind and Solar Wind Transit Time (see figure).

We sponsored the introduction of Git as a distributed revision control and source code management system. We transitioned all of one software development team's Subversion software code repositories to Git, simplifying code control, improving reliabil-



**Solar Wind Transit Time model output, showing 24 hours of magnetic field and solar wind plasma data, as made available to the public at the [SWPC website](#).**



**Predicted Solar Wind at Earth model output, showing 24 hours of magnetic field & solar wind plasma, as made available to the public at the [SWPC website](#).**

# Space Weather Understanding and Prediction

ity, decreasing the repository size, and significantly improving team code reviews. We led efforts to have Git adopted as our organization's source code management system of choice and organized lab-wide training.

We provided timely operational support for the following critical systems and maintained high customer satisfaction:

- ACE processor
- Geostationary Environmental Satellite (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

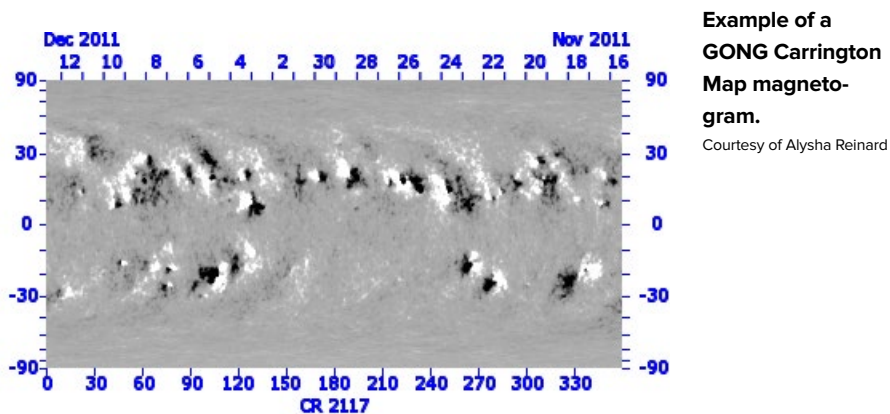
■ CIRES Lead: Alysha Reinard ■ NOAA Lead: Vic Pizzo  
NOAA Theme: Weather-Ready Nation

### Goals & Objective

This project will advance preparedness for solar storms affecting communication, transportation, and other U.S. infrastructure.

### Accomplishments

We investigated the discovery that helicity is oppositely directed in the Northern and Southern Hemispheres. We found a similar dichotomy in the Eastern and Western Hemispheres that we needed to investigate to ensure that there was not a systematic



observational effect. It was found that the north/south feature was much stronger than the east/west feature, indicating that, though there is a systematic effect, there is also a real, solar effect. The figure shows an example a GONG Carrington Map magnetogram. This type of image uses data collected over the course of a full solar rotation (27 days) to construct a map of the magnetic field of the entire sun. In this image, the dark areas show strong negative flux, while the bright areas show strong positive flux. These strong flux regions are most likely to erupt as flares or coronal mass ejections. This map is used as an input to the WSA-Enlil model which predicts the details of the solar wind that will pass the Earth.

These results are being incorporated into a publication that will be submitted next year.

## 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 & Objective

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

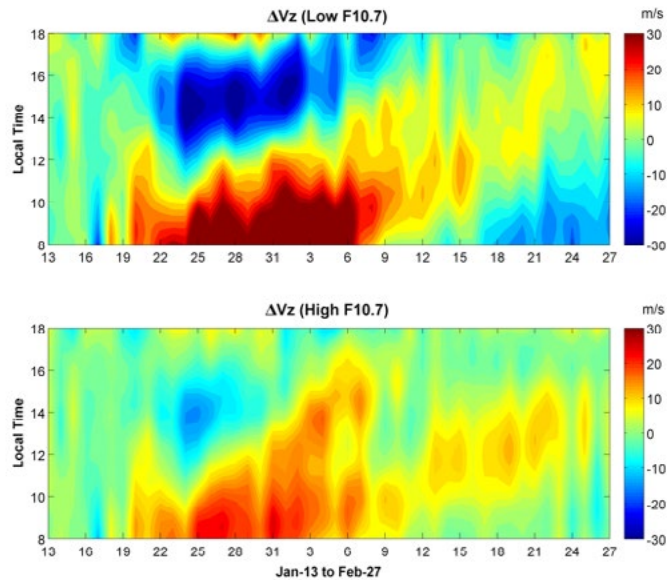
### Accomplishments

This year, we were able to use the Whole Atmosphere-Global Ionosphere Plasmasphere (WAM-GIP) model to anticipate what the response to a sudden stratospheric warming (SSW) might be at higher solar activity. WAM-GIP was run at high solar activity conditions, using the same lower atmosphere conditions as present in the January 2009 SSW event. The simulations indicated the amplitude and phase of migrating tides in the dynamo region during the event had similar magnitudes for both solar flux conditions. However, comparing the ionospheric responses to a major SSW under low and high solar activity, we found that the ionospheric changes were less at high solar activity. Figure 1 shows that the change in the dayside vertical plasma drift at the magnetic equator during the event at higher solar activity (lower panel) was significantly less than at low solar activity (upper panel). Simulations from our test runs showed that it is the increase in the ionospheric conductivity that decreases the ionospheric response. Firstly, the increase in F-region conductivity allows the closure of E-region currents through the F-region, reducing the polarization electric field before noon. Secondly, the F-region dynamo contributes an upward drift post noon, which helps maintain upward drifts until after sunset. So the different response at high solar activity is due to the conductivity changes, and not due to changes of the neutral winds. With weaker upward plasma drifts, we expect the relative ionospheric plasma density changes to be smaller at high solar activity. In absolute terms, the change could

be bigger simply due to larger electron content at high solar activity. The response appeared reasonably consistent with observations during the 2013 SSW, which occurred at higher solar activity.

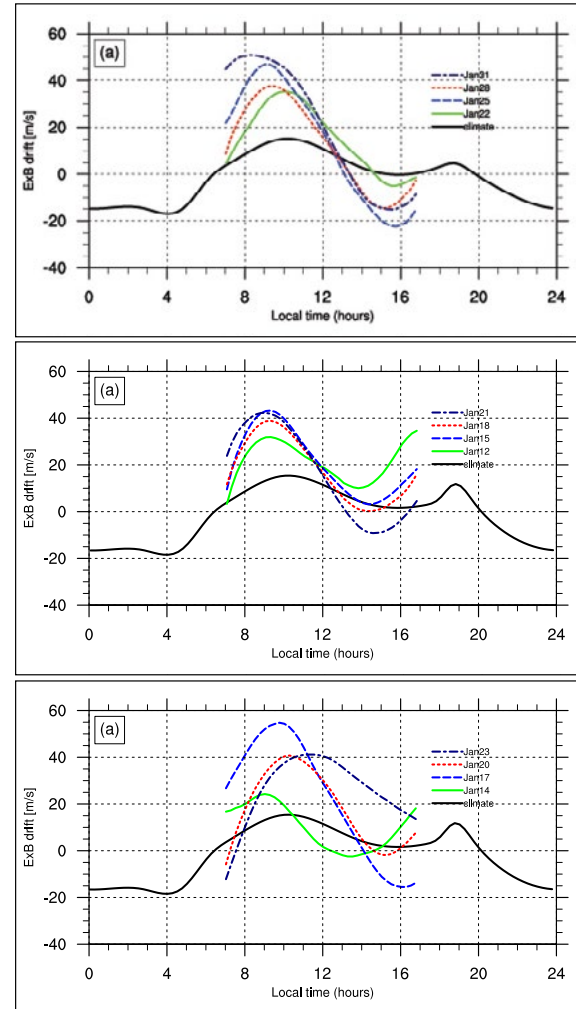
The coupled model was also used to simulate the response to the January 2012 and 2013 periods when two SSWs occurred. The two SSW periods were quite different. The 2012 SSW was a planetary wave one event, when the stratospheric polar vortex was offset from the geographic pole. The 2013 warming was a planetary wave two event, where the stratospheric vortex split into two. Another difference between the

two periods was the change in solar and geomagnetic activity. The contrasting stratospheric dynamics, together with the changing solar and geomagnetic activity, make the two periods challenging to simulate. The event in 2013 with a split vortex appeared to show some of the same characteristics as the record-breaking 2009 event, which was also a split vortex event with a strong increase in planetary wave number two.



