



2016 Annual Report



COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES



COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

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Cover: "Early Season Snow"
The first snow of the year in the White River National Forest above Vail.
Photo: Gijs de Boer/CIRES

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Executive Summary & Research Highlights

From the Director

Fiscal year 2016 marks my third year as Director of CIRES. As I look back at this past year, and look forward to those ahead, I continue to feel an enormous sense of privilege to be Director of an institute with such a talented workforce engaged in such important and high-impact activities. At CIRES, we not only conduct and support research that is of the highest quality, we also carry out research and related activities that are of tremendous societal value through our partnership with NOAA, as well as our contributions to the University mission.

In FY 2016, our expenditures were nearly \$85 million, which comprised nearly a fifth of the University's research funding. Approximately half of our funding 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 nearly \$37 million in additional funding from a diverse array of other sources. Among these were NASA and the National Science Foundation. With support from these and other sources, CIRES scientists published more than 700 publications across the full spectrum of environmental disciplines in many of the world's most prestigious journals. Four of CU Boulder's seven "highly cited researchers" (top 1% of citations in their fields) are CIRES scientists. We have played a critical role in the University's educational mission through our 20 faculty and our 210 graduate and undergraduate students in a wide range of departments across campus.

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 380 scientists and science support personnel located at the David Skaggs Research Center, and dozens 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, the National Weather Service's Space Weather Prediction Center and Weather Forecast Office, 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, as well as various awards from NOAA and the U.S. Department of Commerce recognizing the outstanding achievements realized by NOAA/CIRES teams. CIRES researchers were key members of teams that won Department of Commerce Gold and Bronze medals and the NOAA Technology Transfer Award last year. In addition, two groups of CIRES and NOAA scientists won the COLABS/Governor's High Impact Award. We are also delighted to report that in February, the White House informed Gijs de Boer, a CIRES researcher who works in NOAA's Physical Sciences Division, that he

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.

had won a Presidential Early Career Award in Science and Engineering. De Boer's innovative and bridge-building work on Arctic atmospheric processes and their impact on climate is partly funded by the

U.S. Department of Energy. Clearly our work with NOAA is having far reaching impacts in Colorado, the nation, and the world.

One additional indication of the strength of the CIRES-NOAA relationship is the fact that our scientists continue to occupy leadership roles in the Divisions and Centers at NOAA, and our scientists are viewed favorably as strong candidates when civil servant positions become available at NOAA. During the 2016 federal fiscal year so far, NOAA Boulder groups reported nine new hires, seven of whom were CIRES employees. All of this indicates the partnership is working well. On main campus, we welcome the arrival of our newest faculty member, Michael Willis, who strengthens our capabilities and expertise in remote sensing and geodesy. 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. We advance science, and we improve lives. I am very proud of the work we do at CIRES, and as you read through this report, I am confident you will agree.



Waleed Abdalati
CIRES Director



CIRES: Science in Service to Society

The Cooperative Institute for Research in Environmental Sciences (CIRES) is an international leader in research, addressing some of the most pressing challenges facing the planet. Many of these challenges are priorities for NOAA, such as adapting to and mitigating climate change and conducting research that aids decision makers from the local to the international level. Since its inception as NOAA's first cooperative institute—now, almost 50 years ago—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):

- Developed an inventory for vehicle (gasoline- and diesel-powered) emissions that relies on intensive roadside monitoring programs and tunnel studies to derive emission factors.
- Completed the Synthesis Report of the United Nations Montreal Protocol on Substances that Deplete the Ozone Layer, which synthesizes the major findings from the 2014

reports of the Protocol's three assessment panels: scientific, technology and economic, and environmental effects.

- Used research aircraft and an instrumented van to measure methane, ammonia, nitrous oxide, and other chemicals released from animal feedlots and dairies.
- Conducted aerosol measurements in the Brazilian state of Amazonia to study the evolution of pollution aerosol from Manaus in the Amazon rainforest and its impact on cloud formation.
- Updated the NOAA Annual Greenhouse Gas Index to include 2015 GHG measurements and infer the direct impact of different gases on global radiative forcing.
- Presented a large-scale assessment of the observed occurrences of extreme daily rainfall (such as the flash-floods in Texas in May 2015) over the entire contiguous United States during 2015.

Flares burn at sunset in the Bakken oil and gas fields near New Town, North Dakota. Photo: Jeff Peischl/CIRES



- Investigated the impact of El Niño on surface pH and dissolved oxygen in California Current System.

Weather-Ready Nation Goal

CIRES scientists (often with NOAA and other colleagues):

- Quantified methane emissions from oil and natural gas extraction in the Bakken oil and gas field in North Dakota and found the methane leak rate was significantly lower than had been reported using satellite remote sensing data.
- Analyzed measurements of methane released from the Aliso Canyon underground storage facility in California, which helped document human exposure, formulate intervention strategies, and quantify the efficacy of control measures.
- Successfully upgraded the Tunable Optical Profiler for Aerosol and oZone (TOPAZ) lidar data acquisition system, which significantly increased TOPAZ's measurement range from 2 km to at least 6 km. This will allow researchers

to better document ozone transport mechanisms with important implications for ground-level air quality, such as stratospheric intrusions and long-range transport of ozone from Asia.

- Brought together the Forecast Impact and Quality Assessment Section (FIQAS) with National Weather Service (NWS) aviation forecasters to develop a tool (Central Weather Service Unit Briefing and Verification Tool, CBVT) to capture the information from weather briefings to FAA traffic managers and provide a report on the performance of these forecasts to managers. The first phase of this project—related to forecasts of wind shifts affecting airport operations—is nearing completion.
- The capability of the multi-storm Hurricane Weather Research and Forecast (HWRF), developed to both speed up and improve numerical forecasting of tropical cyclones by incorporating multiple storms in a single forecast realization, was incorporated onto the centralized HWRF

code. This HWRF configuration underwent realtime testing during the 2015 Atlantic hurricane season, and is a candidate for 2017 operational implementation.

Engagement Enterprise

CIRES scientists (often with NOAA and other colleagues):

- Brought a traveling version of Science On a Sphere® (SOS) to the U.S. Pavilion at the 2015 United Nations Climate Change Conference in Paris, France. The traveling SOS exhibit also appeared at four other events, including the American Meteorological Society Annual Meeting and the USA Science and Engineering Festival. This work earned the NOAA members of the team a U.S. Department of Commerce Gold Medal; the CIRES members received a CIRES Gold.
- Transitioned new and restored projects from MADIS, the Meteorological Assimilation Data Ingest System, into operations at the National Weather Service. These included



Great Basin thunderstorm near Ely, Nevada. Photo: John Cassano/CIRES



Dr. Stephen Volz, NOAA Assistant Administrator for Satellite and Information Services, demonstrated NOAA's Science on a Sphere® at the opening reception for the American Meteorological Society's Annual Meeting in January, 2016. Photo: NOAA

the Automated Flood Warning System (AFWS) product, as well as the addition and restoration of weather data from several state departments of transportation. CIRES scientists in ESRL's Global Systems Division were part of a NOAA team awarded the NOAA Administrator's Award for the group's extraordinary collaboration and leadership.

- Continually maintained and updated the Sea Ice Index, which provides thousands of users with a quick look at Arctic-wide changes in sea ice. Arctic sea ice reached its annual maximum extent on March 24, 2016 and is now the lowest maximum in the satellite record.

Science and Technology Enterprise

CIRES scientists (often with NOAA and other colleagues):

- Received a Governor's Award for High Impact Research: Foundational Science and Technology for the production of mission-critical representations of Earth's magnetic field used daily by millions of people for military, mobile phone

and other navigation needs, as well as other and innovations that could improve the ability to detect tsunamis and navigate more accurately through cities or under ice.

- Published a paper entitled "Future cost-competitive electricity systems and their impact on U.S. CO₂ emissions," which showed the United States could slash greenhouse gas emissions from power production by up to 78 percent below 1990 levels within 15 years while meeting increased demand.
- Worked with modelers at agencies and universities across the country to better coordinate U.S. Earth System modeling. National modeling systems provide critical functions in weather forecasting, military operations, and climate projections. CIRES- and NOAA-developed software enables the groups that develop these modeling systems to share infrastructure code and exchange science components, such as ocean and ice models.
- Developed geographic information system (GIS) analysis

methods, cartographic content, and preliminary scientific documentation for the U.S. Extended Continental Shelf (ECS) Project.

- Turned the MASIE-AMSR2 (MASAM2): Daily 4 km Arctic Sea Ice Concentration into a near-real-time, daily update product, which meets a need for greater accuracy and higher resolution in ice concentration fields that are used to initialize an operational sea ice forecast model.
- Deployed a wide array of instruments to improve the skill of NOAA's forecast models at predicting weather that impacts wind energy generation around the Columbia River Gorge.
- Initiated the El Niño Rapid Response (ENRR) project in advance of the 2015-16 El Niño event, which provided an exceptional scientific opportunity to accelerate advances in understanding and predictions of an extreme climate event and its impacts while the event was ongoing.



Pancake sea ice stretches to the horizon on approach to the Antarctic Peninsula. Photo: Glenn E. Grant/CIRES



Sunrise aboard the NOAA Ship *Ronald H. Brown* during the El Niño Rapid Response field campaign. Photo: Dan Wolfe/CIRES

This is CIRES

CIRES mission is to conduct innovative research that advances our understanding of the global, regional, and local environments and the human relationship with those environments, for the benefit of society.

Established in 1967, the Cooperative Institute for Research in Environmental Sciences (CIRES) facilitates collaboration between the University of Colorado Boulder and the 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 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 26)
- Center for Science and Technology Policy Research (page 28)
- Earth Science and Observation Center (page 30)
- National Snow and Ice Data Center (page 32)
- Western Water Assessment (page 34)
- Education and Outreach (page 36)

Other Programs

- Visiting Fellows (page 38)
- Innovative Research Program (page 43)
- Graduate Student Research Awards (page 44)
- Diversity and Undergraduate Programs (page 45)
- Awards (page 48)
- Events (page 51)
- Integrated Instrument Design Facility (page 54)
- Communications (page 55)

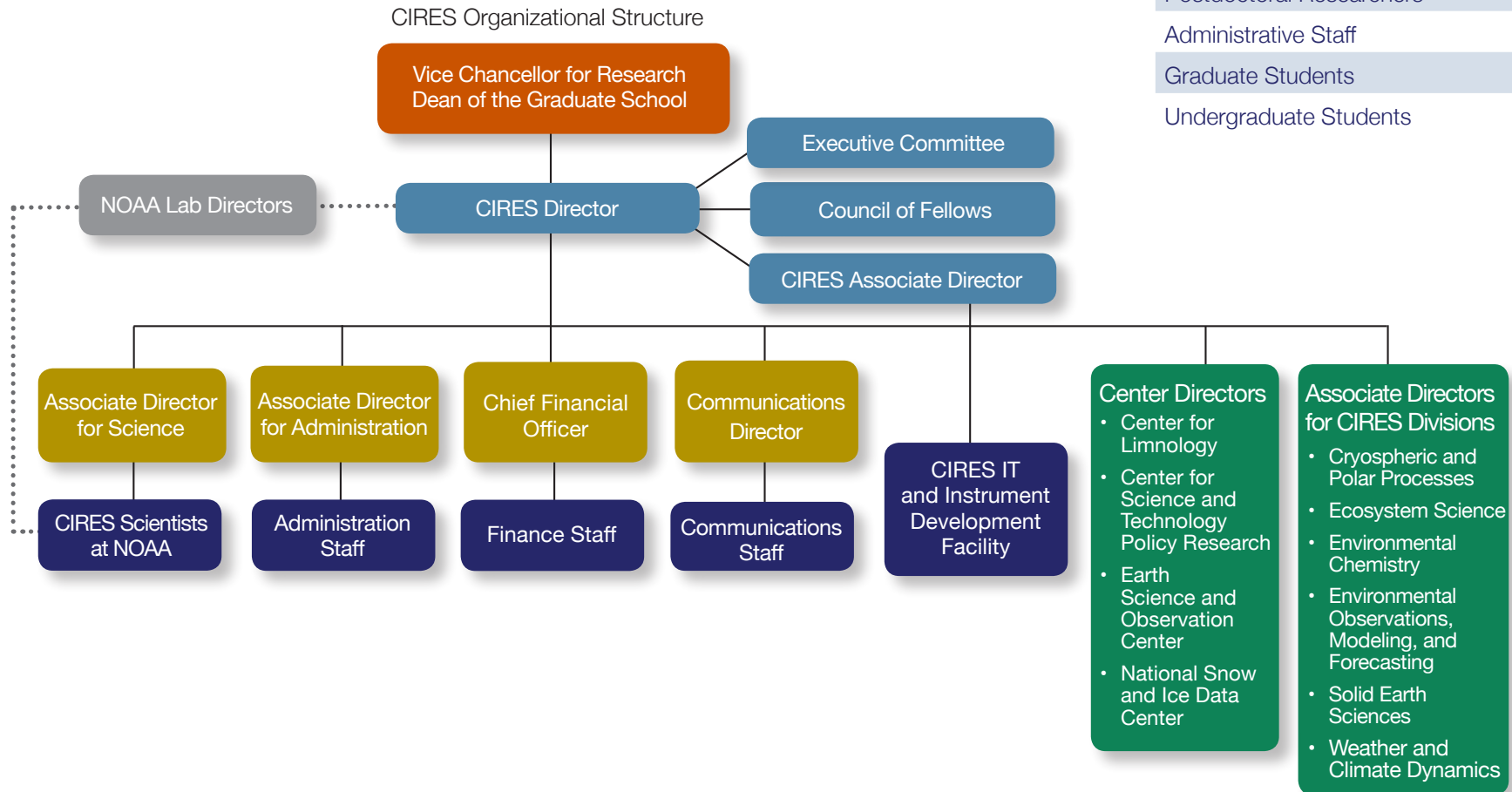
Organization

The Council of Fellows and the Executive Committee, with input from the CIRES Members' Council, advise CIRES Director Waleed Abdalati. The CIRES Centers—the Center for Limnology, the Center for Science and Technology Policy Research, the Earth Science and

Observation Center, and the National Snow and Ice Data Center—along with our other programs link NOAA to nine university departments. Coordination among all these entities is facilitated through the CIRES administration.

The CIRES Team FY2016

Faculty Lines	20
Research Scientists	257
Associate Scientists	264
Visiting Scientists	15
Postdoctoral Researchers	29
Administrative Staff	34
Graduate Students	113
Undergraduate Students	97



Governance

Council of Fellows

The Council of Fellows constitutes the Board of Directors and chief advisory body of CIRES. Fellows are selected because of their outstanding achievements and abilities in diverse areas of environmental sciences. These university faculty, 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,
- advise 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 10, October 8, November 12, and December 10 of 2015; and January 21, February 18, March 14, and April 21 of 2016. For more details about the 45 members of the Council of Fellows, please see page 11.

Executive Committee

The Executive Committee assists and advises the director in matters regarding strategic 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

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

CIRES is committed to enhancing diversity by extending its community and knowledge across the full spectrum of cultures and backgrounds. Staff in CIRES' Education and Outreach program, administration, and all science groups work to identify programs, mentorships, and other opportunities for CIRES to foster diversity and enrich our professional community (pages 45-47 highlight some specific diversity-oriented 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 (page 38)

Distinguished Lecture (page 51)

Graduate Student Research Award (page 44)

Innovative Research Program (page 43)

Finance

Please note that data shown on this page are preliminary; the University of Colorado switched to a new accounting system in 2015, which has delayed the usual close of the fiscal year. We will provide final data when available.

During the university fiscal year of July 1, 2015, to June 30, 2016, CIRES had total expenditures of more than \$85 million, including the university portion (graph 1).

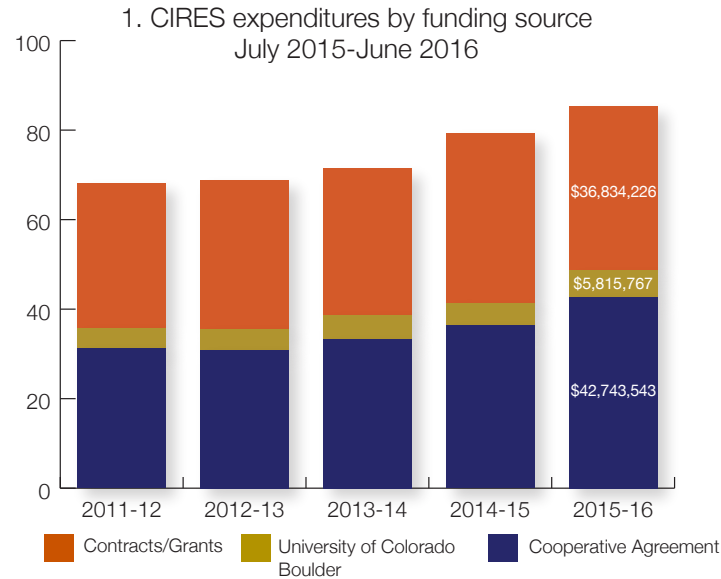
CIRES researchers enjoy enviable success in obtaining external research awards (50 percent of total expenses). Graph 2 breaks down our contracts and grant funding by source.

As of June 30, 2016, NOAA provided \$51,203,805 for the preceding 12 months of our Cooperative Agreement NA12OAR4320137.

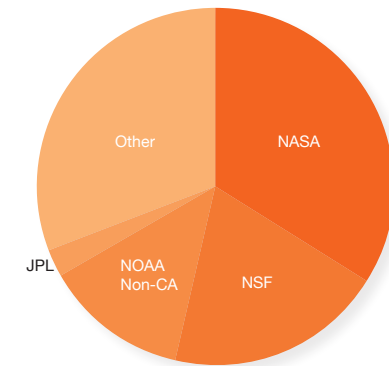
Graph 3 provides an overall look at our Cooperative Agreement funding, by task. Task I funding (further described in graph 4) is for CIRES administration and internal scientific programs, such as the Visiting Fellows and Graduate Student Research Award programs. Task II funds CIRES' collaboration with NOAA groups in Boulder, Colorado. Task III funds support individual CIRES investigators who conduct stand-alone projects under the umbrella of our Cooperative Agreement, at NOAA's request.

NOAA Cooperative Agreements	Start Date	End Date	Amount in \$
NA12OAR4320137 CIRES Five-Year Cooperative Agreement	9/1/2012	8/31/2017	108,804,151.92
NA15OAR4320137 CIRES Five-Year Cooperative Agreement (new award no.)	9/1/2012	8/31/2017	46,114,468.85

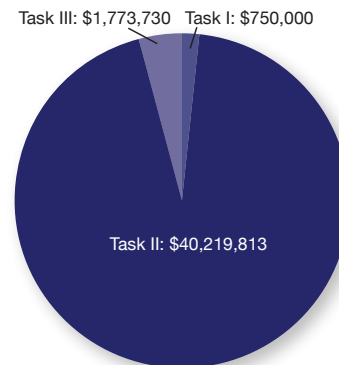
*Please see page 133 for other active NOAA awards. Our other agency awards are represented in graph 2 above; they are too numerous to list in full here.



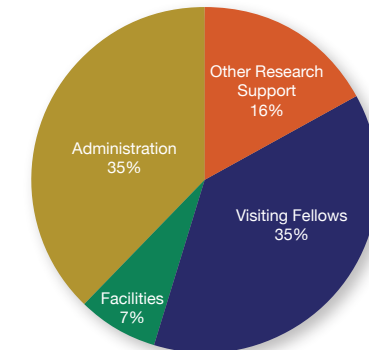
2. Contract/Grants by source



3. Agreement expenditures by Task
July 2015-June 2016



4. Breakdown of Task I expenditures



People & Programs

CIRES starts with people

In this section, we highlight the diverse environmental science work being done at CIRES, beginning with CIRES Fellows. Fellows pages are followed by reports on CIRES' four centers (page 26) and two programs (page 34).

We also report on our prestigious Visiting Fellowships (page 38), pioneering research funded by CIRES' Innovative Research Program (page 43), and graduate and undergraduate programs including award and diversity programs (page 45).

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 58).



CIRES Fellows

NOAA Scientists

Stan Benjamin
Randall Dole
David Fahey

Christopher Fairall
Graham Feingold
Stephen Montzka

CU-Boulder Teaching Faculty

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

José-Luis Jiménez
Craig Jones
Kris Karnauskas
Jennifer Kay
William M. Lewis Jr.
Ben Livneh
Peter Molnar
William Neff
R. Steven Nerem
Balaji Rajagopalan

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

CIRES Research Scientists

Richard Armstrong
Thomas Chase
Joost de Gouw
Fred Fehsenfeld

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

Participants in the Juneau Icefield Research Program jump while taking in the view of the Taku Glacier in southeast Alaska. Photo: Allen Pope/CIRES

Fellows



Waleed Abdalati

CIRES Director,
Professor of Geography

My group's research focuses on using space-based, airborne, and in situ observations to study changes in Earth's glaciers and ice sheets, and their contributions to sea level rise. We focus on three areas. The first is the development of methods for determining how much meltwater is stored in and lost from melt lakes on the surface of the Greenland Ice Sheet. This meltwater has significant implications for the speed at which the ice sheet flows toward the sea, because the meltwater can reduce friction between the ice and the bedrock on which it rests. It also changes the deformation properties of the ice as the warm meltwater penetrates into the ice. The second focus is on understanding the nature of compaction of the near-surface firn (aging snow) on the Greenland Ice Sheet in order to understand the changes in ice sheet melt with time and to improve the interpretation of satellite and aircraft altimetry observations of ice-sheet elevation changes for which accurate density information is critical. Finally, we are working with data from NASA's airborne and spaceborne laser altimetry observations to detect and understand the evolution of crevasses on the Greenland Ice Sheet and their implications for ice sheet mass changes. 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

Adjunct Associate
Professor of Geography

The Contribution to High Asia Runoff from Ice and Snow (CHARIS) project's basic research goal is to determine how much river flow originates as glacier melt and how much comes from melting seasonal snow and rainfall within the five major basins across High Asia (Brahmaputra, Ganges, Indus, Syr Darya, Amu Darya). This distinction is important because while seasonal snow cover returns every year, albeit in varying amounts, glaciers disappear as a result of a warming climate, and that water source is totally lost for the current era. The CHARIS project methodology achieves this goal by identifying the surface type (snow on ground, snow on glacier ice, glacier ice) using satellite remote sensing data and then applying a melt model appropriate to that surface. Preliminary estimates for glacier melt contribution vary from as little as 5 percent in the monsoon rainfall dominated regions of eastern High Asia to nearly 50 percent in drier western regions. The United States Agency for International Development-funded CHARIS project also serves as a capacity building/technology transfer effort in support of eleven research institutions in eight countries. This is accomplished by annual workshops conducted by NSIDC/CIRES staff for training in the applications of GIS to mountain regions, along with energy balance and melt model development. For details see <http://nsidc.org/charis>.



Stanley G. Benjamin

Chief, Assimilation and
Modeling Branch,
NOAA Global Systems Division

I lead a group that focuses on developing the next-generation weather models, data assimilation techniques, and other research projects aimed at improving operational weather up to seasonal forecasting. We contribute to regional and global model development, and we collaborate extensively with NOAA's National Centers for Environmental Prediction (NCEP), the National Center for Atmospheric Research, other groups in NOAA/ESRL and other laboratories and universities. For example, we developed the High-Resolution Rapid Refresh (HRRR), a 3 km model initialized with latest radar data, now operational in the NWS, providing guidance to weather forecasters for rapidly changing weather conditions. We are currently improving representation of clouds and turbulence in future refinements of the HRRR for the aviation/transportation community, and for renewable energy, including ongoing wind and solar energy projects for the U.S. Department of Energy and NOAA. We also continue to develop the Flow-following finite-volume Icosahedral Model (FIM) in preparation for other future global models. The FIM global model uses a unique icosahedral grid comprised of nearly uniform hexagons and an adaptive vertical coordinate. Finally, our team works with developing and evaluating a related icosahedral coupled atmospheric-ocean-chemistry model to improve week 3-4 forecast guidance. This key effort within NOAA to improve outlooks on extreme weather includes focus on understanding and improving simulations of global circulation drivers in the tropics (Madden-Julian Oscillation) and the stratosphere (sudden warming events).

CIRES Fellows



Roger Bilham

Professor Emeritus of
Geological Sciences

The long anticipated April 2015 Mw=7.8 Nepal earthquake caused less damage than had been expected considering that its rupture shifted the capital, Kathmandu, one meter upward and southward relative to India in less than 12 seconds. Because it occurred at midday on a holiday, few people were indoors in villages where most of the collapse occurred. Had the mainshock occurred just twelve hours later, the death toll would have been four times higher. Concern that the southern and western Himalaya had been stressed by the earthquake, and that a second damaging earthquake might soon shake weakened buildings in the city, we supplemented existing recording systems with numerous GPS receivers recording at rates up to 5 Hz. An interpretation of these data indicate that stable conditions were established about six months after the earthquake. We conjecture that this residual stress will be mobilized in a future major earthquake nucleating to the north and west. A re-evaluation of the Mw=8.3 1897 Shillong earthquake north of Kolkota showed that although it slipped upwards of 25m (the largest blind thrust ever recorded), its rupture stopped 6 km below the Earth's surface and its surface manifestation was entirely in the form of secondary faulting. One of these secondary faults was identified on space imagery and used to constrain the western end of the subsurface rupture.

England, P., and R. Bilham (2015), The Shillong Plateau and the Great 1897 Earthquake, *Tectonics*, 34, doi:10.1002/2015TC003902.

Bilham, R., Raising Kathmandu, (2015) *Nature Geoscience*, 8, 582-4.



Maxwell Boykoff

Director, Center for Science and
Technology Policy Research
Associate Professor of
Environmental Studies

Max Boykoff's ongoing research and creative work focuses on cultural politics and environmental governance, climate change communication, science-policy interactions, disaster risk reduction, and climate adaptation. As one output from these research endeavors, Max co-authored a 2015 *Nature Climate Change* article, "Dominant frames evident in legacy and social media coverage of the IPCC 5th Assessment Report." It examined U.K. and US broadcast, print, and global social media coverage on the IPCC 5th Assessment Report. The paper showed coverage—varying by media institutions—of IPCC Working Group I (WGI) was contested and politicized in these media sources, employing the 'Settled Science,' 'Uncertain Science,' 'Political or Ideological Struggle,' and 'Role of Science' frames. WGII coverage commonly used 'Disaster' and 'Security' frames. Coverage of WGII and WGIII also regularly included 'Economics' and 'Morality and Ethics' frames. By extension, Max spoke on a side event panel on 'IPCC Communications' at the U.N. Climate Change Conference meeting in December, 2015 in Paris, France. He elaborated on these findings and provided additional comments, including that innovation and transparency remain key challenges in IPCC communications. He argued that the IPCC motto of 'policy relevant not policy prescriptive' has served the organization well for the past 25 years but to stay useful in the public arena for the next 25 years, IPCC communications must find ways to reach public audiences through resonant and meaningful strategies that integrate insights gained from social science work over the past decade.



Eleanor C. Browne

Assistant Professor of
Chemistry and Biochemistry

Emissions of nitrogen that are biologically, photochemically, or radiatively active (reactive nitrogen) have drastically increased since the beginning of the 20th century primarily as a result of processes related to energy and food production. This increase in reactive nitrogen has resulted in numerous unintended consequences that have affected ecosystem health, air quality, and climate. Understanding these impacts is thus both a scientific and a policy concern and requires detailed knowledge of both the transport and the chemical transformations of reactive nitrogen. Constraining transport and chemical transformations has been particularly difficult for the organic nitrogen component due to its chemical complexity and reactivity.

Currently, our group is working on developing analytical measurement techniques capable of detecting and quantifying organic nitrogen compounds at atmospherically relevant concentrations and time-scales. We use these techniques in both the field and the lab to investigate how organic nitrogen is chemically transformed in the atmosphere and how this chemistry affects tropospheric ozone and the formation, growth, and physical properties of aerosols. Ongoing experiments are focused on understanding how urea chemistry impacts the transport of nitrogen from agricultural areas and in constraining the gas- and multiphase-chemistry of nitrogen heterocycles in biomass burning plumes.



John Cassano

Associate Professor of
Atmospheric and Oceanic
Sciences

Our research group studies the weather and climate of the polar regions with an emphasis on processes that couple the atmosphere to the other components of the climate system (ocean, sea ice, and land). We use both computer models and observation data for our research. Over the past several years we have developed a high resolution Regional Arctic System Model (RASM) that allows us to simulate the Arctic climate system and to explore the interactions between the atmosphere and the ocean, sea ice, and land. This model is similar to global climate system models used to make projections of future climate change but can be run at higher resolution, allowing us to study processes and features that occur on smaller scales but are important drivers of climate. Our modeling effort is complemented by a strong observational focus. In addition to using existing observational datasets, ranging from long-term weather and climate observations to detailed observations from limited duration field campaigns, we also deploy and use autonomous observing systems (automatic weather stations and unmanned aerial systems) to observe the lower atmosphere and underlying surface. These observational tools let us make observations throughout the year in the polar regions with most of our observational work taking place in Antarctica.



Thomas Chase

CIRES Senior Research
Scientist

Why do mid-tropospheric atmospheric temperatures display a clear physical limit? Any lasting physical system must be self regulated; changes to the system cannot amplify but must tend back towards the original state. We have recently documented a regulation mechanism in the Earth's climate system, oceanic sea surface temperature (SST) initiated convection, which keeps average temperatures in a meteorologically important atmospheric level (500mb, mid-troposphere) in the range between about -42°C and -3°C (Chase et al., 2015). Northern Hemisphere, mid-tropospheric temperatures seldom exceed these extremes which then limit the pace and extent of any changes in future climate. Mid-tropospheric temperatures are significant meteorologically and climatologically and this limited range of temperatures suggests a constraining physical process which we suggest is atmospheric convection (vertical movement in the atmosphere due to surface heating which transfers energy upward). This self-regulation of tropospheric temperatures affects jet stream and baroclinic storm dynamics and therefore limits changes in climate variability. Based on these data, these limits will continue unless SST warms to more than -2°C in high latitudes, more than 32°C in the tropics, or both. That such self-regulation exists in a stable physical system is not surprising.

Chase, T. N., B. M. Herman, R. A. Pielke, Sr. 2015.

“Bracketing Climatological Mid-Tropospheric Temperatures in the Northern Hemisphere: An Observational Study 1979 – 2013,” *Climatology and Weather Forecasting* 3, 1-3, doi: 10.4172/2332-2594.1000131.



Xinzhao Chu

Professor of Aerospace
Engineering Sciences

My group's research goal is to explore the unknown in the atmosphere, space, and beyond. Seeing limitations in detection capabilities hampering progress in atmosphere and space sciences, we have pursued research to meet these challenges through developing new lidar technologies and by pushing the science field forward with new discoveries. We work to explore advanced spectroscopy principles and develop the next-generation lidar technologies. By making measurements with unprecedented accuracy, precision, and coverage, we study the fundamental physical and chemical processes that govern the structures and dynamics of the whole atmosphere, and advance understanding of the universal processes in the Earth's space-atmosphere interaction region and how they shape the atmosphere of Earth-like planets throughout our galaxy. In our quest to develop whole atmosphere lidar and to explore the unmapped, we also aim to realize the full potential of lidar, making practical use of it to serve the world.

My group has achieved numerous lidar technology breakthroughs and groundbreaking science discoveries in the atmosphere and space sciences. We have advanced the upper atmosphere field by making frontier lidar measurements and numerical simulations of meteoric free atoms of iron to altitudes nearly 200 km at McMurdo Station in Antarctica. Besides being a CIRES Fellow, I am a professor in the CU Boulder Department of Aerospace Engineering Sciences. I teach graduate classes in spectroscopy and lidar remote sensing, and undergraduate classes in “Electronics and Communications” and “Thermodynamics and Heat Transfer.”