**Comparison of dayside vertical plasma drift for a sudden stratospheric warming occurring at either low (upper panel) or high (lower panel) solar activity. There is a significant reduction in the magnitude at high solar activity so we expect the relative change in the ionospheric response to be smaller.**

Courtesy of Timothy Fuller-Rowell, CIRES



**Comparison of vertical plasma drift at the magnetic equator on selected days for the three sudden stratospheric warmings in 2009 (top), 2012 (middle), and 2013 (bottom). Similar responses are seen in 2012 and 2013 despite the higher solar activity.**

Courtesy of Houjun Wang/CIRES

# Stratospheric Processes and Trends

## CSD-09: Stratospheric Radiative and Chemical Processes That Affect Climate

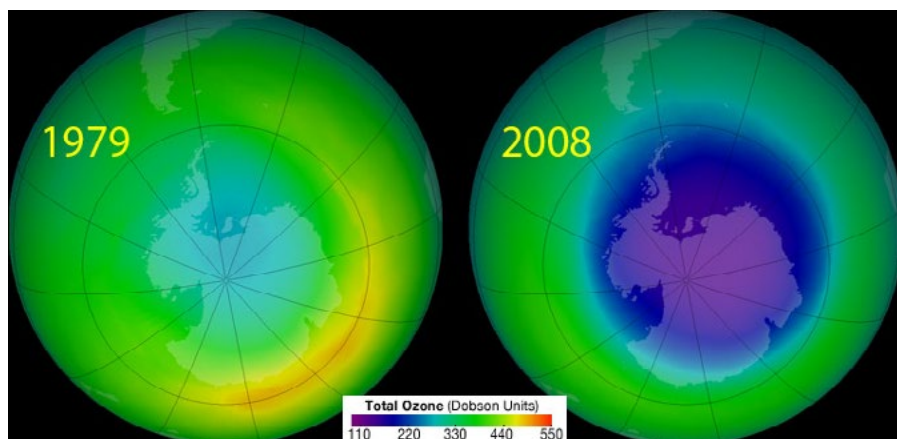
■ CIRES Lead: Sean Davis ■ NOAA Lead: Karen Rosenlof  
NOAA Theme: Climate Adaptation and Mitigation

### Goals & Objective

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

One theme of this project is improving past estimates of stratospheric ozone depletion for improved understanding of ozone-caused climate impacts. In 2014, the Stratospheric Water Vapor and Ozone Satellite Homogenized (SWOOSH) data set, a CIRES/CSD-led data record of ozone and water vapor, participated in an international dataset intercomparison activity (Tummon et al., 2015; Harris et al., 2015). These CIRES/CSD-authored papers intercompared numerous ozone data sets, and showed that unambiguous detection of ozone recovery is not yet possible. Also, in early 2015, the Binary Database of Profiles (BDBP), another CIRES/CSD-developed ozone data set, was officially archived as a climate data record at the NOAA National Climate Data Center.



Ozone concentrations over Antarctica in October 1979 and October 2008. The ozone hole is the large purple and blue area in the 2008 image. NASA

CIRES/CSD also used the BDBP data set as input to a climate model to study the climate impact from stratospheric ozone depletion since 1980. We found that the BDBP ozone caused a significantly stronger climate response than the dataset used in the Intergovernmental Panel on Climate Change (IPCC) assessments. Our work suggests that the IPCC models have underestimated past climate changes due to stratospheric ozone depletion (Young et al., 2014). In a separate study (Neely et al., 2014), we showed that the IPCC models further underestimate climate impacts because they use coarse time resolution data as input and fail to capture the rapid ozone depletion that occurs during October. Together, these studies point towards an increased role for stratospheric ozone depletion in driving recent climate changes.

Using a trajectory model, reanalysis data, and the SWOOSH water vapor data, CIRES/CSD identified the primary causes of variations in stratospheric water vapor over the past decades (Dessler et al., 2014). By disentangling the competing variations due to tropospheric temperature and stratospheric circulation changes, we showed a lack of long-term trend in water entering the stratosphere, in contrast to balloon-borne observations made from Boulder. The reason for this discrepancy is still a mystery, and ongoing work is aimed at reconciling these conflicting results.

In addition, CIRES/CSD also studied variability and long-term change in the stratospheric circulation. Climate models predict that the stratospheric circulation strength will increase in response to climate change. Several previous studies have pointed to a discrepancy between model-predicted increases in stratospheric circulation and observations, which don't show a speeding of the circulation. Our study presents a new analysis of the observational data to better explain the discrepancy (Ray et al., 2014).

## GMD-02: Analysis of the Causes of Ozone Depletion

■ CIRES Lead: Irina Petropavlovskikh ■ NOAA Lead: Russ Schnell  
NOAA Theme: Climate Adaptation and Mitigation

### Goals & Objective

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

For all NOAA-GMD stations, we evaluated results of homogenization of historical ozone profile datasets. The reprocessing procedure, based on ozonesonde laboratory tests and intercomparison campaigns, involves applying corrections for sensor cell

backgrounds, sensor solution composition changes, radiosonde pressure offsets, and air pump flow rate humidity. Validation of the long-term changes in the homogenized ozone columns was accomplished through comparisons between integrated ozonesonde profiles and Dobson column measurements at several NOAA stations, where both types of measurements have been routinely performed since the 1980s. This project is aimed at preparing historical datasets for trend analysis, which is coming in FY16. Data were archived at the NOAA ESRL Global Monitoring Division ftp site (<ftp://aftp.cmdl.noaa.gov/data/ozwv/Ozonesonde/>) and submitted to the Network for the Detection of Atmospheric Composition Change (NDACC) archive at <http://www.ndsc.ncep.noaa.gov/data/> for further distribution.

NEUBrew (NOAA-EPA Brewer Spectrophotometer UV and Ozone Network) Mark IV Brewers were refurbished and upgraded during the summer of 2014. In the past, problematic NISO<sub>4</sub> filters have challenged the stability of ozone and UV measurements in the network; we replaced these with new thermally stable crystal, to better

maintain stable measurements. Ozone calibrations traceable to the World Meteorological Organization triad of NEUBrew instruments were performed in fall 2014. Ozone data record at six NOAA sites was continued. Comparisons with co-located Dobson Umkehr and ozonesondes profiles is ongoing in Boulder to verify the consistency of the nine years of measurements, and to check for possible shifts in the data processing after applying new constants.