CIRES Fellows



Shelley Copley

Professor of Molecular,
Cellular and Developmental
Biology

In the Copley lab, we study the evolution of new enzymes and metabolic pathways in bacteria that are exposed to novel environmental opportunities or challenges. The genomes of most bacteria encode on the order of 1000-2000 enzymes. Each of these enzymes serves a primary function that is important for the bacterium to generate the building blocks of macromolecules such as DNA, RNA, proteins, and lipids. Because the active sites of enzymes contain a variety of catalytic components, including acids, bases, nucleophiles, metal ions, and organic cofactors, they often can catalyze secondary reactions if a non-canonical substrate happens to bind in proximity to the catalytic machinery. These secondary “promiscuous” reactions play no role under normal conditions. However, if the environment changes, a promiscuous activity may become important for fitness or even survival. In such cases, a promiscuous enzyme may be recruited to do a new job. Multiple promiscuous activities can even be patched together to constitute new metabolic pathways. Current projects in the lab include investigations of 1. The trajectory toward evolution of an efficient new enzyme starting from an inefficient promiscuous activity; 2. How the evolutionary potential of a promiscuous activity varies in enzymes from different bacteria that catalyze the same physiological reaction; 3. Pathways that can be patched together from promiscuous enzymes to compensate for the loss of an essential enzyme.



Joost de Gouw

Research Physicist, NOAA
Chemical Sciences Division,
Adjoint Professor of Chemistry
and Biochemistry

Volatile organic compounds are released to the atmosphere from natural and man-made sources, for example from forests, motor vehicles, and industrial processes. Hundreds of different compounds have been detected, each with different chemical and physical properties. Chemical reactions in the atmosphere that involve volatile organic compounds lead to the formation of pollutants such as ozone and fine particles, which impact air quality and climate. We use measurements by mass spectrometry and gas chromatography to quantify the emissions of volatile organic compounds to the atmosphere and study their chemical reactions. We make these measurements from research aircraft, ships, ground sites, and mobile laboratories. Current projects include the formation of fine particles from natural and man-made precursors in the southeast United States and the Los Angeles Basin, two regions with completely different emissions. We study energy sources such as corn ethanol, shale oil, and natural gas: The production of these has expanded rapidly over the past decade with uncertain impacts on air quality and greenhouse gas emissions. We are also interested in biomass burning, including wildfires, agricultural, and residential wood burning. Wildfires are increasingly common in the U.S. and can have episodic and strong impacts on the atmosphere. However, the chemical composition of smoke is complex and our understanding is limited by current analytical capabilities.



Lisa Dilling

Director, Western Water
Assessment,
Associate Professor of
Environmental Studies

My research focuses on how we can improve societal outcomes with respect to climate-related risks. I have examined why current science policies lead to research that is less usable for decision making and now will focus on how decision making affects adaptive capacity, or the ability to effectively respond and adjust to climate-related risks. My research program asks questions under three, interrelated themes with respect to climate and societal outcomes: 1. How can information be more usable in resource management and climate adaptation decision making?; 2. How does decision context affect policy options and demand for information?; and 3. What factors shape the adaptive capacity of organizations managing resources at the local level? I am a problem-oriented scholar utilizing mainly social and policy science mixed-method approaches. My research is also interdisciplinary and collaborative, combining disciplines such as geography, political science, and the natural sciences. I currently lead the Western Water Assessment, a Regional Integrated Sciences and Assessment program funded by NOAA that conducts innovative research in partnership with decision makers in the Rocky Mountain West, helping them make the best use of science to manage for climate impacts. My current research projects focus on drought in urban water systems, water governance and climate change, municipal adaptation to hazards, and knowledge for adaptation among pastoralists.



Randall Dole

NOAA Senior Scientist, Physical Sciences Division

My research focuses on physical processes and phenomena linking weather and climate. I am interested especially in the connections between extreme events and climate variations and change. The ultimate goal of this research is to improve NOAA services that inform decisions on early warning, preparedness, and adaptation. For the last year, I have been focused on the NOAA-led El Niño Rapid Response Mission, which engaged dozens of NOAA, CIRES, and other scientists around the world, in an effort to better understand one of the strongest El Niño events in decades. This mission, which rapidly pulled in NOAA aircraft, ship, and ground-based resources, has resulted in an unprecedented air-sea dataset, which will be scrutinized for years to come. I serve on the World Weather Research Program Scientific Steering Committee, which provides scientific oversight and guidance for a diverse set of major international weather research programs and activities coordinated through the World Meteorological Organization. I am a Fellow of the American Meteorological Society and of CIRES, and Division Director of the CIRES Weather and Climate Dynamics Division. I am the recipient of a U.S. Department of Commerce Silver Medal, the NOAA Administrator's Award, and four NOAA Bronze Medal Awards.



David Fahey

Director, NOAA Chemical Sciences Division

David Fahey is currently Director of the Chemical Sciences Division of NOAA's Earth System Research Laboratory in Boulder. The Division's mission is to advance scientific understanding of three major environmental and societal issues of our time, namely, climate change, air quality, and the stratospheric ozone layer, through research on the chemical and physical processes that affect Earth's atmospheric composition. His personal research interests are measurements of trace gases and aerosols in the troposphere and lower stratosphere and the interpretation of these measurements to advance understanding and support decision making. His current interests include water vapor and ice microphysics in the lower stratosphere, the role of black carbon and other aerosols in climate and air quality, the role of aviation in climate, and reducing the uncertainty in the calculation of radiative forcing of present day carbon dioxide in the atmosphere.



Chris Fairall

Team Lead, Boundary Layer Observations and Process, NOAA Physical Sciences Division

Chris Fairall is a physicist in NOAA's Earth System Research Laboratory in Boulder, Colorado, where he heads the Boundary-Layer Observations and Processes team. He works in unraveling the mysteries of how the ocean and atmosphere battle each other as part of the Earth's climate system from El Niño to hurricanes. He has spent decades developing and deploying air-sea interaction observing systems for NOAA ships and aircraft and has participated in nearly 50 research field programs and cruises from the tropics to the Arctic icecap. His work is devoted to making direct measurements for verifying and improving the representation of air-sea interaction processes (surface evaporation, absorption of heat, generation of waves, uptake of carbon dioxide) in climate models used for climate change projections. Do the models get the right clouds (stratus, cumulus, thunderstorms) over the right ocean? Do they transfer the right amount of carbon dioxide from the air to the water? Do they put the right amount of heat into the tropical oceans and take it out in the polar oceans? How does the ocean power hurricanes and what is required to allow realistic hurricanes to 'live' in climate models? Do models correctly represent the heat balance of the Arctic Ocean ice cap? Fairall's observing technology work has also led to improvements in the global ocean observing system. He is currently working on improving hurricane intensity forecasts.

CIRES Fellows



G. Lang Farmer

Professor of
Geological Sciences

My research interests are in investigating the origin and evolution of continental lithosphere through the use of natural chemical and isotopic variations in Earth materials. One such project, published in 2015, involved a study of sediments strewn on the surface of North America some 550 million years ago during the breakup (rifting) of the Rodinia “supercontinent” (Howard et al, *Earth and Planetary Science Letters*, v. 432, p. 300-310). The distribution of these sediments is controlled by variations in the sources of the sediments (what eroded) and the geography of the land surface at the time. Our approach was to determine the sources of the mineral zircon transported in these sediments, through the use of in situ uranium-lead age determinations and hafnium isotopic analyses from individual minerals. We concentrated on zircon with ages in the range from 1.0 Ga to 1.2 Ga, mineral grains that are thought to have been eroded from rocks of this age at the eastern margin of the North American continent and then transported across the continent to the west. Armed with hafnium isotopic data from these zircon grains, we were able to recognize changes in the elevation of the rifting continental margin and the continental interior and to identify the extent of marine transgression onto the continent through time.



Fred Fehsenfeld

CIRES Senior Research
Scientist, NOAA Chemical
Sciences Division

The goal of my research is to identify and quantify the emissions and processes that determine tropospheric distribution of ozone and aerosols to better understand how these atmospheric species jointly influence regional air quality and climate forcing. The research approach uses measurements of these species through comprehensive, integrated field studies followed by a systematic analysis and appraisal of the results. Since 1999, NOAA and CIRES have jointly undertaken nine integrated field studies, many under my leadership. These field programs provide 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. In 2016, I will assist in the interpretation and reporting of the data taken during these studies in order to better understand the atmospheric effects of chemical emissions on regional and local air quality and regional and global climate forcing. The immediate aim of my future research will be on assisting in the development of a major multi-year NOAA/CIRES field and laboratory study titled FIREX (Fire Influence on Regional and Global Environments Experiment). The initial focus of the studies will be on the western United States with the goal of better identifying and quantifying the emissions from major forest fires and the subsequent chemical processing, transformation, and transport of the emissions. With this information, we hope to better assess the impact that forest fires have on regional air quality in the U.S. West and on regional and global climate forcing.



Graham Feingold

Research Scientist, NOAA
Chemical Sciences Division

Graham Feingold is a research scientist at NOAA's Earth System Research Laboratory in Boulder, Colorado. His interests lie in aerosol-cloud-precipitation interactions and implications for climate change. His focus is on process level studies using high resolution models and observations (aircraft and surface remote sensing) at the cloud scale (tens of meters to tens of kms). He received his Ph.D. in Geophysics and Planetary Sciences (*summa cum laude*) from the Tel Aviv University in 1989. His research interests include lidar and radar remote sensing of clouds and aerosol, modeling and remote sensing of aerosol-cloud interactions (“indirect effects”), “cloud burning” or the “semi-direct effect,” and cloud processing of aerosol through multiphase chemistry. He has authored or co-authored more than 150 peer-reviewed articles on these subjects. Feingold was a lead author on the IPCC AR5 Chapter 7 (Clouds and Aerosols), and is an associate editor of the online journal *Atmospheric Chemistry and Physics*, a contributor to the Climate Change Science Program, and a chapter author of the International Aerosol-Precipitation Scientific Assessment Project. He has served as a NOAA representative to EarthCare and IGAC and is currently on the Aerosol-Cloud-Precipitation-Climate (ACPC) steering committee.



Noah Fierer

Associate Professor of Ecology and Evolutionary Biology

Noah Fierer is a microbial ecologist. He studies those microscopic organisms, namely bacteria and fungi, that are abundant and ubiquitous in nearly every environment on Earth, where they are critical to the functioning of ecosystems. Work by his lab group has focused on those microorganisms living inside our homes, in soil, on the human body, and in the atmosphere. His work largely focuses on exploring the diversity of microbial communities (using high-throughput DNA sequencing-based approaches), identifying the fundamental controls on microbial processes, and examining the mechanisms by which microorganisms influence human health and the health of ecosystems. As one example of recent work, his lab group has demonstrated that excessive inputs of nitrogen to terrestrial ecosystems are contributing to consistent shifts in the composition soil microbial communities, shifts that have direct impacts on soil carbon storage and soil fertility levels. Other recent work has focused on characterizing the surprisingly high levels of microbial diversity found inside our homes, how home characteristics and occupant activities influence those microbial communities, and the potential effects of these bacteria and fungi on human health. Lastly, he has been engaged in a series of studies leveraging recent advances in DNA sequencing to begin building the first high-resolution map of the diversity and abundances of airborne plant pollens, fungi, and bacteria across the continental United States.



Timothy J. Fuller-Rowell

CIRES Senior Research Scientist, NOAA Space Weather Prediction Center

At CIRES, as well as studying traditional terrestrial weather, we also study Space Weather, which is how changes in the space environment surrounding Earth affect things like satellite communications and GPS navigation and positioning. When the Sun is active it can spew out big clouds of plasma that sometimes strike Earth and drive currents in the upper atmosphere, which perturb Earth's magnetic field. During these "geomagnetic storms," plasma around us in the ionosphere can increase by as much as a factor of five, which together with steep gradients can severely impact GPS systems, like in your car. Although we know from measurements the plasma content increases, we are not sure where and when the increases will occur, and where in the ionosphere the plasma is created and stored. Scientists at CIRES are trying to model one of the biggest recent storms that occurred on St. Patrick's Day, March 17, 2015. With a new model of the ionosphere we are now able to capture these big increases in plasma content. We think a lot of the plasma is stored at higher altitudes, beyond the reach of some ground-based instruments measuring the electron density profile. With the new model we hope to understand the three-dimensional structure and how it is created and transported, so we can mitigate the impact on our GPS system.



R. Michael Hardesty

CIRES Senior Research Scientist

My current research focuses on use of lidar (laser radar) to characterize atmospheric dynamical processes. By employing Doppler lidar techniques, in which laser light reflected from small atmospheric particles is analyzed to measure the small wavelength shift caused by motion of the particles, winds and turbulence at multiple distances can be measured. We are evaluating the applicability of Doppler lidars deployed around Indianapolis in conjunction with chemical observations to characterize greenhouse gas emissions at urban scales. The lidar observations are processed to estimate transport and mixing of pollutants for use in models that compute the emissions from Indianapolis. The goal of this research is to develop and validate methodologies that can be deployed at diverse urban locations to establish baselines for tracking changes in emissions and evaluating mitigation strategies. We are also investigating space-based Doppler lidar instrumentation for providing wind measurements on a global scale to improve medium range weather prediction and better track atmospheric change on global scales. In collaboration with Ball Aerospace, a Doppler wind lidar concept suitable for deployment on the International Space Station or a free-flying satellite is being tested. A prototype instrument has been designed and constructed, and will be flown on a NASA WB-57 research aircraft during mid-2016 to evaluate and validate performance.

CIRES Fellows



José-Luis Jiménez

Professor of Chemistry
and Biochemistry

Aerosols are small particles suspended in air, with typical lifetimes of one to two weeks in the atmosphere before they are returned to Earth's surface. They have major effects on climate forcing, human health, regional visibility, crops, and ecosystems. About half of the mass of the longest-lived ("submicron") aerosols is composed of organic compounds—i.e., molecules composed of chains of carbon atoms with other elements such as hydrogen, oxygen, and nitrogen. Important sources of these organic aerosols (OA) include anthropogenic pollution (e.g., cars and trucks), biogenic compounds (emitted from plants and soils), and biomass burning (e.g., agricultural and wildfires). Gas-phase chemistry followed by gas-to-particle conversion leading to secondary organic aerosols (SOA) is a key component of all those sources. The amount, properties, and evolution of the OA from each of these sources are poorly characterized, and our group combines field, laboratory, and modeling research to better understand and constrain them. Our field measurements, on ground and aircraft platforms, span from urban to rural to remote locations within North America, Europe, South America, and Asia. Our main research tools include aerosol mass spectrometry, chemical ionization mass spectrometry, portable oxidation flow reactors, large atmospheric simulation chambers, and chemical kinetic models. In addition to application of these tools to a wide range of atmospheric systems, we are heavily invested in developing and improving cutting edge instrumentation to better understand atmospheric chemistry.



Craig H. Jones

Professor of
Geological Sciences

Craig Jones's research centers on the evolution of mountain belts, in particular aspects of mountains that are not obvious from their plate tectonic context. Recently he has focused on the Sierra Nevada, the Rocky Mountains, and the High Plains. He and his coauthors published work suggesting that the reason Denver is the Mile High City is because of alteration of the lower crust, where water that rose from subducting ocean floor reacted with garnet in the lower crust, replacing garnet with lower-density minerals, thus reducing the density of the lower crust and causing regional uplift. Ongoing work seeks to try and observe variations in the crust that would test this idea. Work in the Sierra Nevada seeks to determine how the modern high elevations are supported and how that fits in with a controversial geologic history. Inversion of observed arrivals of shear waves is being merged in with previously published work using pressure (P) waves; this has revealed some areas where deviations from a constant ratio in the speeds of these two waves is required. Such deviations probably reflect melt in the upper mantle under the Long Valley volcanic center and the presence of atypical lithologies in a high wavespeed body under the southwestern Sierra. This latter anomaly might represent the old root of the granites of the Sierra in the process of sinking into the mantle, allowing for uplift of the Sierra.



Kris Karnauskas

Assistant Professor of
Atmospheric and Oceanic
Sciences

The overarching goal of my research is to understand how the climate system changes, and the impacts of such changes on humans as well as marine ecosystems. For example, why does the climate vary from one year to the next, and how will it respond to more greenhouse gases? A particular focus is on the dynamics of the tropical ocean and atmosphere as a coupled system, such as El Niño. The thermal inertia of the climate system is in the ocean, so understanding the physics of the ocean's storage and movement of heat by currents is essential to understanding climate variability. Ocean circulation also serves as the mediator between global climate change and localized impacts on marine ecosystems. "No challenge poses a greater threat to future generations than climate change," said President Obama in his 2015 State of the Union address. "The Pentagon says that climate change poses immediate risks to our national security. We should act like it." To this end, I combine "big data" (hundreds of global climate model simulations) as well as observations ranging from satellites to pinpoint underwater measurements in order to understand the fundamental dynamics of the climate system along with a broad range of impacts including marine ecosystems, tropical cyclones, freshwater resources, wind energy, and transportation networks.



Jennifer Kay

Assistant Professor of
Atmospheric and Oceanic
Sciences

The Kay group works at the nexus of observations and modeling to understand the processes controlling climate change and variability. We often focus on cloud and precipitation processes, and their coupling with the global circulation. We primarily work in polar regions, though lately we have been going global! Together with Line Bourdages (Ph.D. student, McGill University), our recently accepted *Journal of Geophysical Research-Atmospheres* paper evaluates cloud phase in the atmospheric component of a global coupled climate model using spaceborne lidar observations. Our scale-aware and definition-aware comparisons enabled us to motivate improvements to the model clouds, and to “fix” two long-standing model biases: excessive absorption of shortwave radiation over the Southern Ocean and insufficient absorption of shortwave radiation over the Tropics. Atmospheric and Oceanic Sciences (ATOC) Ph.D. candidate Ariel Morrison uses spaceborne lidar to measure the observed cloud response to Arctic sea ice loss. ATOC Ph.D. candidate Vineel Yettella recently submitted a paper to *Climate Dynamics* on precipitation changes in extratropical cyclones in a warming world, and is now breaking ground on climate prediction using initial-condition climate model ensembles. ATOC Ph.D. candidate Bill Frey researches: “How does “fixing” the Southern Ocean absorbed shortwave radiation bias impact climate sensitivity and atmospheric circulation.” Finally, visiting postdoc Cyril Palerme researches Antarctic precipitation distributions in a warming world. We have had a busy and productive year.



William M. Lewis Jr.

CIRES Associate Director,
Professor of Ecology and
Evolutionary Biology

My research deals with limnology, the study of inland water ecosystems (lakes, streams, rivers, wetlands). Recently, research in the CIRES Center for Limnology has focused on food web dynamics as viewed through lakes of the Rocky Mountain National Park (RMNP). Some of these lakes have fish and some not. In a study led by Thomas Detmer, a Ph.D. student, lakes with and without fish were sampled over three years for fish, invertebrate prey, and algal food sources of invertebrates. The study showed that fish are very effective at removing large invertebrates. Thus, it seems that fish suppress total growth (production) of invertebrates in lakes, but total invertebrate production in RMNP lakes is in fact the same in lakes with and without fish. The invertebrates have a compensatory response to fish predation. The invertebrate communities affected by fish show an increase in abundance of smaller organisms, which grow more rapidly than the larger organisms that they replace, and thereby stabilize total production of invertebrate biomass. Ecological compensation mechanisms such as this are of interest in estimating the response of community functions to environmental change. The work will be published during 2016 in *Limnology and Oceanography* (Predator driven changes in prey size distribution stabilize secondary production in lacustrine food webs, Thomas Detmer, James McCutchan, Jr., and William Lewis, Jr.).



Ben Livneh

Assistant Professor of Civil,
Environmental, and
Architectural Engineering

Livneh’s research focus this year has been primarily focused on quantifying the hydrologic impacts of extremes and the response of catchments to wildfire and drought in the western United States. Pertaining to extremes, his group has investigated the causes for the unprecedented 2011 Missouri Basin flood event in the context of both increasing decadal variability since the 1970s and projected future climate changes. The 2012 Great Plains drought occurred on the heels of the 2011 flood, and brought widespread impacts to agriculture and the economy. We used sophisticated models of the land surface, meteorological observations, and remote sensing to better characterize the physics of these events and to explore potential predictability. These projects are in collaboration with colleagues at NOAA and the U.S. Army Corps of Engineers. Other research has focused on developing comprehensive numerical models of sediment responses to drought and wildfire on the Front Range. This latter project is part of an EPA project geared towards understanding the impacts of drought on water supply and water quality.

CIRES Fellows



Peter Molnar

Professor of
Geological Sciences

I continue to work on two general questions: how mountain ranges and high terrain are built and how geologic processes affect climate on geological time scales. For the first, Philip England (Oxford University), Craig Jones, and I explored how mantle dynamics creates high terrain, and in particular the degree to which flow within the mantle induces stress that supports high terrain. We concluded that this general concept, “Dynamic Topography,” is a gross exaggeration. Such flow-induced stress contribute <300 m to topography, just noise in a place like Tibet, where elevations are 5000 m. Among studies of the second type, Tim Cronin (Harvard post-doc) and I assessed the possibility that islands emerging in Indonesia could have affected global climate. Since 5 million years ago, the areal extent of islands in Indonesia increased by ~60 percent. Islands attract rainfall, and latent heating associated with condensation of moisture heats the upper troposphere. Thus the growth of islands in Indonesia could have heated the overlying upper troposphere and in doing so, it would have strengthened atmospheric circulation over the tropical Pacific, transforming Pacific climates from resembling that of El Niño in the past to resembling that of La Niña today, with only rare El Niño events and facilitating recurring ice ages. Finally, Oxford University Press published a short book that I wrote entitled *Plate Tectonics: A Very Short Introduction*.



Stephen A. Montzka

NOAA Research Chemist

Research in the Montzka lab revolves around understanding how and why the chemical composition of our atmosphere is changing over time. Chemicals that deplete ozone, influence climate, or affect air quality are typically the center of attention. In 2015, much of the focus was on trace gases that deplete the ozone layer, but for which emissions arise naturally or from industrial production not controlled by an international law tasked with guiding the recovery of stratospheric ozone. Measurements from the Montzka lab showed that global concentrations of one particular chemical (dichloromethane, or CH_2Cl_2 , used as a cleaning agent and in chemical manufacturing) not controlled by international agreements have increased nearly a factor of two over the past decade. In so doing, this chemical augmented ozone-depleting chlorine concentrations notably more than others that are controlled by international agreements.

2015 also brought progress in quantifying emissions of trace gases from the United States based on atmospheric measurements in a fairly high-density sampling network. One goal of this effort is to understand the U.S. contribution to global atmospheric changes. While preliminary efforts focused on understanding the source of dichloromethane emissions, U.S. emissions of a chemical (HFC-134a) used as a substitute for ozone depleting substances in automobile air conditioning, and of a primary ozone depleting gas (carbon tetrachloride) were derived.



William Neff

CIRES Senior Research
Scientist

My research focuses on the atmospheric boundary layer (ABL) where the Earth’s atmosphere interacts with its surface. The stable ABL, where the atmosphere is coldest near the surface, is most common at night in mid-latitudes and in the high latitudes throughout the day. Improving our understanding of the stable ABL in high latitudes is important as the science community seeks to better forecast changes in the climate of the poles as the Earth continues to warm. Currently I am using data from two polar sites, in Greenland and Antarctica. Recently, results related to the ICECAPS field program (Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit) have focused on the role of atmospheric rivers in transporting warm, high-moisture air into the Arctic region. In contrast, the South Pole, at 2835 m above sea level, is useful to advance fundamental understanding of stable ABL surface exchange processes because it has no daily cycle of sunshine and is generally dry and cold. In addition, ice cores from Antarctica trace past climate back at least 800,000 years and can allow us to interpret current climate in a historical context. Nitrate, with biological and anthropogenic sources, is one signal of great interest in ice cores in both Antarctica and Greenland. To this end, the South Pole has been the site for a number of studies related to boundary layer effects on nitrogen recycling and loss, prior to its signal being recorded in the ice.



R. Steven Nerem

Professor of Aerospace
Engineering Sciences

Since 1992, a series of satellite altimeter missions (TOPEX/Poseidon, Jason-1, -2, -3) have precisely measured the height of the sea surface nearly globally between $\pm 66^\circ$ latitude. Twenty-three years of measurements now show us that global average sea level has been increasing at an average rate of 3.3 mm/year, but with substantial variation from one year to the next, mostly due to changing rain patterns during El Niño and La Niña events. In 2002, the twin GRACE (Gravity Recovery and Climate Experiment) satellites were launched to precisely measure changes in the Earth's gravitational field over time. GRACE tells us how water moves around on the surface of the Earth and in particular, how much meltwater the glaciers and ice sheets are contributing to sea level change. Together, these missions tell us that about a third of the sea level rise is due to melting of Greenland and Antarctica, about a third to melting of mountain glaciers, and the remaining third to the addition of heat to the oceans (which causes the water to expand its volume). Moving forward, the long-term goal of this research is to better understand present-day sea level change so that we can better calibrate models predicting future sea level change, which is important for coastal planners and to understand the socioeconomics impacts of sea level rise.



Judith Perlwitz

CIRES Senior Research
Scientist, Team Lead, Attribution
and Predictability Assessments,
NOAA Physical Sciences
Division

Winter climate and frequency of extreme daily weather events over large and heavily populated regions of Europe and North America are strongly affected by the variability of the North Atlantic Oscillation (NAO). Therefore, the ability to predict the phase and magnitude of the NAO on subseasonal to seasonal time scale is of great societal benefit. There is increasing evidence that stratospheric processes and stratospheric-tropospheric coupling contribute to an enhanced predictive skill of tropospheric phenomena, including the El Niño/Southern Oscillation-North Atlantic Oscillation (ENSO-NAO) connections on seasonal time scale. The role of the stratosphere on the predictive skill on the subseasonal time scale has not been systematically explored, and the available data and model studies are not conducive to understanding the responsible processes. In a new project in collaboration with scientists at NCAR's Global Dynamics Division (CGD), we aim to improve our understanding of the role of the stratosphere on the predictability of the North Atlantic circulation (NAO) and related extremes and to quantify to what extent NAO predictability can be improved by including a well-resolved stratosphere in a subseasonal modeling framework. In a collaboration with NASA Goddard Space Flight Center, we are currently investigating the importance of stratospheric ozone chemistry-climate interactions on the NAO predictability.



Balaji Rajagopalan

Professor of Civil,
Environmental, and Architectural
Engineering

Competition for freshwater resources is intense as global populations increase. Two places where this is starkly evident are the western United States and Indian subcontinent, where developmental pressures are stressing already limited water resources, exacerbated by substantial year-to-year and multi-decadal variability. My research program attempts to address these problems with three interconnected themes: 1. Understanding the causes for spatial and temporal variability and predictability of the water cycle; 2. Forecasting and scenario generation tools for water resource management that incorporate understanding of climatic variability and change; and 3. Evaluating decision strategies for resources management—water supply, agriculture, wastewater, etc. In the western United States, we find that the Colorado River flows are strongly modulated by Atlantic Multidecadal Oscillation and Pacific Decadal Oscillation at multi-decadal time scales, besides nonlinear dynamical analysis indicate that the predictability is regime dependent and varies over time. These insights motivate stochastic time series flow projection techniques using wavelets and a new paradigm for water resources management. Analysis of space-time variability of Indian summer monsoon rainfall indicates sub-seasonal asymmetry in the El Niño and La Niña teleconnections and significant spatial variability over India, which provokes a new approach to monsoon forecasting. These findings were used to propose a new hypothesis based on Pacific teleconnections to explain Holocene wetness over India. In addition, my research explores understanding space-time extremes and multivariate extremes of hydroclimatology, water quality variables, and construction safety, using Bayesian hierarchical techniques.

CIRES Fellows



Prashant Sardeshmukh
CIRES Senior Research
Scientist

The probability distributions of climate system variables are skewed and heavy tailed in a distinctive way. Ignoring or misrepresenting this can have large implications for detecting, attributing, and predicting changes in extreme climate risks using limited observations and imperfect models. We are developing a new approach to this problem by exploiting the fact that the observed skewness and heavy tails are well captured by a general class of so-called Stochastically Generated Skewed distributions (SGS distributions) that includes Normal distributions as special cases. SGS distributions are associated with damped linear Markov processes perturbed by asymmetric stochastic noise, and as such represent the simplest physically based prototypes of the observed distributions. The tails of SGS distributions can also be directly linked to the Generalized Extreme Value (GEV) and Generalized Pareto (GP) distributions traditionally employed in extreme value analysis. This correspondence provides a simple physical explanation of the shape of the GEV/GP distributions, and also the fatter-than-exponential Pareto-like tails of precipitation distributions. From a practical standpoint, the extreme value distributions associated with SGS distributions can be more accurately estimated using all available data in a data record instead of only the extreme values as in the GEV/GP approaches. The associated Markov process model can be used to provide rigorous confidence intervals, and to investigate the persistence statistics of extreme events.



Mark Serreze
Director, National Snow and
Ice Data Center, Professor of
Geography

Mark Serreze's research primarily covers topics related to Arctic climate and climate change. One focus is predictability of summertime Arctic sea ice conditions at the regional scale; this research is driven by recognition that as the Arctic loses its sea ice cover, it becomes more accessible to shipping and other activities. Predicting ice conditions several months out is a difficult problem, in considerable part because summer weather patterns are highly variable. Understanding this variability in weather patterns is of long-standing interest to Serreze. For example, with graduate student Alexander Crawford, Serreze has recently been looking at how storm activity over the central Arctic Ocean relates to the summer Arctic Frontal Zone—a band of pronounced temperature gradients that develops in preferred areas along the Arctic coastline, related to the stronger heating of the land surface relative to the ocean. Related work has examined extreme precipitation events in the Arctic. An effort published in 2015 focused on events at Spitsbergen, a high Arctic island. A fascinating finding is that extreme precipitation events can be linked not just to the presence of strong storms but to the influence of atmospheric rivers—narrow corridors of atmospheric water vapor typically several thousands of kilometers long and only a few hundreds of kilometers wide that bring moisture into the Arctic from tropical sources.



Anne F. Sheehan
Professor of Geological
Sciences

Research in the Sheehan group includes a range of geophysical investigations related to earthquake and tsunami hazards, structure of the crust and mantle, and active tectonics. Sheehan is working with an international team of collaborators to study earthquake processes of the Hikurangi subduction zone off the east coast of the North Island of New Zealand. The shallow part of the Hikurangi subduction zone experiences 'slow slip' earthquakes approximately every 18-24 months, and data from a deployment of ocean bottom seismometers and absolute pressure gauges is being used to better characterize the fault slip behavior and physical processes of the subduction interface. Seafloor pressure data is typically used to measure differences in water height, such as in the case of a tsunami, but in the Hikurangi experiment was successfully used to measure vertical deformation of the seafloor. Sheehan used seafloor pressure measurements to study the Haida Gwaii tsunami offshore Washington and Oregon, published recently in *Seismological Research Letters*. Sheehan is collaborating with researchers at the University of Tokyo to further develop methods for tsunami forecasts using arrays of seafloor pressure data. Closer to home, the Sheehan group has several geophysical investigations in the Rocky Mountain region, including studies of induced seismicity, a magnetotelluric study to resolve electrical conductivity of the crust and mantle beneath the Rocky Mountains and Great Plains, and an ongoing GPS study to monitor crustal deformation of the region.



Robert E. Sievers

Professor of Chemistry and Biochemistry

The researchers in my group and I are interested in analytical chemistry, pharmaceutical science, aerosols, microparticles and nanoparticles, inhalable vaccines and antibiotics, protection against concussions, and supercritical fluids. We study the simultaneous stabilization, drying, and micronization of vaccines, antibodies, proteins, antibiotics, and anti-inflammatory pharmaceuticals and other products of the biotechnology revolution. My team is working on two of the 14 “Grand Challenges in Global Health” identified by the Bill and Melinda Gates Foundation and the National Institutes of Health Foundation as critical to world health: needle-free administration of vaccines (by pulmonary sub-lingual or nasal aerosols), and vaccines that do not need refrigeration for long-term storage. To this end, I have developed strong collaborations with groups in India. My team, the Global Health Research Group in CIRES, has invented new methods for synthesizing, and purifying novel, beneficial aerosols that treat medical conditions by delivery of respirable aerosols through the pulmonary tract. We study the aerosols for their prospective or proven ability to treat or prevent a variety of maladies such as infections, stress, pain, concussions, and inflammation. For example, we are synthesizing and stabilizing live attenuated virus measles vaccine, and also creating and preserving amorphous, rather than the usually obtained crystalline, aspirin, by Bubble Drying solutions of aspirin with carefully selected modifying excipients by pressurized carbon dioxide or nitrogen-assisted nebulization (patents granted and pending).