Dobson Total Column Ozone (TCO) measurements continued at 13 WMO-supported sites during the first months of 2015. At the time of this writing, there appears to be interest in resuming measurements at another site in Tallahassee, Florida. In addition, balloon-borne ozonesonde profile launches were continued at 10 stations nationally and globally through the first half of 2015 to support the WMO ground-based ozone observation network. The work is dedicated to monitoring the health of the ozone layer and changes due to manmade chemicals and natural processes. The data are also used to provide continuous ground-based verification of the performance

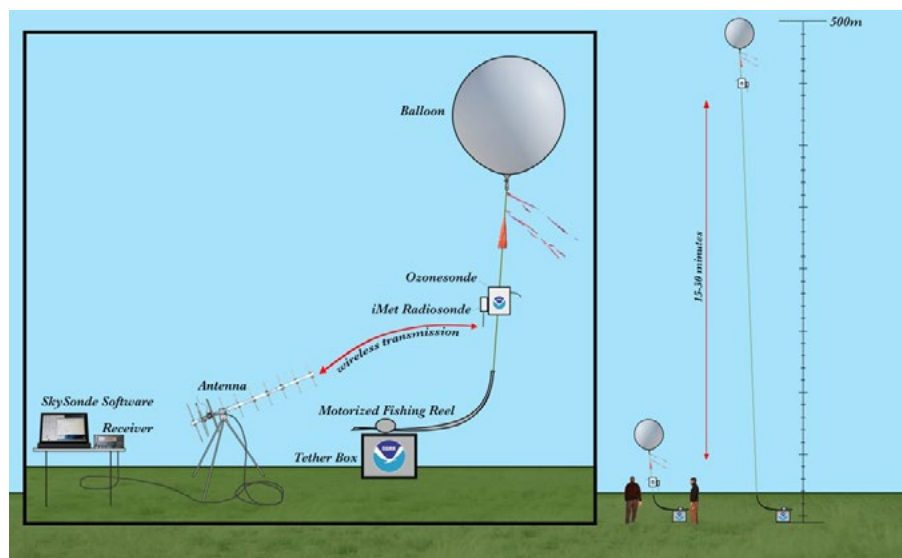


Figure 1. Schematic diagram of NOAA/GMD tethered ozonesonde system. CIRES/NOAA

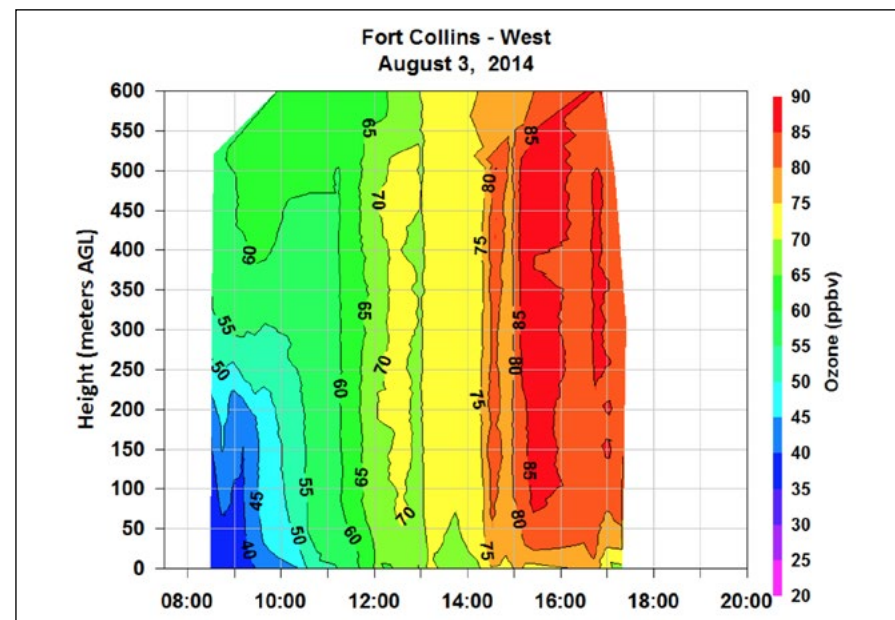
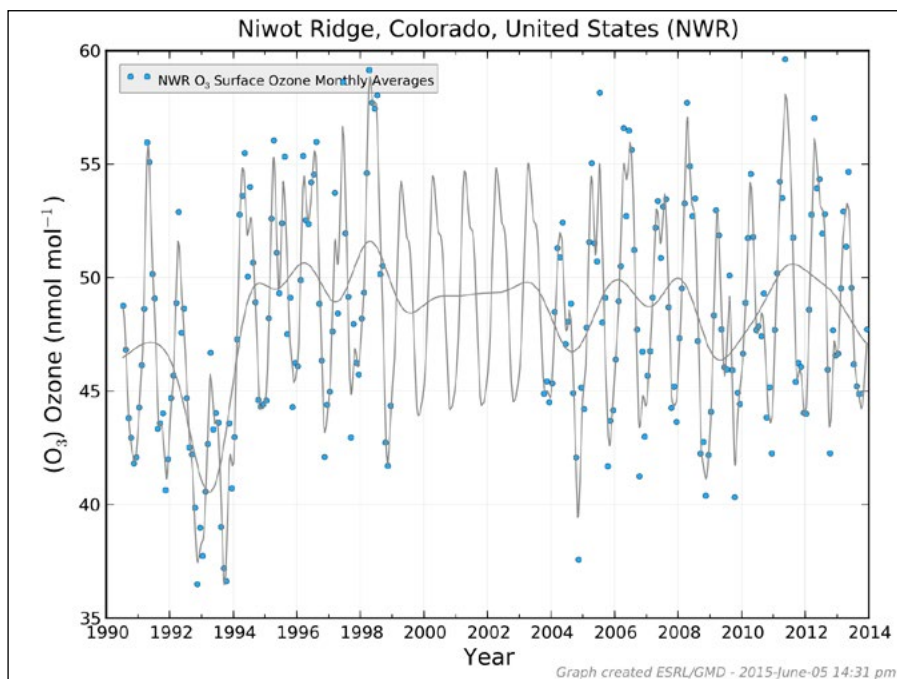


Figure 2. Ozone contour plot generated from 53 tethered ozonesonde profiles during FRAPPÉ at the Fort Collins-West site on August 3, 2014. CIRES/NOAA

## Stratospheric Processes and Trends

of satellite-based ozone datasets (i.e., JPSS/OMPS). To produce data in near-real-time, a new automation system was installed at Fairbanks, Alaska, in March 2015 that allows for automated data collection. Boulder, MLO, Lauder, and OHP stations had new automation systems installed in 2009, 2010, 2012, and 2014 respectively.

World standard Dobson #083 resides in the Global Monitoring Division and is used to calibrate local network and regional standards for traceability of the WMO ozone network. Every two years, the calibration of this instrument is checked by the Langley technique at the GMD observatory in Mauna Loa, Hawaii. In 2014, it showed less than a 0.5 percent change. It is important to keep the record free of instrumental interferences and produce necessary corrections to the record after calibration. During late May 2015, world standard Dobson #083 was shipped to the Polytechnische Institute at Braunschweig, Germany, where tunable lasers were used to more accurately define the light band-passes used to infer TCO. The initial results are quite promising and we hope to publish a collaborative paper on this topic in 2016.



**Figure 3. Time series of surface ozone monthly averages (dots) measured at the NOAA/GMD Niwot Ridge C1 site. The seasonal cycle and long-term variability in the time series are shown as cyclical and flattened grey lines respectively.** CIRES/NOAA

The year-worth of total ozone data from 13 Dobson stations was processed by GMD personnel at the end of the physical year (i.e., 2014 and 2015) and archived locally at NOAA and at the WMO ozone and UV archive center in Canada (WOUDC).