Kristy Tiampo

Director, CIRES Earth Science and Observation Center, Professor of Geological Sciences

The primary goal of my research is to provide a comprehensive understanding of the processes that govern natural and manmade hazards and, in particular, those that generate earthquakes, in order to improve estimates of local and regional seismic hazard. This is accomplished through the integration of large quantities of remote sensing data such as space-based Global Navigation Satellite System (GNSS) measurements, differential Interferometric Synthetic Aperture Radar (DInSAR), satellite gravity data, and seismicity. These big data sets provide critical information on the nature and magnitude of multiple hazards of interest. This research program includes developing new methods aimed at improving both the quality and quantity of that data, innovative analysis techniques, accurate models of the underlying physical causes of those hazards, and timely and appropriate assimilation into various computational models. Current research projects include studies of earthquakes triggered by fracking in Colorado, Texas, Oklahoma, and Alberta, Canada; infrastructure damage caused by ground-water mining in Seattle, Washington and California; recent episodes of volcanic unrest at Kilauea, Hawaii; Mt. Etna and Campi Flegrei, Italy; and the Canary Islands, Spain; and the use of real-time social media data, such as Twitter, for rapid hazard mapping and response after large disasters such as floods or earthquakes.



Margaret Tolbert

Distinguished Professor of Chemistry and Biochemistry

Research in the Tolbert group is focused on heterogeneous atmospheric chemistry, specifically determining the chemical, physical, and optical properties of atmospheric particulate. A specific focus of our work is unraveling how these properties vary with relative humidity and temperature in the atmosphere. As particles are exposed to increasing relative humidity, some particles take up water forming solid hydrate particles or aqueous droplets. Further increases in relative humidity can result in ice cloud formation if nucleation conditions are met. In contrast, decreasing relative humidity results in particle morphologies and water content that are difficult to predict theoretically, and must be measured in the laboratory. We develop novel experimental techniques including Raman microscopy, optical levitation, and cavity ring down spectroscopy to probe water content, aerosol phase, and impact on aerosol optical properties. In addition to fundamental studies of particles, we are also exploring how atmospheric particulate water impacts current problems such as stratospheric ozone depletion, global climate change, urban smog, and visibility degradation. As well as studies of atmospheric aerosols on the Earth, we are also probing particles that are present on other worlds including Titan and Mars.

CIRES Fellows



Greg Tucker

Professor of
Geological Sciences

When most of us hear the word “flood,” we imagine things getting wet. What is often less appreciated is that the most dramatic and costly impacts of flooding are about erosion and sedimentation: washed out roads and bridges, sediment-impaired water quality, water-triggered landslides and debris flows, fields and neighborhoods buried in silt. Average annual costs related to erosion and sediment management in the United States have been estimated at over \$10 billion annually. Greg Tucker’s research group works to understand these and other erosion and sedimentation processes. They address both short-term processes—those with direct human impacts—and the ways in which those processes play out over geologic time to shape landforms and landscapes. Examples of recent projects include: documenting soil erosion following wildfire using 3D laser survey technology; studying the long-term evolution of topography along seismically active mountain fronts in Utah and central Italy; and assessing the potential for mineral-grain luminescence to provide a new source of information about sediment transport in rivers. The group also leads the Landlab project (<http://landlab.github.io>), which provides an open-source software library for efficiently building and combining computational models in the earth and environmental sciences.



Veronica Vaida

Professor of Chemistry
and Biochemistry

Our program explores water and sunlight-mediated processes in planetary atmospheres including the contemporary and prebiotic Earth to provide new inputs for models of planetary atmospheric chemistry and climate. With tools and concepts of physical chemistry, we investigate the possibility of harnessing solar radiation and converting it to usable chemical energy. Using solar simulators in laboratory studies, our group has been exploring the importance of water and the environment to the photochemistry of organic species involved in isoprene oxidation. A specific example studied in the last year is pyruvic acid, a small organic molecule found in the atmosphere in both the gas and the aqueous phases. Sunlight driven chemistry of pyruvic acid in water generates complex organic molecules and molecular aggregates, building complexity in the environment. We have scaled the fundamental experimental laboratory results with pyruvic acid to realistic atmospheric conditions by using environmental chamber studies. Specifically we are using the simulation chamber CESAM at the Université Paris–Est Créteil Val de Marne (UPEC) in collaboration with Professor Jean-François Doussin. By combining these laboratory and chamber studies we hope to connect our understanding of the photolysis of pyruvic acid to mechanisms for aerosol nucleation and growth. The sunlight driven chemistry has been extended to other similar compounds found at the sea surface, in sea spray, and on atmospheric aerosols.



Rainer Volkamer

Associate Professor of
Chemistry and Biochemistry

Rainer Volkamer is an Associate Professor in Chemistry. His research informs air quality and climate discussions. He teaches Instrumental Analysis at the undergraduate level, and Atmospheric Optical Spectroscopy at the graduate level. His research group designs optical spectroscopic instruments to conduct in-situ and remote sensing field measurements of atmospheric trace gases, radicals, and aerosol optical properties from ground, ships and aircraft, and studies multiphase chemistry of aerosols in the laboratory. His group is part of the CIRES Energy Initiative. Recently, Prof. Volkamer was awarded the Karlsruhe Institute of Technology Distinguished International Scholar award. In 2015, his group demonstrated the first vertical profile measurements of bromine oxide (BrO) and iodine oxide (IO) radicals in the tropical troposphere (Volkamer et al., 2015; Wang et al., 2015). These measurements show that tropospheric halogen chemistry has a larger capacity to destroy ozone (O₃) and oxidize atmospheric mercury than previously recognized. Halogen chemistry is currently missing in most global and climate models, and helps explain the low O₃ levels in preindustrial times. Public health concerns arise from bioaccumulation of the neurotoxin mercury in fish. Bromine chemistry in the free troposphere oxidizes mercury at a faster rate, and makes water-soluble mercury available for scavenging by thunderstorms. These novel findings illustrate the global interconnectedness between energy choices affecting mercury emissions in developing nations and mercury deposition in, for example in Nevada, or the southeastern United States.



Carol A. Wessman

Professor of Ecology
and Ecology and
Evolutionary Biology

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. As part of the University of Colorado's Earth Lab, over the next years we seek to determine factors driving the broad-scale structure and pattern of dieback of Colorado forests. Key to understanding the impact of widespread tree mortality in Colorado landscapes is teasing apart the overlap and interactions between the disturbances common to these ecosystems: insect infestations, wind, and fire. This is particularly important in the context of drought and projected climate change, which may influence successful regeneration patterns and related ecosystem services such as carbon storage, forest habitat, and water resources. Data from Unmanned Aircraft Systems (UAS) could provide critical information needed to link smaller-scale stand structure (e.g. tree densities, live/dead) and processes (regeneration success, soil moisture) to ecosystem dynamics at landscape scales. We propose to connect UAS data collected from overflights in western Boulder County with tree inventory and canopy health data collected near the Niwot Ridge Long-Term Ecological Research station. Subsequently, UAS analyses will inform our proposed integration of satellite-based and other aerial-flight information on multiple disturbances such as beetle-kill and fire, existing survey data on regeneration densities, and in situ data on past and current climate.



Paul Ziemann

Professor of Chemistry
and Biochemistry

In the past year research, the Ziemann group has primarily investigated the chemistry involved in the formation of secondary organic aerosol particles in the atmosphere. These microscopic particles are formed when volatile organic compounds that are emitted by vegetation, vehicles, and industry are oxidized in the atmosphere to less volatile products, which can condense into particulate matter. Atmospheric particulate matter has important environmental effects, influencing visibility, climate, and human health. Laboratory studies were conducted under simulated atmospheric conditions to identify the products of oxidation reactions, especially those that form particles, in order to develop models for predicting atmospheric oxidation and aerosol formation processes. In addition, collaborative studies investigated the potential role of these particles in cloud formation and sought to determine how mixtures of emissions from urban areas and forests react to form secondary organic aerosol in the southeastern United States. Finally, in a new project being conducted with the Jiménez group, research methods that have previously been used for studies of outdoor air have been applied to studies of indoor air. These studies have identified sources of volatile organic compounds in a University of Colorado Boulder classroom and determined the influence of ventilation, wall chemistry, and emissions from human breath and skin oxidation on the composition of indoor air.

Center for Limnology

The Center for Limnology conducts field and laboratory studies of aquatic ecosystems in Colorado. The studies fall into several categories: biogeochemical (e.g., nutrient cycling), bioenergetics (e.g., photosynthesis, growth rates of consumer communities), and ecosystem structure (e.g., biodiversity, physical and chemical constraints on ecosystem processes). During 2015-2016, the greatest activity for the Center was finalization of a four-year study of foodweb

characteristics in lakes of Rocky Mountain National Park. The park makes a good setting for comparative studies because it offers lakes that have foodwebs containing fish and lakes without fish.

Our principal interest for 2015 was analysis of trophic cascades. Professor Steven Carpenter and colleagues at the University of Wisconsin invented and defined the term “trophic cascades” in the 1980s. They pointed out that the abundance of organisms in the top trophic level (feeding level) of a food chain create an inverse relationship with the abundance of the level below, upon which they feed. These relationships cascade to the bottom of the food chain (plants). Because of the inverse relationships passed through the food chain it is possible, they argued, to control the characteristics of the first level in the food chain (plants) by manipulating the top level in the food chain (top predators), so that plants are suppressed by aggressive grazing of animal populations that feed on them (see figure at left).

Applied to lakes, the trophic cascade predicts that a food chain with four trophic levels will show piscivorous fish at the top, invertivorous fish second, invertebrate grazers third, and algae at the bottom. Carpenter and colleagues argued that a food chain of this type, if strongly reinforced with pisciv-

orous fish at the top, will show suppression of algae because invertivorous fish are held in check by piscivorous fish, which means that the invertebrates become abundant and consume the algae. They recommended implementation of this principle for management purposes to counteract a worldwide nuisance, which is excessive abundance of algal populations in lakes in response to nutrient enrichment by humans.

Studies headed by graduate student Tommy Detmer (photo at right) in Rocky Mountain National Park showed that lakes with fish suppress invertebrate biomass because fish remove invertebrate biomass through predation, and they preferentially consume the largest of invertebrates. This outcome is as predicted by Carpenter and colleagues. He also showed, however, that the abundance of algae (phytoplankton) in these lakes is not significantly affected by the presence or absence of fish, which is contrary to the trophic cascade theory. Others have also shown that the trophic cascade mechanism does not work as expected in many cases, for reasons unknown. Detmer, however, was able to show why. Because fish are size selective, and feed on the largest invertebrates, they change the invertebrate community from a mixture of large and small invertebrates to a community consisting entirely of small invertebrates. These small invertebrates, which are no longer in competition with larger invertebrates, become more abundant than they were in the presence of larger invertebrates. Small invertebrates also grow faster than large invertebrates. Therefore, a shift to abundant small invertebrates in the presence of fish is a compensatory response in terms of invertebrate community growth rate because a community with only small organisms produces just as much biomass per unit time as a community with both small and large organisms, even though the trophic cascade concept would suggest otherwise. Detmer has shown that nature contrives to disrupt the trophic cascade by mechanisms that were unexpected when the trophic cascade concept was introduced. Using trophic cascades to achieve human purposes will be more complicated than it seemed at first.

Trophic Cascade Theory

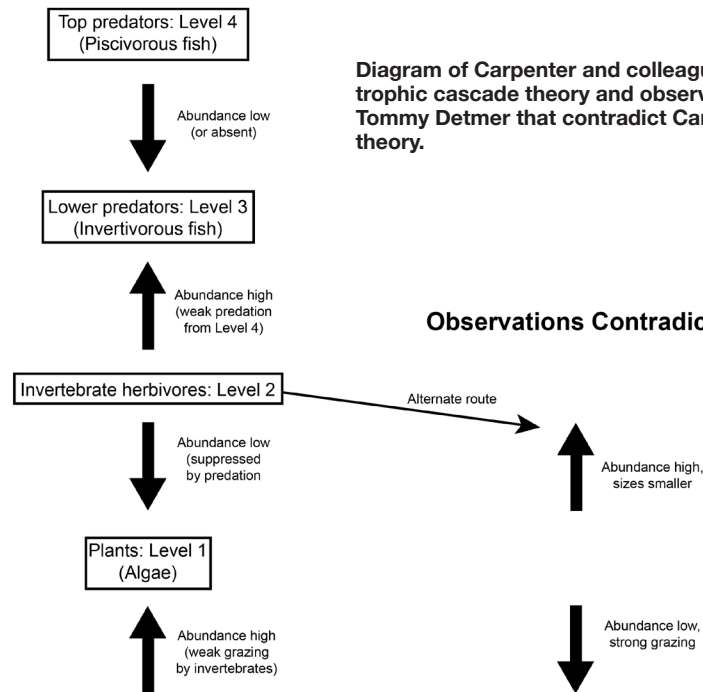
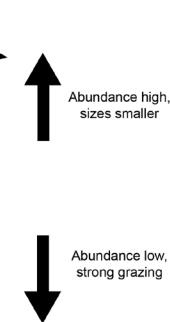


Diagram of Carpenter and colleagues' trophic cascade theory and observations by Tommy Detmer that contradict Carpenter's theory.

Observations Contradict Theory





Tommy Detmer sampling a lake in Rocky Mountain National Park. Photo: Morgan Heim/CIRES

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. We work to improve how science and technology policies and politics address societal needs. 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.

Highlights

- CIRES Fellow Max Boykoff assumed the directorship of CSTPR in March 2016 after Roger Pielke, Jr.’s term ended. Max joined the University of Colorado faculty (and CIRES) in the fall of 2009. His research focuses on the cultural politics of climate change and the transformation of carbon-based economies.
- CSTPR’s Katie Dickinson (also UCAR) was awarded a three-year, \$456,282 grant from the National Science Foundation (NSF) for the CU Boulder portion of a project titled “Prices, Peers, and Perceptions: Field Experiments on Technology Adoption in the Context of Improved Cookstoves.” CSTPR’s Deseraï Crow (CU Boulder Environmental Studies Program) was awarded a three-year, \$216,344 NSF grant for the CU Boulder portion of a project titled “Community Recovery and Colorado’s Extreme Floods of 2013: Policy Learning in the Context of Resources, Coalitions, and Political Conditions.” CIRES Fellow Lisa Dilling led a successful five-year, \$4,084,818 renewal of the Western Water Assessment project from the NOAA Regional Integrated Sciences and Assessments (RISA) program. Lisa was also part of a successful NOAA Sectoral Applications Research Program grant proposal, “Advancing the Use of Drought Early Warning Systems in the Upper Colorado River Basin.” CSTPR’s Media and Climate Change Observatory (MeCCO) was awarded a grant from the Center to Advance Research and Teaching

in the Social Sciences to continue its work monitoring media coverage of climate change around the world.

- CSTPR core faculty published in *Nature Climate Change*, *Public Understanding of Science*, *Water Resources Research*, *Environment and Planning C: Government and Policy*, *Review of Policy Research*, and more.
- “Information, Resources, and Management Priorities: Agency Outreach and Mitigation of Wildfire Risk in the Western United States,” by CSTPR’s Deseraï A. Crow et al., was awarded the Charles Redd Award for Best Paper on the Politics of the American West. “Learning Processes, Public and Stakeholder Engagement: Analyzing Responses to Colorado’s Extreme Flood Events of 2013,” by Elizabeth A. Albright and CSTPR’s Deseraï A. Crow, was awarded the 2015 Sabatier Award for Best Conference Paper in Science, Technology, and Environmental Politics. Lisa Dilling and Christine Kirchhoff’s paper, “The Role of U.S. States in Facilitating Effective Water Governance under Stress and Change,” was highlighted in the April 2016 edition of *EOS*.
- CIRES Fellow Max Boykoff spoke at a side event at the 21st annual Conference of Parties (COP21) in Paris where participants negotiated an international agreement on climate change. Max

wrote an article for *Climate Matters*, “Do the mainstream media tell the full story? A critical account of coverage at COP21,” and blogged about the conference. Max and CSTPR graduate student Marilyn Averill were both interviewed about the conference for CIRES News. CIRES Fellow Lisa Dilling was interviewed by KGNU Radio for a show titled “Beyond COP21 Paris: Climate Science & Policy.”