NOAA/GMD and CIRES personnel operated tethered ozonesondes at three sites during the FRAPPÉ (Front Range Air Pollution And Photochemistry Experiment) field campaign in July-August 2014. FRAPPÉ intensive field measurements help to investigate causes for high ozone levels in Colorado's Front Range that exceed EPA's standard. Measurements were coordinated with NASA's DISCOVER-AQ (Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality) aircraft and field campaign held in Colorado for the same time period. This was a collaborative effort with the Colorado Department of Public Health and the Environment (CDPHE), CU-Boulder, and Colorado State University (CSU). The low-cost, mobile, tethered ozonesonde, shown in Figure 1, was initially developed, including control software, at GMD for monitoring the ozone formation from surface to 300 meters altitude within the Uintah Basin during air quality measurement campaigns in 2012 and 2013. GMD provided hourly measurements of highly resolved vertical ozone profiles made with the ozonesondes on the tethered systems in three locations along the Front Range. Figure 2 shows an example of a full day of tethered measurements summary at the Fort Collins-West site. The report was submitted to the CDPHE in December 2014. The tethered method allows us to track and probe pockets of elevated ozone airmasses produced by pollution over the gas and oil fields and transported to the Denver and Boulder areas by very complex meteorological circulation caused by proximity to the Colorado Mountain range.

Ozonesondes were also used in July 2014 and prior to the DISCOVER-AQ campaign for validation of several ozone lidars, including the ESRL Chemical Sciences Division TOPAZ instrument. Several ozonesonde balloon launches were made, collecting profiles up to 15 km in altitude. The balloon was cut off to retrieve instruments for further use.

The NOAA surface ozone program has been monitoring near-ground ozone levels in Erie, Colorado, since 2008 (at BAO) and at the CU-Boulder Niwot Ridge research station since 1996 (Figure 3). The work to produce a climatology of ozone variability at rural and mountain stations was performed with special emphasis on extreme events in ozone levels. High levels of ozone at the mountain stations at an altitude of 3.5 km were used to track background ozone levels in contrast to locations near gas and oil fields in the Denver Julesburg basin. The BAO tower has continuous ozone measurements at 300 m and 6 m. It is complemented with wind speed, wind direction, and relative humidity measurements. All data were submitted to the FRAPPÉ/DISCOVER-AQ campaign corresponding archives and shared with other investigators and public. The paper is in preparation.



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

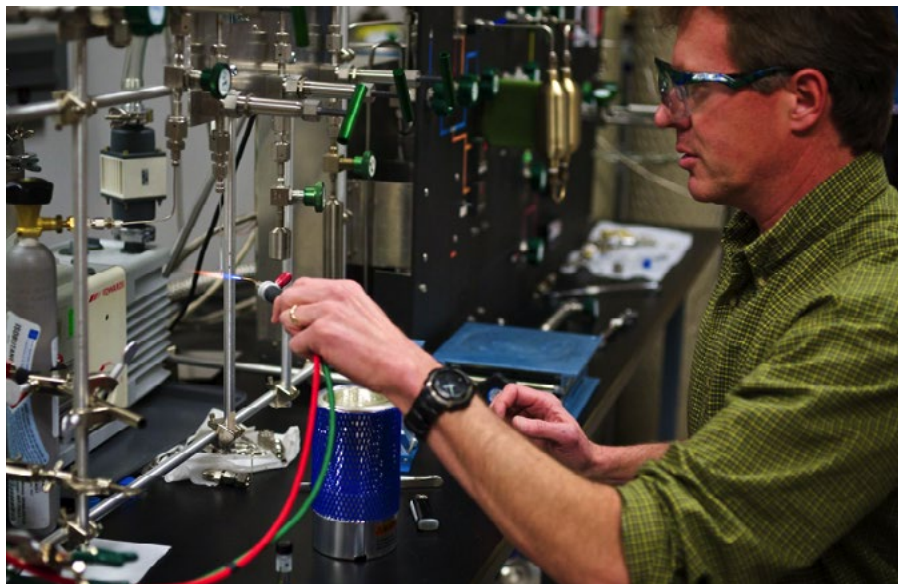
■ CIRES Lead: Fred Moore ■ NOAA Lead: James W. Elkins  
NOAA Theme: Climate Adaptation and Mitigation

### Goals & Objective

This project provides both long-term global surface data sets and correlated vertical.

### Accomplishments

Our work and accomplishments are tied to our long-term global observations derived by the two surface networks mentioned above and from light aircraft profiles conducted at ~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), both of which were updated in spring 2015. These data are integral to the United Nations Environment Programme/World Meteorological Organization "Scientific Assessment of Ozone Depletion" report. A new Gas Chromatograph Mass Spectrometer (GCMS) named Perseus has been tested for stability and accuracy, and compared with the legacy M2 and M3 GCMSs and initial air



This manifold is used to prepare custom gas standards of ozone-depleting compounds in support of GMD measurement programs. Fred Moore/CIRES

sample measurements have begun. We anticipate that the increased throughput, higher precision and accuracy, and the additional measurements 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, this year we proceeded with analysis of data from the NASA Airborne Tropical Tropopause Experiment (ATTREX-3) campaign, based primarily out of Guam and California, which focused on the tropical convective processes near the warm pool and other areas of the tropical Pacific. These processes define transport of water vapor and ozone depleting gases into the Tropical Tropopause Layer and the stratosphere. Our airborne programs help define the processes that connect 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 are especially well suited to analysis by 3-D models. Our in-house standards and calibration capabilities allow us to test instruments and methods in ways that would be much more difficult if such capabilities did not exist (e.g., we are able to explore non-linear instrument response and possible artifacts). Extra effort was taken this year to improve the SF<sub>6</sub>, CH<sub>4</sub>, and CO standards. Emissions studies and global-local process oriented studies continue to be aided by this combined dataset. This year's publication list highlights some of these studies.

We were awarded new funding through a NASA proposal, the Atmospheric Tomography Mission (ATom) - Imaging the Chemistry of the Global Atmosphere, to put our in situ GCMS named PANTHER and UCATS GC on the DC-8. This will generate a chemistry-oriented extension of the global-scale HIPPO observations from 2009 to 2011. We also move forward on our small UAV program with improvements to SkyWisp, a UAV glider return vehicle dropped from 32 km, and new work on the 3-D Robotics Aero electric powered plane that uses an open source software based Pix Hawk auto-pilot.

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Xiang et al., 2014

### 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 & Objective

This project 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 water vapor soundings were performed with the balloon-borne NOAA Frost Point Hygrometer (FPH) at our three monitoring sites (Boulder, Colorado; Hilo, Hawaii; Lauder, New Zealand). Each measured vertical profile extends from the surface to the middle stratosphere (~28 km), spanning a range of water vapor mixing ratios from >10,000 parts per million (ppm) in the boundary layer to ~3 ppm near the tropopause. The FPH water vapor record at Boulder has now surpassed 35 years in length (1980-present). The record lengths at Lauder and Hilo now extend nearly 11 and 5 years, respectively.

A paper (Hurst et al., 2014) was published that compares stratospheric water vapor measurements by the satellite-based Aura Microwave Limb Sounder (MLS) and the NOAA FPH at our three monitoring sites. Good agreement (within 1 percent) was demonstrated at all three sites between the two sets of measurements at stratospheric pressure levels 68 to 26 hPa. Statistically significant biases of 2 to 10 percent were

found for measurements at 83 and 100 hPa above all three sites. These biases are important because the abundance of water vapor near the tropopause has a strong influence on the Earth's radiation budget.

Recently we have found an emerging divergence in the FPH and MLS measurements in the lower stratosphere above Boulder and Hilo. Corroborating evidence from frost point hygrometers at two other sites indicate that MLS retrievals have drifted and/or are drifting. We have alerted the MLS instrument team of this finding and a manuscript describing these discrepancies is currently in preparation.



**Emrys Hall, ready to launch a balloon with radiosonde, ozonesonde, and NOAA frost point hygrometer at the Marshall Field Site near Boulder.**

Allen Jordan/CIRES

# 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 & Objective

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

### Accomplishments

All the Surface Radiation (SURFRAD) and Integrated Surface Irradiance Study (ISIS) measurement sites have now been upgraded to newer data loggers. The old model is a Campbell Scientific CR10X. The new is a Campbell Scientific CR1000.

All SURFRAD and ISIS sites have been transitioned from copper phone lines to broadband wireless technology for the retrieval of collected data. The transition has allowed us to retrieve the measured data in near real-time. We are now pulling data in every 15 minutes, and those real-time datasets are currently being used for solar energy research by a multitude of organizations.

All the SURFRAD Total Sky Imagers (TSIs) have been upgraded to the NOAA Wendell-Jordan mirror controller board. The mirror must rotate with the Sun to keep the direct beam from reflecting into the camera and damaging it. The new boards interface directly with a GPS antenna to automatically set instrument location, and to keep time very accurately.

At this point only one SURFRAD site has been outfitted with a new 1625-nm Multi-Filter Rotating Shadowband Radiometer (MFRSR). This effort is taking a bit more time than expected. Our receipt of the new instruments was delayed by the manufacturer, and the initial instruments had problems with the sensors and had to be returned for repair. As stated last year, we are moving forward with plans to install a MFRSR head on our 10-m tower in an inverted position to measure reflected spectral irradiance. This has meant significant site infrastructure additions, such as running AC power to the towers and adding additional communication capability. To date, one site has received this infrastructure update.

The two mobile SURFRAD sites we operate are both currently operating photovoltaic (PV) power generation sites. In June 2014, one was installed near Alamosa, Colorado, immediately adjacent to a 110,000-panel generation facility. The other mobile site was installed in October 2014 in Rutland, Vermont, immediately adjacent to a much smaller PV array of about 250 panels. Data from both sites are collected every 15 minutes and are being used for short-term cloud forecasting research by IBM and NCAR.

Three ISIS stations underwent ground-up renovations. This was a substantial undertaking for each, and all three are now much improved. The three stations are Sterling, Virginia; Hanford, California; and Albuquerque, New Mexico.



**The refurbished Integrated Surface Irradiance Study (ISIS) measurement site, located adjacent to the Albuquerque, New Mexico, airport. This site measures direct, diffuse, and global broadband shortwave radiation, as well as UV-B radiation.**

Gary Hodges/CIRES

# Systems and Prediction Models Development

## GSD-01: Improve Weather Information Systems

■ CIRES Lead: Leon Benjamin ■ NOAA Lead: Gregory Pratt  
NOAA Theme: NOAA Engagement Enterprise

### Goals & Objective

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

### Accomplishments

MADIS reached “final operating capability” at the National Weather Service. Specifically:

- MADIS was successfully transitioned from research to operations at NWS January 21, 2015 at 12z. The new system runs at NOAA’s Integrated Dissemination Program computer system, maintained by National Centers for Environmental Prediction Central Operations.
- MADIS’s NWS “initial operating capability” systems were decommissioned in April 2015.
- MADIS was refined to run in the new computer center.

CIRES staff also commenced development for Initial Operating Capability of the Prototype Hazard Services in AWIPSII.



This graphic shows the increasing density of weather data sources provided by MADIS to NOAA weather forecasters and the global weather forecasting community. The number of data sources has increased from about 20,000 to 64,000 during the development of this new data tool. NOAA

## GSD-03: Improving Numerical Weather Prediction

■ CIRES Lead: Curtis Alexander ■ NOAA Lead: Georg Grell  
NOAA Theme: Science and Technology Enterprise

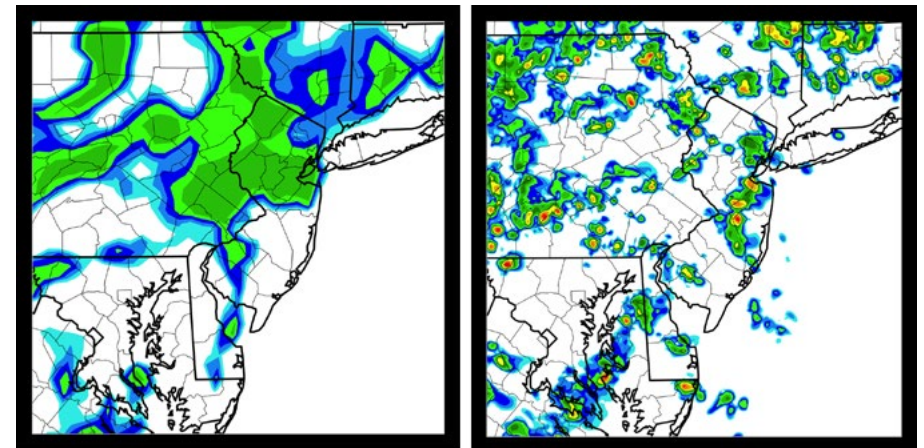
### Goals & Objective

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

### Accomplishments

The High Resolution Rapid Refresh (HRRR) was transitioned, for the first time, from a real-time experimental research model into the operational production suite at the National Centers for Environmental Prediction (NCEP) on September 30, 2014, to enhance the short-term prediction capability of the National Weather Service (NWS) for a variety of high-impact weather events including severe thunderstorms and heavy precipitation bands. Comprehensive HRRR training modules were also prepared and disseminated to NWS.

Development of the third version of the Rapid Refresh (RAP) and the second version of the HRRR was accomplished between June 2014 and May 2015. These model versions were then transitioned to NCEP with an anticipated operational implementa-



Rapid Refresh (RAP, left) model output at eight-mile (13-km) resolution and the High-Resolution Rapid Refresh (HRRR, right) model output at two-mile (three-km) resolution. Shown are six-hour forecasts of thunderstorms, with the more detailed HRRR forecast enabling better airline flight planning around weather-related hazards. NOAA

tion in late 2015, including an expanded RAP domain to match the North American Mesoscale model and forecast length extensions of the RAP and HRRR.

With these versions, the RAP and HRRR assimilation enhancements include extension of surface data assimilation to include mesonet observations and improved use of all surface observations through better background estimates of 2-m temperature and dewpoint including projection of 2-m temperature observations through the model boundary layer and extending the use of radar observations to include both radial velocity and 3-D retrieval of rain hydrometeors from observed radar reflectivities in the warm-season. The RAP hybrid EnKF 3D-variational data assimilation will increase weighting of Global Forecasting System ensemble-based background error covariance estimation and introduce this hybrid data assimilation configuration in the HRRR.