- CSTPR core faculty delivered public lectures around the world on various science, technology and policy research topics. These included a keynote talk at the “Comuni-

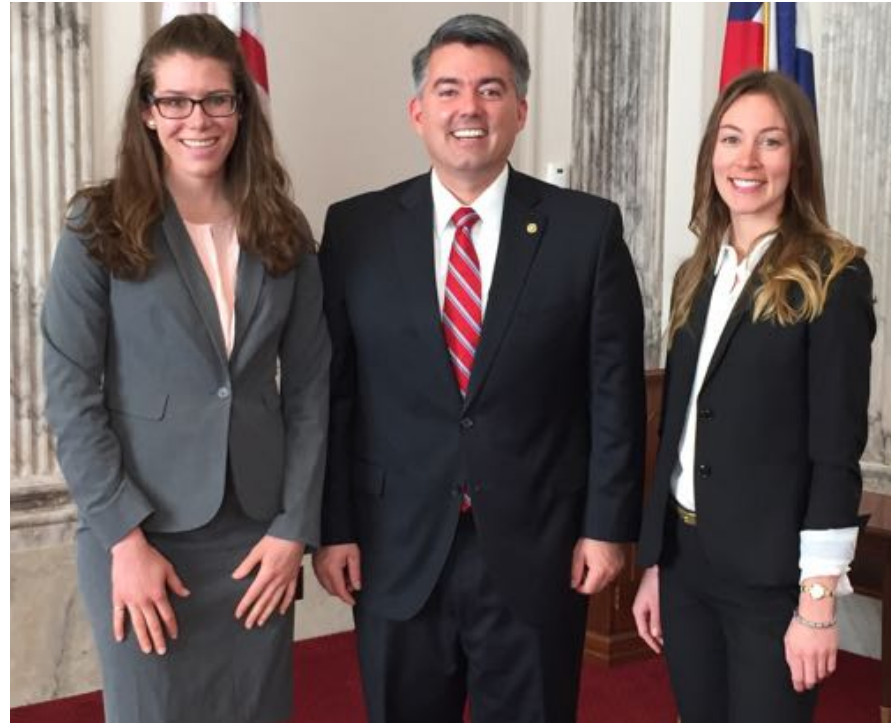


New CSTPR Director Max Boykoff. Photo: David Oonk/CIRES

We work to improve how science and technology policies and politics address societal needs.

cación de la ciencia del cambio climático: oportunidades y retos” meeting at the Basque Center for Climate Change (Max Boykoff); The Royal Society of New Zealand (Max Boykoff); the University of Hamburg (Max Boykoff); the Institute for Research Information and Quality Assurance, Berlin (Roger Pielke, Jr.); the keynote address at the Senator George J. Mitchell Lecture On Sustainability, University of Maine (Roger Pielke, Jr.); the American Political Science Association Annual Meeting, San Francisco (Deseraí Crow); the American Meteorological Society Annual Meeting, Phoenix (Lisa Dilling); and the TU-Delft Philosophy Colloquium series, Delft, Netherlands (Steve Vanderheiden), among many others.

- As part of the project “Inside the Greenhouse,” CIRES Fellow Max Boykoff taught “Creative Climate Communications” in which students worked to deepen their understanding of how issues associated with climate change are/could be communicated creatively, by analyzing previously created expressions from a variety of media and then by creating new artifacts and compositions. <http://insidethegreenhouse.org/projects>
- The Center organized the third campus-wide competition to select two CU Boulder students to attend the American Association for the Advancement of Science “Catalyzing Advocacy in Science and Engineering” workshop in Washington, D.C. The 2016 winners, Sarah Welsh-Huggins, a Ph.D. candidate in Civil, Environmental, and Architectural Engineering and Angela Boag, a Ph.D. candidate in the Environmental Studies program, met with Colorado Senators Michael Bennet and Cory Gardner after the workshop to discuss the policy implications of their research. The competition is supported by the CU- Boulder Graduate School and Center for STEM Learning.
- The Center hosted a sabbatical visit by Jan Marco Muller, a policy officer for international relations in the European Commission’s Joint Research Centre.
- CSTPR graduate students Marisa McNatt received a Beverly Sears Graduate Research Grant; Juhi Huda and Lucy



AAAS CASE competition winners Sarah Welsh-Huggins and Angela Boag meet with Colorado Senator Cory Gardner in Washington, D.C. Photo: Heather Bené/CU Boulder

McAllister were awarded CARTSS grants; John Berggren received a CIRES Graduate Student Research Award; and Elizabeth Koebele was awarded a Horowitz Foundation for Social Policy Grant.

Earth Science and Observation Center

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 study natural and anthropogenic processes on all scales, from technique development in small test sites to understanding problems and patterns on regional and global scales. A long-term goal of ESOC research is to advance our understanding of the Earth system and its interactions with human society and activities through remote sensing observations.

Cryospheric Research

During 2015, our cryospheric research continued to focus 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; and characterizing the distribution and evolution of crevasses on the Greenland ice sheet near the margins using visible imagery and lidar surface return signals. These surface and dynamic features, and our ability to observe them from space, provide important insights into how glaciers and ice sheets are contributing to sea level rise.

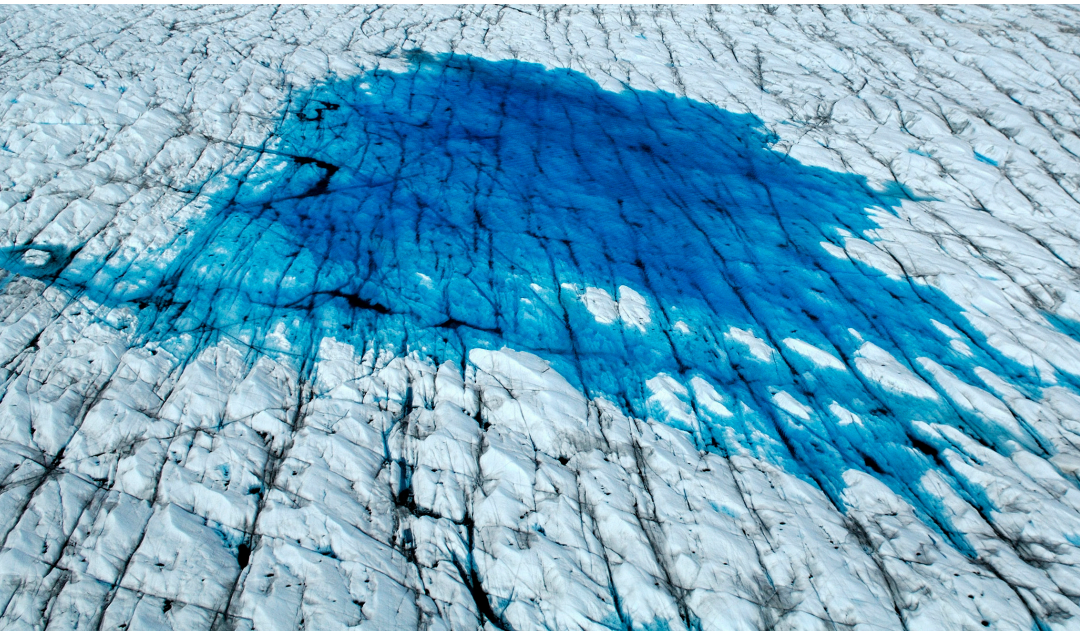
Vegetation and Ecosystem Studies

We have been studying potential vulnerabilities of forest

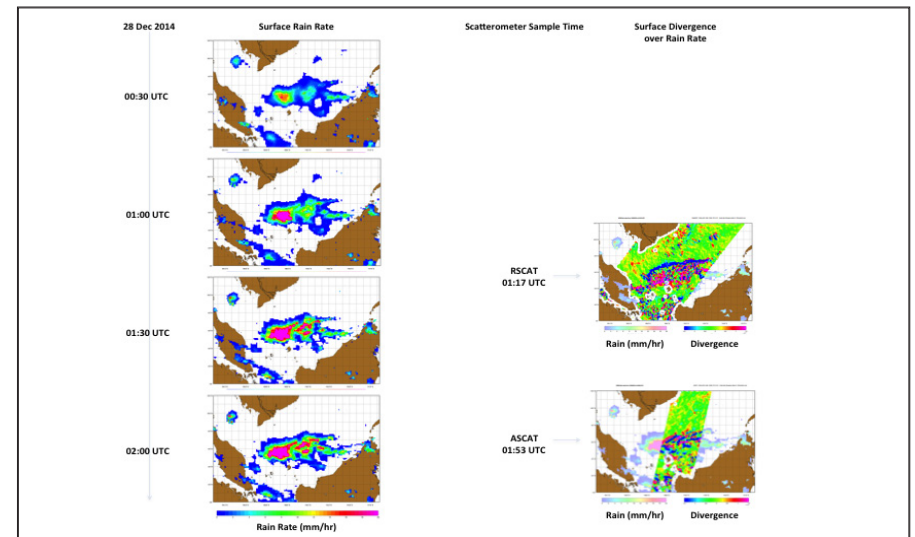
ecosystems and their carbon stocks to multiple disturbances and their interactions, with a focus on the resilience of carbon stocks and coniferous forest to catastrophic disturbances and climate change. We modeled the recovery and growth of trees under a changing climate (using IPCC scenarios), and demonstrated that under various warming scenarios, forests were unable to survive, even with a mitigative management strategy.

Oceanographic Studies

The tropical ocean absorbs, stores and transports vast quantities of heat input from the sun. The dynamics and thermodynamics of atmosphere-ocean interactions in the tropical Indian and western Pacific Ocean basins drive



Meltpond and crevasses on the Greenland ice sheet. Photo courtesy of James Balog/ James Balog Photography



Comparison of surface rain rate with nearly coincident surface wind convergence and divergence. The coherent patch of surface rain outlines a mature and propagating MCS in the Gulf of Thailand, 28 December 2014. Snapshots of surface convergence from separate satellites demonstrate surface convergence lines at the leading edge of the MCS and convergence and divergence patterns in rainband structures in the trailing parts of the MCS.

Arctic sea ice loss is one of the most visible manifestations of climate change.

local, regional, and global weather and climate phenomena including monsoons, tropical storms and cyclones, atmospheric rivers, the Madden Julian Oscillation (MJO), and the El Niño Southern Oscillation (ENSO) warm events. The building blocks for each of these phenomena are organized populations of atmospheric deep-convection events called mesoscale convective systems (MCS). Ralph Milliff and collaborators have been exploring the extent to which existing datasets from several Earth-observing satellite systems can resolve MCS life-cycle stages on their natural timescales. The initial focus is on the population of MCS in the tropical Indian and western Pacific Ocean basins during the active phase of an MJO event December 2014 - January 2015. Several animations of individual and combined satellite datasets for this event demonstrate the multi-scale implications of MCS and the ensemble of MCS evolving on hourly timescales (see cires.colorado.edu/esoc/media).

Polar Climate Change and Variability

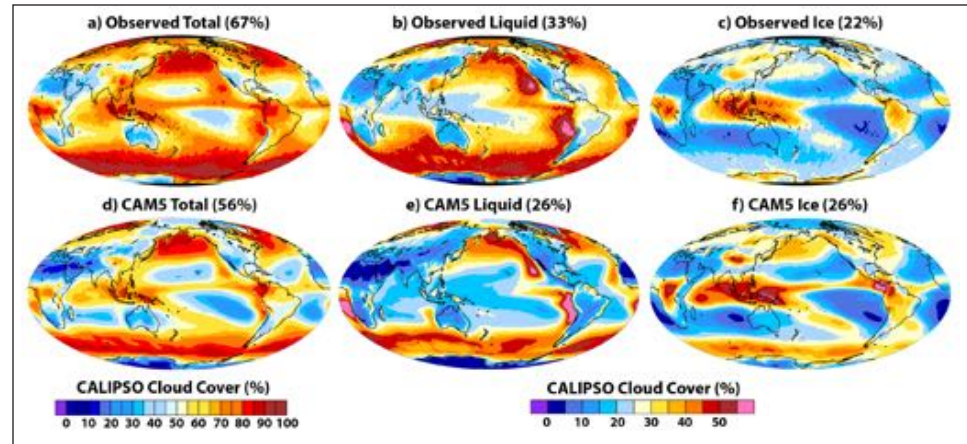
Arctic sea ice loss is one of the most visible manifestations of climate change. Yet, if cloud cover increases in the wake of sea ice loss, the canonical positive surface albedo feedback has no impact. Are we replacing one bright surface (sea ice) with another (clouds)? Data from active remote sensing instruments such as the spaceborne radar CloudSat and lidar CALIPSO are key to answering this, and other pressing high-latitude science questions. Surface-blind spaceborne radar and lidar data are truly ground-breaking and enable us to better understand the cloud response to, and influence on, the future of ice in a way that passive satellite observations and ground-based observations cannot. CloudSat is a cloud radar, but in Polar Regions also measures precipitation throughout most of the atmospheric column (minus the 1 km above the surface affected by ground clutter). CALIPSO provides previously unknown information about cloud phase, cloud vertical structure, and also near-surface snow in Polar Regions. The cloud phase information is especially important because liquid-containing clouds have a dominant influence on polar surface energy budgets. With simulators, the Kay

Group uses CloudSat and CALIPSO observations to make scale-aware and definition-aware evaluations of the representation of clouds & precipitation in models used for future climate prediction.

Hydrological Research

Hydrological research was conducted in collaboration with scientists at NOAA, exploring the fundamental physics of drought on the central U.S. Great Plains using satellite remote sensing data and an ensemble of land surface model

(LSM) experiments. The analysis quantified the contribution of precipitation versus temperature in the 2012 Great Plains drought, and identified the unique signatures of different categories of drought, exploring the relationship between radiation, surface heat fluxes, and antecedent moisture across a broad range of droughts in this region. Other research funded by the U.S. Environmental Protection Agency (EPA) focused on understanding the response of land-cover and water quality to drought in partnership with colleagues in Environmental Engineering, the Water Research Foundation, and a number of water utilities across the country. This project involved developing a sophisticated suspended sediment transport model constrained by in situ and remotely sensed observations, capable of testing multiple hypotheses of sediment delivery as they respond to projected future climate and drought risks.



Global maps of CALIPSO cloud cover (units %): (a) observed total, (b) observed liquid, (c) observed ice, (d) CAM5 total, (e) CAM5 liquid, and (f) CAM5 ice. Global mean values are indicated in parenthesis.

Hazards Studies

This research seeks to provide a comprehensive understanding of the processes that govern natural and anthropogenic hazards. Studies focus on the integration of large quantities of remote sensing data such as space-based Global Positioning System (GPS) data, differential interferometric synthetic aperture radar (DInSAR), seismicity, and gravity, in order to provide critical information on the nature and scale of these hazards. Specific projects focus on improvements in the nature and quantity of that data, development of innovative analysis techniques, and appropriate assimilation into various geophysical models of the underlying processes. In partnership with colleagues from around CU and at other institutions, ESOC researchers are investigating the implications and consequences of hazards such as groundwater extraction, volcanic unrest, and induced seismicity on infrastructure and society.

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, 2015, to May 31, 2016, follow.



NASA Operation IceBridge surveys Thwaites Glacier in West Antarctica. Photo: Jim Yungel/NASA

A sharper view of the ice edge

NSIDC researchers and colleagues have developed improved sea ice edge forecasts in the Arctic. Although harsh weather and sea conditions keep most commercial ships out of the region, some ships are able to navigate near the ice edge. The U.S. Navy had been able to forecast ice conditions six hours out, with a spatial resolution of 25 kilometers. Researchers at NSIDC, NASA, and the NOAA National Ice Center blended data with a 10-kilometer resolution from the Advanced Microwave Scanning Radiometer 2 on Japan's GCOM-W1 satellite, with a sea ice mask called MASIE (Multisensor Analyzed Sea Ice Extent, <https://nsidc.org/data/masie/>), developed at NSIDC. The resulting dataset can capture small patches of sea ice a few miles across. The Navy has used the blended product to provide sea ice edge forecasts at a sharper 2-kilometer resolution since July 2015. The researchers found a 40 percent improvement in accuracy all year round. The scientists detailed the new method in *The Cryosphere* (doi:10.5194/tc-9-1735-2015, 2015). The blended dataset is updated daily and is available from NSIDC (doi: 10.7265/N5ZS2TFT).