Enhancement of RAP and HRRR model physics in these versions include improved land surface and boundary layer prediction using the updated Mellor-Yamada-Nakanishi-Niino parameterization scheme with short-wave radiation attenuation from sub-grid scale clouds, Grell-Freitas-Olson shallow and deep convective parameterization, aerosol-aware Thompson microphysics and an upgraded Rapid Update Cycle land-surface model to reduce certain systematic forecast biases, including a warm and dry daytime bias over the central and eastern United States during the warm season, along with improved convective forecasts in more weakly-forced diurnally-driven events.

Preliminary work on a North American Rapid Refresh Ensemble was conducted using a combination of the advanced research WRF and non-hydrostatic mesoscale model (NMM) dynamic cores with various physics options to populate a limited member ensemble at the 13-km scale for individual case studies and real-time evaluation at the 2015 Winter Weather Experiment.

Expansion of the HRRR time-lagged forecasts to an ensemble-based hazard detection guidance tool for high-impact weather such as heavy precipitation (rain or snow), lightning, hail, high winds, and tornadoes was accepted for transition to operations at NWS over the next three years.

## GSD-05: Development of High-Performance Computing Systems

■ CIRES Lead: Craig Tierney ■ NOAA Lead: Forrest Hobbs  
NOAA Theme: Science and Technology Enterprise

### Goals & Objective

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, CIRES researchers have helped support NOAA's High Performance Computing (HPC) in the Global Systems Division (GSD). Work spanned

several areas, including new system acquisition and planning, application optimization, software development, and user management and support.

In 2014, NOAA acquired a new HPC system to support the computational needs of the Hurricane Forecast Improvement Project (HFIP) users. Our role in this acquisition included defining requirements, performing trade-off studies, system validation, and performance benchmarking. This new system, named vJet, represents a 27 percent increase in overall computational performance at GSD.

Rocoto, a software system designed to help NOAA scientists improve the reliability of their computational experiments on NOAA's HPC systems, saw important bug fixes and performance enhancements. An increasing number of NOAA's GSD scientists rely on Rocoto to help them construct complex job workflows that reliably complete. Also, other NOAA labs, including NCEP's Environmental Modeling Center, have started to adopt Rocoto for their critical projects.

One of the more important experiments that we support on the HPC systems at GSD is the annual real-time hurricane season experiments for HFIP. The goal of this experiment is to demonstrate their ability to deliver improved hurricane forecasts. Our responsibility is to develop the tools and techniques for these scientists to use so that their experiments can run reliably and on-time. Rocoto is a big part of this process. Also, we implemented a complex system based on reservations that guarantees system



Latest High Performance Computing system at GSD. Will von Dauster/NOAA

# Systems and Prediction Models Development

resources when needed while still letting the rest of the research and development projects to continue to execute as resources are available.

Scientists who use computational models are often limited not by their ideas but by the amount of computational resources available to them. To help them, application performance analysis and optimization can help identify bottlenecks and other inefficiencies in their software that when fixed can lead to better performance. Over the past year, we informally worked with several key users to identify performance issues in their code and propose fixes. Without much effort, we are often able to improve the performance of their applications by 10 to 15 percent.

## GSD-06: Verification Techniques for Evaluation of Aviation Weather Forecasts

■ CIRES Lead: Matthew Wandishin ■ NOAA Lead: Jennifer Mahoney  
NOAA Theme: Weather-Ready Nation

### Goals & Objective

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

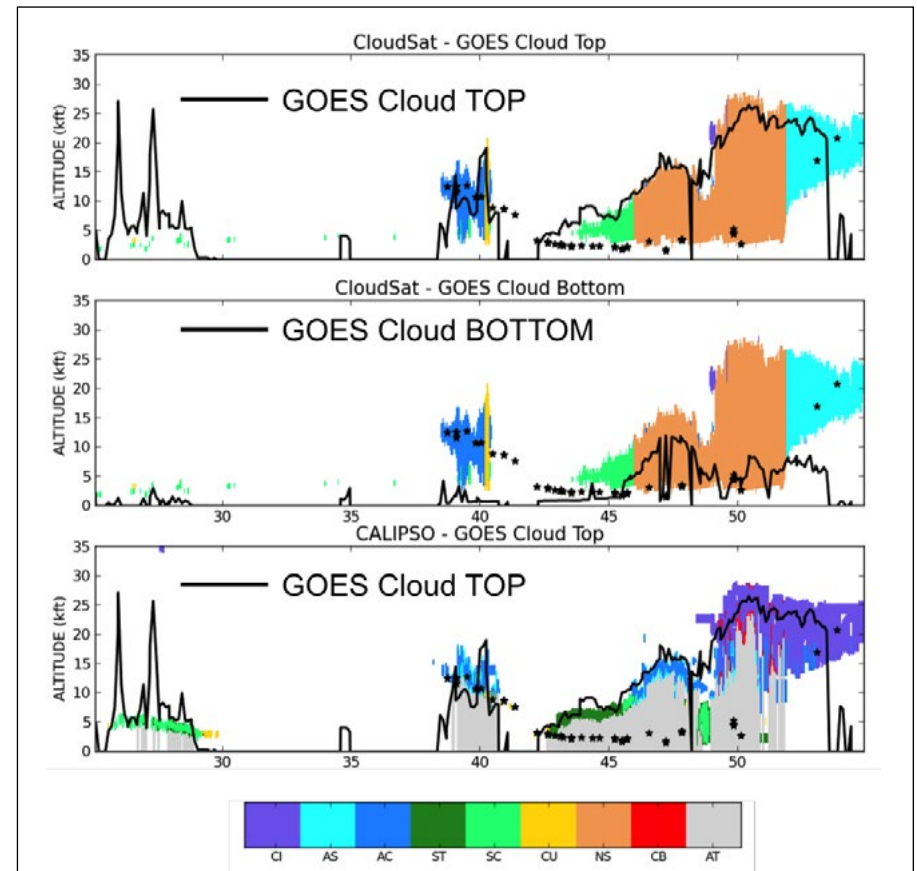
### Accomplishments

CIRES staff in the Global Systems Division:

- Completed upgrade to version 3 of the Integrated Support for Air-Traffic Environments (INSITE) decision support tool to support the new Collaborative Aviation Weather Statement product.
- Developed INSITE version 3.5, in which historical air traffic information is replaced with traffic based on planned flight paths, as requested by users.
- Completed evaluation of version 1.1 of the Current Icing Potential and Forecast Icing Potential products.
- Completed evaluation of the Icing Product Alaska.
- Completed evaluation of version 3 of the Graphical Turbulence Guidance product.
- The GTG-Nowcast product has been delayed, again, by the FAA.
- Completed evaluation comparing the Corridor Integrated Weather System radar mosaic with the soon-to-be-operational Multi-Radar Multi-Sensor (MRMS) mosaic, which prompted the MRMS producer to include an additional aviation-targeted analysis field.
- Completed assessment of the newly-automated Collaborative Convective Forecast Product to inform users of the differences that will be seen relative to the previous human-generated product.
- Extended the Verification Requirements and Monitoring Capability Web-based tool to support the IPA assessment, including the introduction of satellite-based

verification techniques.

- Began the development of the Center Weather Service Unit (CWSU) Briefing and Verification Tool, a web-based tool for gathering, verifying, and reporting CWSU airport wind forecasts and reporting the results to National Weather Service management. Development will continue, with ongoing consultation from CWSU



**Comparison of Geostationary Operational Environmental Satellite (GOES) cloud top (black line; top and bottom panels) against CloudSat (color fill; top and middle panel) and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) (color fill; bottom panel) and METAR observations (black stars). CloudSat and CALIPSO colors denote diagnosed cloud type (bottom color bar).** CIRES/NOAA

forecasters.

- Nearly completed the Terminal Radar Approach Control Gate Forecast Verification Tool that gathers thunderstorm forecasts for arrival and departure sectors at major airports and reports verification results to NWS management.
- Began preliminary investigation in support of the extension of the Event-based Verification and Evaluation of NWS gridded products Tool (EVENT) to wind forecasts at the Core-30 airport terminals.
- Core research and development efforts include:
  - Investigation into the variety of potential verification methods appropriate for probabilistic forecasts.
  - Investigation into the use of additional (geostationary) satellite data for the verification of icing forecasts.
  - Investigation into the use of multiple uncertain truth sets (e.g., satellite, radar, pilot reports (PIREPs), cruise ship reports, etc.) in support of a forthcoming assessment of the Offshore Precipitation Forecast product.
  - Investigation into the use of Aircraft Meteorological Data Relay data for use in the verification of global turbulence and icing forecasts.
  - Beginning investigation into PIREP location errors to support icing and turbulence verification.
  - Beginning investigation of the ability to identify air traffic deviations associated with weather hazards.

### GSD-07: Testbed Center for Numerical Prediction Developmental

■ CIRES Lead: Ligia Bernardet ■ NOAA Lead: Zoltan Toth  
NOAA Theme: Weather-Ready Nation

#### Goals & Objective

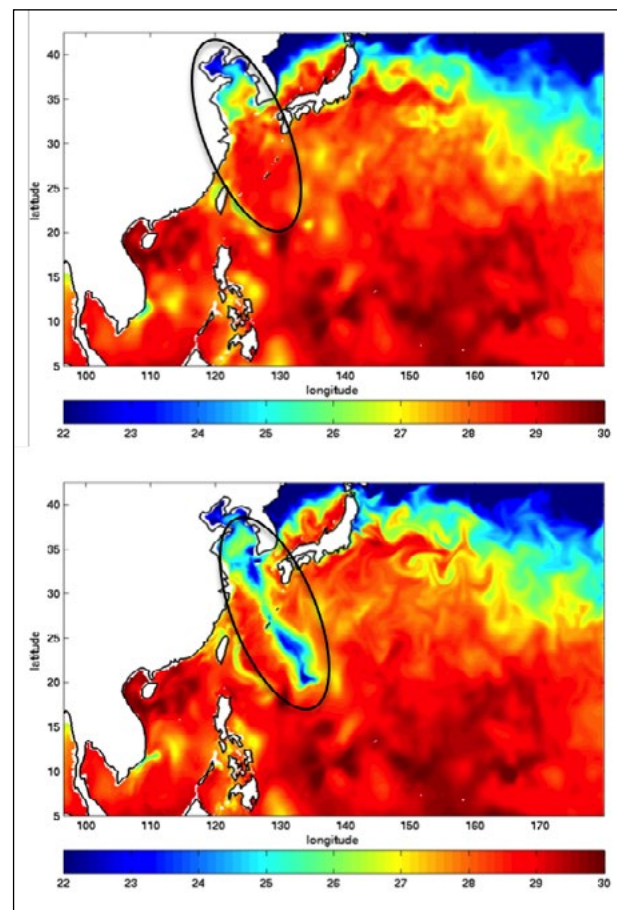
This project is directed toward maintenance and improvement of the hurricane prediction system and is supportive of government agencies and public information systems that provide hurricane warning.

#### Accomplishments

The Hurricane Weather Research and Forecast (HWRF) model and the Gridpoint Statistical Interpolator (GSI) codes continue to be used both in NOAA operations and in the research and development community. CIRES and collaborators 1.) maintained the community and operational codes, synchronized to prevent divergence and facilitate transition of research to operation; 2.) assisted the community in using, developing, and integrating code; 3.) acted as a liaison between the operational and research communities by hosting developers' committees; and 4.) implemented, tested, and evaluated innovations to provide input to decision making in NOAA operational

numerical weather prediction.

One important outcome was the initial implementation of a regional high-resolution ensemble for use in data assimilation with GSI in the experimental version of the Rapid Refresh (RAP) model. Another significant achievement was the transition to the operational HWRF of new radiation and partial cloudiness parameterizations, following an extensive multi-season test and evaluation exercise. Finally, through the assistance provided to community developers, capabilities such as additional synthetic satellite images and ability to initialize the ocean component from alternate datasets



**Sea Surface Temperature (SST) on the West Pacific oceanic basin for a forecast of Supertyphoon Bolaven.**

**Top: SST analysis obtained from the Navy Coupled Ocean Data Assimilation (NCODA) system.**

**Bottom: SST at the five-day forecast, showing cooling due to upwelling associated with the supertyphoon. CIRES staff worked with Yablonsky of the University of Rhode Island (URI) to transition to the centralized HWRF code repository the ability to initialize the ocean component of HWRF using NCODA. Richard Yablonsky/URI**

# Systems and Prediction Models Development

have been added to HWRF.

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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. 15<sup>th</sup> WRF Users' Workshop, June 24-26, Boulder, CO.

## PSD-12: Analysis of the Causes of Extreme Events

■ CIRES Lead: Judith Perlwitz ■ NOAA Lead: Randall Dole  
NOAA Theme: Weather-Ready Nation

### Goals & Objective

This project will promote more accurate forecasting of extreme events

### Accomplishments

Instead of studying the linkage between blocking frequency and European heat waves, we focused on the characteristics of extreme precipitation changes over the United States, motivated by findings of the *2014 National Climate Assessment*. For this study, the analyses were carried out and a publication will be submitted to the *Journal of Climate* by the end of June 2015.

Factors responsible for the regionality and seasonality in 1979–2013 trends of observed U.S. daily heavy precipitation (in the 95<sup>th</sup> percentile) are studied utilizing a set of historical climate simulations. For annual conditions, contiguous U.S. trends have been characterized by increases in precipitation associated with heavy daily events across the North, and decreases across the South. Diagnosis of historical climate simulations reveals the evolution of observed sea surface temperatures (SSTs)



MorgueFile

to be a more important factor influencing these trends than the evolution of external radiative forcing alone. The latter induces widespread, but weak, increases in precipitation associated with heavy daily events. The former induces a meridional pattern of increases in the U.S. North and decreases in the South, as observed, the magnitude of which is also more closely aligned with observed changes, especially over the South and Far West. Analysis of model ensemble spread reveals that appreciable 35-year trends in heavy daily precipitation can occur in the absence of forcing, limiting detection of the weak anthropogenic influence at regional scales.

Analysis of the seasonality in heavy daily precipitation trends during 1979–2013 supports physical arguments that changing statistics of observed heavy precipitation were intimately linked to internal decadal ocean variability. Most of the U.S. South decrease occurred during the cold season that has been dynamically driven by atmospheric circulation changes reminiscent of teleconnections linked to cold states of the eastern tropical Pacific. Most of the increase in the U.S. Northeast was a warm season phenomenon; the immediate cause appears linked to an increasing effect of Atlantic hurricanes in recent decades, the forcing of which (if any) remains unresolved.

## PSD-14: Forecasts for Wind Energy

■ CIRES Lead: Laura Bianco ■ NOAA Lead: James Wilczak  
NOAA Theme: Science and Technology Enterprise

### Goals & Objective

This project will quantify improvements made to numerical weather prediction models by assimilating new observations and by developing and implementing new model physical parameterization schemes.