Runaway glaciers

NSIDC Lead Scientist Ted Scambos and colleague published a briefing (<http://dx.doi.org/10.1680/feng.14.00014>) discussing Antarctic mass loss and future sea level rise, including the potential demise of Thwaites Glacier. Although the Amundsen Sea glaciers make up only a fraction of the whole West Antarctic Ice Sheet (WAIS), the region contains enough ice to raise global sea levels by 1.2 meters (4 feet). Thwaites Glacier is thought to be particularly vulnerable to a runaway, when a glacier lifts off the continent and slides into the ocean. Extensive sections of Antarctic bedrock drop up to a mile and a half below sea level. Warming waters grind away at the ice along its grounding lines, where ice flows off the continent and begins to float. Warmer temperatures in the ocean's middle layers and shifting winds are driving warm water onto the continental shelf. The warm water pulses weaken the ice shelves from underneath. While

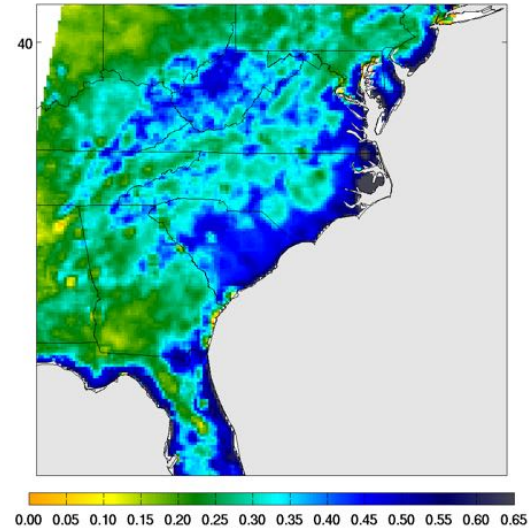
Cutting ice: U.S. Coast Guard Cutter *Healy* cuts through thick multiyear ice in the Arctic Ocean to get researchers to remote sites. The ICESCAPE mission, or "Impacts of Climate on Ecosystems and Chemistry of the Arctic Pacific Environment," was a NASA shipborne investigation that took place in the Beaufort and Chukchi seas in summer 2010 and 2011. Photo: Kathryn Hansen/NASA



it will take centuries for the gigantic Thwaites ice mass to melt away, the formation of ice cliffs could accelerate its demise, possibly in as little as 50 to 100 years. Thwaites is only one element of suspense surrounding ice decline in the WAIS, where mass loss increased by 75 percent from 1996 to 2006.

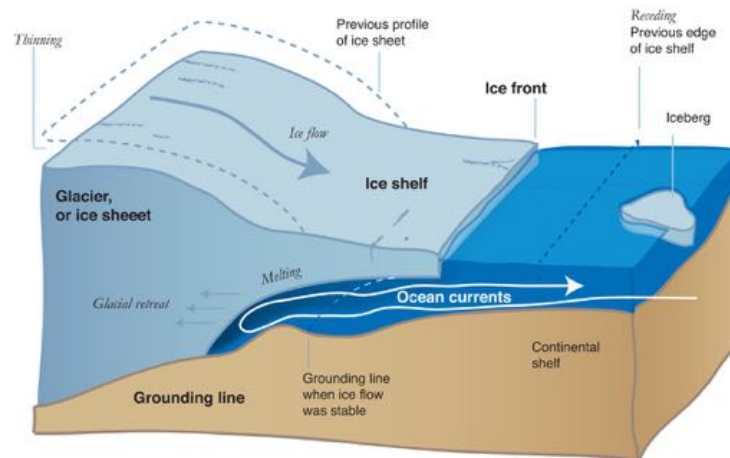
NSIDC DAAC releases soil moisture data

Only about 1 percent of Earth's water moistens the soil. This small amount, however, plays a large role in crops, flooding, cloud formation, and weather. On January 31, 2015, NASA launched the Soil Moisture Active Passive (SMAP) observatory to produce global maps of soil moisture. In August 2015, the NASA NSIDC Distributed Active Archive Center began distributing SMAP radiometer



▲ Surface soil moisture in the Southeastern United States as retrieved from NASA's Soil Moisture Active Passive satellite observatory at around 6 a.m. on Oct. 5, 2015. Regions in blue indicate areas with saturated soil conditions and possible standing water. Large parts of South Carolina appear blue, representing the impact of heavy localized rains and flooding. Large-scale flooding was experienced all over South Carolina on Oct. 5-6, 2015. Image: NASA

data from March 31, 2015 to present, including brightness, temperature, and soil moisture data, updated in near real time. NSIDC was chosen for the SMAP mission because of previous success with soil moisture data from the Advanced Microwave Scanning Radiometer—EOS instrument. (<http://nsidc.org/data/smap>)



◀ When bedrock slopes inward toward the continent, warm, deep ocean water can flow downward under the ice shelf, chewing away at the grounding line. Melting can be as much as 20 to 50 meters of ice thickness each year. As the glacier's base recedes, the brakes holding the continental ice ease up and the glaciers feeding the ice shelf accelerate, and thus further thin and recede the ice sheet. Illustration: NSIDC and NASA

Institutional Programs & Teams

Western Water Assessment

Western Water Assessment (WWA) is one of 10 NOAA-funded Regional Integrated Sciences and Assessments (RISA) programs across the country, covering Colorado, Utah, and Wyoming. The WWA team conducts innovative research in partnership with decision makers in the Rocky Mountain West, helping them make the best use of science to manage for climate impacts. By keeping the needs of decision-makers front and center in designing and conducting research, WWA generates usable and actionable research results and information products.

In FY16, WWA was renewed for another 5-year grant by the NOAA Climate Program Office and will focus their work on three overarching themes for the next several years:

1. Climate Vulnerability and Adaptive Capacity in the WWA Region
2. Extremes and Climate Risk Management
3. Designing Organizations and Networks for Usable Science

Most projects within these themes are being conducted in collaboration with stakeholders, and cutting across all projects are significant outreach and communication efforts. A sampling of noteworthy results in the past year are highlighted below.

Snowpack Monitoring for Streamflow Forecasting and Drought Planning Workshops

WWA and its partners convened three one-day workshops in late summer 2015 focused on improving the usability of snowpack monitoring information for runoff forecasting, drought early warning and planning, and other applications. The workshops were held in Broomfield, Colorado, West Jordan, Utah, and Lander, Wyoming, and were each attended by 50-75 water managers, forecasters, researchers, and others who rely on snow-monitoring products and runoff forecasts. WWA's partners in this effort included the National Integrated Drought Information System, the NOAA Colorado Basin River Forecast Center, the Natural Resources Conservation Service Snow Survey, the Colorado Water Conservation Board, and the Wyoming State Engineer's Office. The workshops were successful in

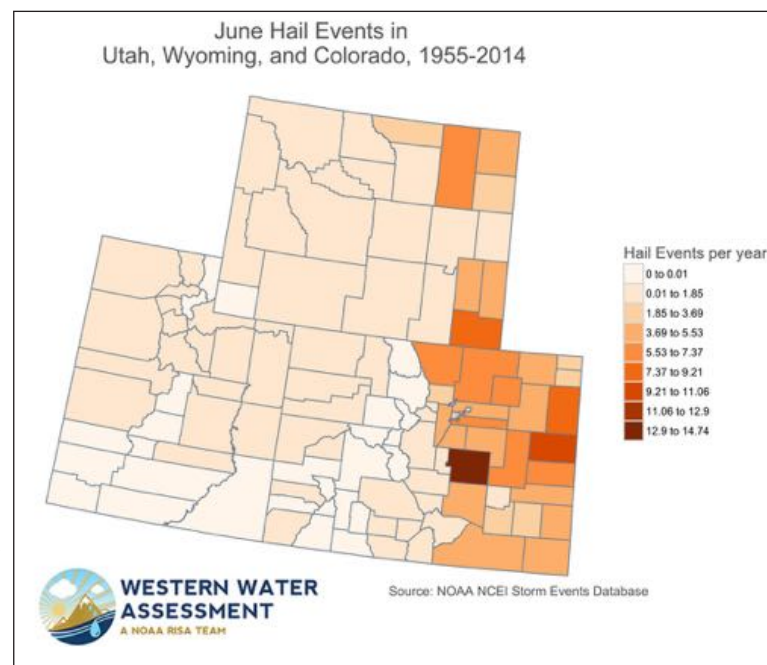
bringing water managers and other stakeholders into conversations with researchers and operational providers to improve snowpack monitoring. In post-workshop evaluations, nearly all participants reported gains in their understanding of snow hydrology and monitoring, and improved awareness of existing and emerging monitoring products.

Extreme Events Roster

WWA developed an online database of historical high-impact weather and climate events—encompassing floods, winter storms, hailstorms, tornadoes, windstorms, cold waves, droughts, wildfires, and landslides—for our three-state region of Colorado, Utah, and Wyoming. The database contains nearly 200 major events, searchable by key characteristics, with descriptions of the events and links to online sources. In a complementary effort, WWA also generated maps of the county-level historical risk of the different weather and climate event types in our region, using the much larger NOAA Storm Events Database, which captures about 20,000 events. WWA is now working with the hazard-planning and emergency-response communities to refine these products and spread the word about them.

Upper Colorado River Basin Drought Early Warning System Evaluation

WWA completed an evaluation of the Upper Colorado River Basin Drought Early Warning System (UCRB DEWS), which is part of the National Integrated Drought Information System (NIDIS) and is operated out of the Colorado Climate Center at Colorado State University. The UCRB DEWS was the first of nine DEWS across the



Number of hail storms in June in Colorado, Utah, and Wyoming by county, from 1955 – 2014.

United States, and is based around regular webinars and a website that communicate drought conditions to water managers, agricultural producers, and other decision-makers. WWA's evaluation assessed whether the UCRB DEWS is meeting NIDIS' goals for the DEWS and improving drought preparedness in the Upper Colorado River Basin. The evaluation report describes several areas where the UCRB DEWS is succeeding and recommends steps that could be taken to improve its effectiveness. WWA's evaluation is currently being used to inform NIDIS strategic planning across all of the DEWS.

Energy balance tower in the Senator Beck Basin in southern Colorado, winter 2014. Photo: Emily Baker/CU Boulder



CIRES Education and Outreach

The CIRES Education and Outreach group works across the spectrum of geosciences education, including teacher professional development, digital learning resources, student programs, and program evaluation. This year, the CIRES Education and Outreach group developed new capacity to support students' spatial reasoning skills, reach community college faculty and students, help students communicate about environmental change, and more.

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 opportunities.

Students will make videos about local climate impacts

A student snapshot of graffiti, taken above a hill in Tsaile, Arizona, featured in the Tribe's Eye photography exhibit. Photo: Kyle Sorrell



through the Lens on Climate Change project, with the support of science researchers, graduate students, and film students.

The CIRES Education and Outreach group was honored to be included as part of a White House Climate Education and Literacy effort to support climate science instruction on Climate.gov.

The Tribe's Eye photography exhibit, photography by Native students showing environmental change on tribal lands, was shown at the American Indian Science and Engineering Society (AISES) annual meeting and in federal building lobbies in Washington D.C. and Oklahoma.

The CLEAN collection (cleanet.org) is a peer-reviewed digital repository of climate and energy learning resources and is syndicated through NOAA's Climate.gov. This year,

the collection of 650 resources was aligned with the new Next Generation Science Standards.

Undergraduate Education

A CIRES Education and Outreach group member received a Chancellor's Award for Excellence in STEM Education, including funding to study undergraduate students' spatial reasoning skills. Because spatial reasoning is a threshold skill to become a geoscientist, teaching these skills supports career aspirations. This study was further supported by an award to compare the experiences and skills of American and German students.

Two projects reached Colorado community college faculty and students. The Research Experiences for Community College Students (RECCS) project supports community college students in conducting research at CIRES, NOAA, and in partnership with the Boulder Critical Zone Observatory. Building on our relationships with community college faculty, the "Colorado's Changing Energy Portfolio" workshop reached faculty throughout Colorado.

Broader Impacts

In collaboration with CIRES and University of Colorado scientists, CIRES Education and Outreach provides programming to increase public scientific understanding and to broaden participation in geosciences. The Mysterious Microbes series, in collaboration with the Fierer Research Group, introduced the public to modern microbiology through a webinar series and workshop. Three webinars introduced modern microbiological research methods, described the use of microbes in compost tea for organic management of the University of Colorado Boulder turf, and shared results of a national study of microbes in the home. A two-day workshop on soil microbiology reached pre-college and college educators, business owners, farmers and gardeners, and representatives from local agencies and food organizations.

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

Program and Project Evaluation

Through NOAA requests, CIRES Education and Outreach completed an evaluation study of the Climate.gov web portal and began a study to inform the new National Integrated Drought Information System (NIDIS) portal, Drought.gov. Surveys, usability studies, and web analytics focus on the extent to which audiences perceive that they

have a relationship with the Drought.gov team, are aware of the services, and find the project 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 2016 Research Experience for Community College Students program, coordinated by the CIRES Education and Outreach program, is hosting ten student researchers from six community colleges across Colorado this summer. The RECCS student researchers participating in this 9-week long, NSF-funded research program are based at a variety of research locations including CU Boulder, the Boulder Creek Critical Zone Observatory field sites, and NOAA. Photo: David Oonk/CIRES



Students from the Liberty Common High School A-Team compete at the Trout Bowl, the annual regional competition of the National Ocean Sciences Bowl. The Liberty Common A-Team went on to win the Trout Bowl and placed 4th in the National Competition! Photo: Robin L. Strelow/CIRES

Institutional Programs & Teams

Visiting Fellows

With partial sponsorship by NOAA, CIRES offers Visiting s at the University of Colorado Boulder. Every year, CIRES awards several s to visiting scientists at two levels, postdoctoral and senior. These s 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.



Paul Carini

Postdoctoral Fellow
Ph.D., Oregon State University
Project: Seasonality in mineral weathering populations of soil microbes
Sponsor: Noah Fierer

The availability of soil nutrients is a key control on plant productivity and rates of ecosystem-level processes, including those processes associated with terrestrial carbon storage. However, in their native rock and mineral forms, many nutrients are biologically unavailable and need to be weathered (dissolved) in order to be assimilated by plants, animals and microbes. While the weathering processes aboveground and in surface soils have been relatively well studied, far less is known about the factors that constrain weathering in deeper soil horizons adjacent to parent materials. Carini employs a two-pronged approach to understand which microbial species are involved in weathering and how their populations change through time. First, deep-dwelling soil microbes are isolated and assayed for their ability to weather minerals in the laboratory. Once weathering microbes are identified, he uses molecular techniques to monitor the temporal population dynamics of these (and other) microbial species in the soils they were isolated from. The isolation and study of pure cultures enables hypothesis-driven experimentation necessary to directly link microbial species to specific geochemical processes. Molecular tools then provide the ability to ‘follow’ the abundances of these species, in the context of the entire microbial community, and to observe how their populations change over time. This combination of microbial cultivation with cultivation-independent molecular approaches yields unique insight into the diversity of subsurface microbes and their influence on mineral weathering rates.



Helene Chepfer

Sabbatical Fellow
Université Pierre and Marie Curie, Laboratoire de Météorologie Dynamique, Institut Pierre Simon Laplace
Project: Greenland clouds, precipitations, and radiative fluxes observed by the A-train
Sponsors: Jennifer Kay and Waleed Abdalati

Helene Chepfer is collaborating with researchers of CIRES Environmental, Observations, Modeling and Forecasting division to understand the role of clouds and precipitations on the polar climate. In particular, they are using observations collected by the active remote sensing instruments (CALIPSO lidar and CloudSat radar), part of the A-train, to understand how clouds and precipitations interact with the ice sheet over Greenland. Clouds and the atmospheric state play fundamental roles in the cryospheric mass budget of the Greenland ice sheet both as a source, via precipitation, and potential sink, via modulation of the surface energy budget. Understanding present and future manifestations of change to the Greenland ice sheet requires an explicit understanding of regional atmospheric processes, including how the atmospheric processes interact with the ice sheet and might be modulated as their environment changes. The observations collected by CALIPSO and CloudSat since 2006 complete the information collected over Greenland ground base sites, providing an almost-decadal view of the detailed vertical distribution of clouds and precipitations over Greenland. Those observations will be used to understand cloud and precipitation-related processes over Greenland, and to constrain the description of polar clouds in climate models, a step toward more reliable predictions of future polar climate evolution.