### Accomplishments

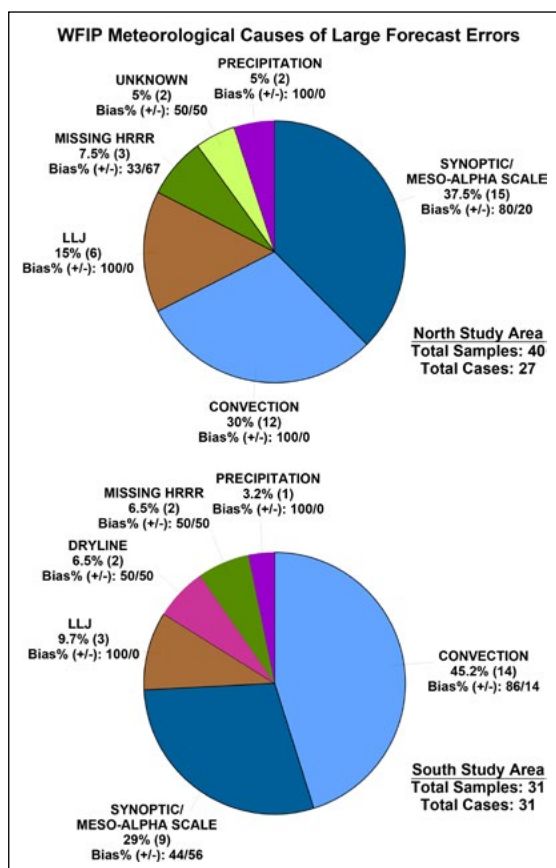
#### Analysis of large forecast errors of wind speed

Electric grid and utility operators rely on numerical weather prediction model forecasts of power production from wind plants. Of greatest concern are instances when the models either greatly over-forecast or greatly under-forecast the amount of power that a wind plant or group of wind plants will produce. We used one year of observation and model data from the Wind Forecast Improvement Project (WFIP) to analyze the characteristics of large power error events. WFIP was a joint U.S. Department of Energy, NOAA, and private sector field campaign whose goal was to improve wind forecasts for the wind energy industry. Observations were collected during WFIP for a 12-month period in 2011–2012 in two study areas within the United States—one in the Northern Great Plains, and one in West Texas.

Large error events were defined on the basis of the three-hour running mean of the difference between forecast and observed power, aggregated within each of the two



WFIP study areas. Using six-hour forecasts from the three-kilometer-resolution NOAA High Resolution Rapid Refresh (HRRR) model, and observed pseudo-power derived from anemometers on 127 tall tower sites in the two study areas, we found 27 events in the Northern Great Plains with aggregate error greater than 20 percent of capacity, and 31 events in the West Texas study area with aggregate error greater than 30 percent of capacity. These events were categorized according to season, meteorological condition, being an over- or under-forecast, and length of the event.



**Summary of large error analysis statistical results.**

Daniel Gottas/NOAA

**Results**

Surprisingly, in the Northern Great Plains, the largest errors are due to synoptic/meso-alpha scale errors. This includes such things as errors in the timing of cold fronts, but mostly just getting the magnitude of the surface pressure gradients wrong. This category of errors in the Northern Great Plains is biased more towards positive errors (model forecasts of more wind power than actually occurred) by 80 percent to 20 percent. The second biggest category is convection, and here the errors are biased 100 percent positive, with near surface convective inflows and outflows too strong in the model. The largest third category is low level jets (LLJs), and once again the errors are all positive, with the model always overforecasting the strength of the LLJ.

For the West Texas study area, the results are fairly similar, although here, convection has moved into the top category, again biased very positive with

86 percent of events having too strong convective inflows and outflows. Synoptic is the second largest category, with an even mix of over and under forecasts. LLJ is again the third category, and again the model always over-forecasts the strength of the LLJ. The fourth category in Texas is the dryline, which, although only two cases, is split between over and under forecasts.

The implications of these findings are: First, the prevalence of synoptic/meso-alpha scale errors of either sign suggests improvements could be made through better observations and data assimilation. Second, the fact that convective outflows and inflows are always too strong suggests that improvements are needed in the physical parameterization schemes of convective processes. Third, the fact that the LLJ errors are always positive suggests that something in the PBL (planetary boundary layer) parameterization scheme is consistently wrong, and that improvements could be found by improving the PBL scheme.

# Appendices

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## Publications by the Numbers

CIRES scientists and faculty published at least 696 peer-reviewed papers during calendar year 2014. Below, we tabulate publications by first author affiliation, per NOAA request. CIRES scientists and faculty published additional non-refereed publications in 2014, many of them listed in the pages that follow. These citations represent a subset of all CIRES publications; our tracking process misses some, although an improved tracking method this year may be partly responsible for the jump to 696. 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 "CIRES: Science in Service to Society" (page 3) and detailed throughout this report.

### Journal articles

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CIRES Lead Author	165	188	141	130	110	158	137	238	186	189	141
NOAA Lead Author	56	20	81	73	99	79	63	41	30	44	65
Other Lead Author	134	145	289	264	385	342	312	293	312	370	490
<b>Total</b>	<b>355</b>	<b>353</b>	<b>511</b>	<b>467</b>	<b>594</b>	<b>579</b>	<b>512</b>	<b>572</b>	<b>528</b>	<b>603</b>	<b>696</b>

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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
NCEI	National Centers for Environmental Information (formerly NGDC)
NGDC	National Geophysical Data Center (now NCEI)
NOAA	National Oceanic and Atmospheric Administration
OAR	NOAA Office of Oceanic and Atmospheric Research
PSD	NOAA ESRL Physical Sciences Division
SWPC	Space Weather Prediction Center

# personnel demographics

## CIRES Personnel Breakdown 2014–2015<sup>1</sup>

	Total Count of CIRES employees	≥50% NOAA <sup>2</sup>	Highest Degree Earned for those ≥50% NOAA <sup>2</sup>			
			BS	MS	PhD	No Degree listed
Faculty	18	0				
Research Scientist	246	136	0	0	136	0
Visiting Scientist	21	5	0	0	5	0
Postdoctoral Researcher	22	4	0	0	4	0
Associate Scientist	272	163	73	74	15	1
Administrative	35	30	17	6	1	6
<b>TOTAL</b>	<b>614</b>	<b>338</b>	<b>90</b>	<b>80</b>	<b>161</b>	<b>7</b>
Undergrads	83	69	0	0	0	69
Grad Students	93	10	1	1	0	8
<b>GRAND TOTAL</b>	<b>790</b>	<b>417</b>	<b>91</b>	<b>81</b>	<b>161</b>	<b>84</b>
>0 and ≤50% NOAA Support	101		18	24	46	13
0% NOAA Support	272					

*During the period June 2014 to May 2015, four CIRES employees obtained federal employment with NOAA groups in Boulder.*

### CIRES Personnel in NOAA Boulder Laboratories receiving any funding from NOAA CA

ESRL DIR	8
CSD	79
GMD	56
GSD	54
PSD	77
<b>TOTAL OAR</b>	<b>274</b>
NCEI/NGDC (NESDIS)	48
SWPC (NWS)	18
<b>GRAND TOTAL</b>	<b>340</b>

<sup>1</sup>Counted on May 1, 2015

<sup>2</sup>CIRES personnel receiving 50% of more of their pay from our NOAA Cooperative Agreement (CA)





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