Matt Coggon

Postdoctoral Fellow
Ph.D., California Institute of
Technology

Project: The impact of organic
compounds in wildlife smoke
on air quality and climate

Sponsors: Joost de Gouw,
José Luiz Jiménez

Matt Coggon is working with Joost de Gouw to understand the properties and evolution of compounds emitted by biomass burning. As the western United States continues to face drought conditions, the probability of wildfire activity will increase. Smoke emitted from biomass burning plays a role in regional air quality, yet there remain large uncertainties to the extent to which smoke impacts health and climate. Matt will work in the laboratory and field to investigate the types of compounds emitted from wildfire smoke and assess their potential to form particulate matter. His work will be in collaboration with scientists from government agencies and universities participating in the Fire Influence on Regional and Global Environments Experiment (FIREX). This work will be important to parameterize wildfire emissions in models and constrain the biomass burning forcing on global climate. Matt is excited to work on this collaborative project. In his spare time, he's looking forward to exploring Colorado's whitewater, trails, and backcountry.



Benjamin Green

Postdoctoral Fellow
Ph.D., Pennsylvania State
University

Project: The Madden-Julian
Oscillation in a global numerical
weather prediction model

Sponsors: Stan Benjamin,
Chris Fairall

Benjamin Green is collaborating with Stan Benjamin and Chris Fairall and their colleagues at NOAA's Physical Sciences and Global Systems Divisions to investigate numerical simulations of the Madden-Julian Oscillation (MJO). Specifically, the simulations couple the atmospheric Flow-following finite-volume Icosahedral Model (FIM) developed at NOAA to an icosahedral version of the HYbrid Coordinate Ocean Model (iHYCOM). The MJO is the primary cause of intraseasonal (30-60 day) variability in the tropical troposphere, and has been found to have impacts on weather across the globe on similar timescales. Therefore, it is believed that numerical weather prediction models capable of adequately simulating the MJO will yield more accurate forecasts at longer lead times. This research is investigating the ability of the coupled FIM-iHYCOM model (hereafter "FIM") to simulate the MJO by comparing month-long FIM hindcasts with observations. Preliminary results have found that different MJO events may be governed by fundamentally different processes: some by coupled air-sea interaction and others by atmospheric internal dynamics. While FIM can reasonably simulate MJOs driven by interaction with the upper ocean, the model struggles to capture MJOs driven by atmospheric dynamics, suggesting a potential deficiency in the parameterization of deep moist convection. Finally, FIM's overall skill in simulating the MJO will be compared against other models including the Climate Forecast System.



Gabriel Jordà-Sanchez

Sabbatical Fellow
Institut Mediterrani d'Estudis
Avançats, Spain

Project: Sea level variability
in the global ocean induced
by atmospheric mechanical
forcing for the period 1871-2012

Sponsor: Steven Nerem

Gabriel Jordà is a visiting fellow from Mallorca (Spain) where he holds a Ramón y Cajal research position at the University of the Balearic Islands. His field of expertise is physical oceanography and particularly sea level variability and the interaction between marine climate and ecosystems. During his stay in Boulder, he is working with Steve Nerem (CIRES-CCAR) and Gil Compo (CIRES-NOAA) in the modelling of sea level variability since 1850. In particular, he is interested in the characterization of the water mass redistribution due to the atmospheric mechanical forcing. This is important in order to better interpret the long term records of sea level obtained at coastal stations where many different processes occur. The new simulations will allow a better assessment of how much sea level has changed during the instrumental period and if significant changes on extreme events characteristics have happened in the past. This exciting project has been a perfect alibi to spend a year with his family in a wonderful place like Boulder, a place with amazing landscapes around and plenty of nice and interesting people from all around the world.

Institutional Programs and Teams: Visiting Fellows



Bernd Karcher

Sabbatical Fellow
Institut für Physik der
Atmosphäre, Deutsches
Zentrum für Luft und Raumfahrt,
Oberpfaffenhofen, Germany
Project: Dynamical and
microphysical controls of ice
formation in tropospheric clouds
Sponsors: David Fahey,
Graham Feingold

Bernd Karcher is working with NOAA's Graham Feingold and David Fahey to investigate dynamical and microphysical controls of ice formation in clouds. A lack of proper representation of cloud ice in global models compromises the fidelity with which weather and climate can be simulated. Karcher will strive to improve the understanding of ice formation processes in tropospheric clouds, resorting to theoretical and numerical methods and making use of results from high resolution atmospheric models. He will be studying fundamental issues regarding links between small-scale variability in relative humidity and ice nucleation, while at the same time recognizing that ice crystals may nucleate on a plethora of atmospheric aerosol particles with vastly different ice-forming properties. Due to their relevance for the Earth's radiative and the stratospheric moisture budget, emphasis is placed on cirrus clouds originating from convective detrainment or forming in-situ.



Yochanan Kushnir

Sabbatical Fellow
Lamont-Doherty Earth
Observatory, Columbia University
Project: Space-time properties
of U.S. extreme hydrological
events: attribution and projection
Sponsors: Judith Perwitz,
Balaji Rajagopalan

Kushnir is collaborating with researchers of NOAA's Physical Sciences Division and CIRES as part of a broader research goal to study the climate of the western United States. The goal here is to characterize, understand and attribute the space-time properties of extreme hydrological events in the U.S. West. These intense and/or prolonged precipitation events regularly inflict property damage and loss, environmental degradation, and sometimes also lead to loss of life. The present-day characteristics of these phenomena require more study. It is also important to determine how the probability of such events and their spatial pattern will change in the future. During his visit, Kushnir joined the study of the space-time organization of high intensity hydrological events at CIRES. He is presently continuing to collaborate with CIRES investigators in characterizing the seasonal distribution of extreme events and their links to large-scale atmospheric patterns and global sea surface temperature variations. Using station observations, reanalyses, and climate models, clusters of events are identified and related to large scale climate variations. Building such links enables understanding of extreme events and verifies that state-of-the-art models can correctly simulate them, ultimately aiding in developing applications that can assist decision makers in addressing the associated hazards.



Amanda Lynch

Sabbatical Fellow
Institute at Brown University for
Environment and Society, Brown
University
Project: Actionable knowledge
at the ice edge
Sponsor: Mark Serreze

Amanda Lynch has published more than 100 articles, policy briefs, book chapters and books in climate science and policy, with a focus on the polar regions. Lynch developed the first Arctic regional climate system model in 1993. As well as climate modeling, she conducts research on adaptation policy and particularly the role of indigenous knowledges in climate change adaptation. She is Chief Editor of the journal *Weather, Climate and Society*, President of the Society of Policy Scientists, and a member of the World Climate Research Programme's Joint Science Committee. At CIRES, she will be working with Mark Serreze and others in the National Snow and Ice Data Center to develop the scientific foundation for actionable knowledge at the ice edge—knowledge that supports decisions on the economic viability, safety, and impact of development opportunities in the Arctic. It is known that synoptic and mesoscale systems play an important role in determining ice edge variability. Lynch and Serreze will collaborate on developing useful approaches for a statistical model of polar low characteristics.



Angie Pendergrass

Postdoctoral Fellow
Ph.D., University of Washington
Project: How will extreme precipitation change with warming?
Sponsor: Prashant Sardeshmukh

Angie Pendergrass is working with Gil Compo and Prashant Sardeshmukh at NOAA ESRL to study extreme precipitation, its dynamics, and its changes in centennial reanalyses and climate model simulations. How extreme precipitation will change with warming is crucial to understand because of its importance for climate impacts and the potential for adaptation action by water managers and hydrologists. The range of projected change in extreme precipitation from climate model simulations is large. In order to make sound projections of how extreme precipitation will change, we need to untangle the factors causing this wide range and determine where we fall within it. As a CIRES fellow, Angie will apply a new analysis technique to deconstruct the factors driving extreme precipitation, in order to see whether the dynamics driving extreme precipitation and its change are related among climate models and reanalyses. Before coming to CIRES, Angie did her Ph.D. at the University of Washington in Seattle and worked as a postdoctoral researcher at the National Center for Atmospheric Research. Angie is excited to work with this new segment of the Boulder atmospheric science community.



Mark Raleigh

Postdoctoral Fellow
Ph.D., University of Washington
Project: Improving operational streamflow forecasting in the Upper Colorado River Basin through extended historical and physical understanding of dust-on-snow impacts
Sponsor: Richard Armstrong

Mark Raleigh is working with researchers at the National Snow and Ice Data Center and colleagues at the Colorado Basin River Forecasting Center on the “dust-on-snow” problem. His research aims to understand the regional and historical context of dust deposition on Rocky Mountain snowpack and to assess how operational streamflow models can best account for the enhanced energy absorption that leads to rapid and earlier snowmelt in the spring. Specifically, Raleigh plans to use in-situ observations, models, and remote sensing to investigate 1. The synoptic conditions associated with dust deposition events, 2. The signature of dust-on-snow variability (space, time, concentration) within readily available historic hydrologic records (snowpack and streamflow), and 3. The array of modeling options that could be employed to account for enhanced snowmelt due to dust-on-snow in streamflow forecasting operations. Recent research suggests that annual runoff in the basin has been reduced on the order of 5% because evapotranspiration has increased with premature snow cover loss from dust effects. Existing operational models do not directly account for the dust effects and recent work has shown a strong correlation between forecasting errors and annual dust loading.



Adam W. Schneider

Postdoctoral Fellow
Ph.D., University of California San Diego
Project: Sociopolitical Impacts of drought, water scarcity, and climatic instability upon past, present, and future societies in greater Mesopotamia
Sponsors: Balaji Rajagopalan, Peter Molnar

Adam Schneider is an environmental archaeologist, with a particular specialization in the long-term evolution of the dynamics of coupled human-environmental systems in the Near East. The purpose of his research, which incorporates a number of archaeological, geographical, historical, and earth science methods, is to investigate the relationship between climate change and political instability in the Middle East, the Eastern Mediterranean Basin, and North Africa over the longue durée, from the beginnings of urban civilization up to the present. At CIRES, he is working with Balaji Rajagopalan and several other scholars to assess the relative impact of specific environmental causal factors in instances of political collapse. One of his research project’s two main objectives is to create a regional Mid-Late Holocene paleoclimate “mosaic” from numerous proxy records for local conditions in different parts of the Near Eastern region. The other is to develop a database of the various cultural and natural factors that have been pointed to as causes of known instances of social disruption, crisis, or outright collapse among pre-industrial societies situated in this area. Together, these two twin databases have the potential to provide a platform that will facilitate the comparative analysis of the various environmental and social factors that influenced the political collapse of past societies.

Institutional Programs and Teams: Visiting Fellows



Jeffery A. Thompson

Postdoctoral Fellow
Ph.D., University of New South
Wales, Australia
Project: Exploring links between
hydrologic changes and land
surface phenology in Greenland
Sponsors: Mark Serreze,
Lora Koenig

Jeff Thompson is collaborating with researchers at the National Snow and Ice Data Center to explore links between hydrologic changes and land. While many studies have focused on changes in individual systems (e.g. ice cover, ocean, vegetation), fewer have focused on the interactions of multiple systems (e.g. ice-ocean interactions) and very few have focused on how changes in multiple physical systems will affect the Greenlandic population. Although small, Greenland's vegetated areas are of primary importance to its indigenous population and hunting is an important aspect of their livelihood strategies. To better understand the link between changes in cryospheric processes, runoff, and vegetative phenology this research explores the following science questions: 1. What effects are rising temperatures, including precipitation, having on the vegetation of Greenland; 2. How is the increase in melt runoff affecting vegetation; and 3. Can the effects of temperature and runoff on vegetation be separated? Answering these science questions will enable better predictions of vegetative changes and ultimately how the change will impact the Greenlandic population.

Tonie Van Dam

Sabbatical Fellow
Faculté des Sciences, de la Technologie et de la
Communication, Université de Luxembourg
Project: 1. Sea level; 2. Absolute gravity to
sustain Sierra Nevada uplift
Sponsors: Craig Jones, Steven Nerem

Tonie van Dam is working with CIRES Fellow Steve Nerem (CU Boulder Aerospace Engineering Sciences) to develop a long-wavelength model of vertical crustal motion along the world's coastline using global GPS vertical velocities. The goal is to arrive at a global model of regional vertical land motion that can be used for regional sea level change studies. Tonie is also collaborating with CIRES Fellow Craig Jones (CU Boulder Geological Sciences) to better understand how changes in water storage can affect uplift of the Sierra Nevada. In addition to working with Nerem and Jones, van Dam has ongoing collaborations with CIRES Fellow Anne Sheehan (Geological Sciences) and University of Colorado professor Kristine Larson (Aerospace Engineering) on GPS and the water cycle. Van Dam is excited to be returning to CIRES and reigniting old collaborations as she got her Ph.D. here in 1991. She is also looking forward to forging new collaborations with other researchers at CIRES who are investigating sea level, ice mass changes, and changes in the global water cycle.



Katabatic snow drifting at a research camp in Southwest Greenland. Mid-May on the Arctic Circle Traverse 2016 Expedition. Photo: Baptiste Vandecrux/ Technical University of Denmark

Innovative Research Program

The CIRES-wide competitive Innovative Research Program (IRP) supports novel, unconventional, and/or fundamental research that may quickly provide concept viability or rule out further consideration. The program stimulates a creative research environment within CIRES and encourages synergy among disciplines and research colleagues.

<http://cires.colorado.edu/about/institutional-programs/innovative-research-program>

Awards for 2016

Investigating the ionospheric gravity and pressure gradient current systems with satellite magnetic measurements

Henry Patrick Alken

Demonstration of a high-signal soft-ionization quantitative method for on-line aerosol mass spectrometry

José-Luis Jiménez

HOVERCAT: A novel aerial system to evaluate aerosol chemistry and its impacts on arctic clouds

Jessie Creamean and Margaret Tolbert

Are there diamonds in the sky? Detection of diamondoid and other large hydrocarbons in the atmosphere

Carsten Warneke, Joost de Gouw, Brian Lerner, and Abigail Koss

Heterogeneous photo-initiated chemistry of alkyl organics in the Earth's atmosphere

Veronica Vaida

Is meltwater responsible for new crevasses in Greenland's interior?

Lora Koenig and Michael MacFerrin

Discerning heat from melt from composition in the deep earth: Exploring a new approach to measuring seismic attenuation

Craig Jones

Graduate Student Research Awards

To promote student scholarship and research excellence, CIRES maintains a Graduate Student Research Award (GSRA) program with the aim of supporting extraordinary young researchers. Any current Ph.D. student advised by a CIRES Fellow or CIRES researcher is eligible for this one-time award opportunity.

The CIRES GSRA is granted in the form of a Research Assistant position for two semesters. The award includes a monthly salary, fully paid tuition, and a partially paid premium (90 percent) towards the Buff Gold insurance plan.

At right are the recipients for this reporting period (June 1, 2015–May 31, 2016).

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

John Berggren

Project: Transitioning to a new era in Western United States water governance: Examining adaptive capacity and equitable water policy in the Colorado River Basin
Advisor: Lisa Dilling, Western Water Assessment

Ryan Davis

Project: Laboratory studies of contact efflorescence involving organic and mixed organic-inorganic aqueous aerosols
Advisor: Margaret Tolbert, Chemistry and Biochemistry

Natalie Kille

Project: Developing the mobile Solar Occultation Flux technique to quantify emission fluxes of trace gases
Advisor: Rainer Volkamer, Chemistry and Biochemistry

Jenny Nakai

Project: Tectonic and anthropogenic causes of small magnitude earthquakes in Colorado and New Mexico
Advisor: Anne Sheehan, Geological Sciences

Rebecca Rapf

Project: Building molecular complexity via aqueous photochemistry in ancient and modern environments
Advisor: Veronica Vaida, Chemistry and Biochemistry

Tasha Snow

Project: Evaluating fjord sea surface temperature influences on Greenland outlet glacier variability
Advisor: Waleed Abdalati, Geography



Jenny Nakai, CIRES Graduate Student Research Award winner. Photo courtesy of Jenny Nakai.

Integrated Instrument Design Facility

The Integrated Instrument Development Facility (IIDF) is operated in partnership between CIRES and the University of Colorado Boulder Department of Chemistry and Biochemistry. The IIDF is multi-faceted, consisting of design, precision machine, electronics, and scientific glassblowing shops dedicated to the design and fabrication of scientific instrumentation. Staffed by two Ph.D. scientists, three engineers, and a technician, the team has more than 120 years of experience designing and building scientific instruments.

State-of-the-art instruments have been designed and built for CIRES, as well as many departments at the University of Colorado Boulder, other major universities, and research institutions worldwide. A number of these instruments have been commercialized, one patented, and are now in production by private companies.

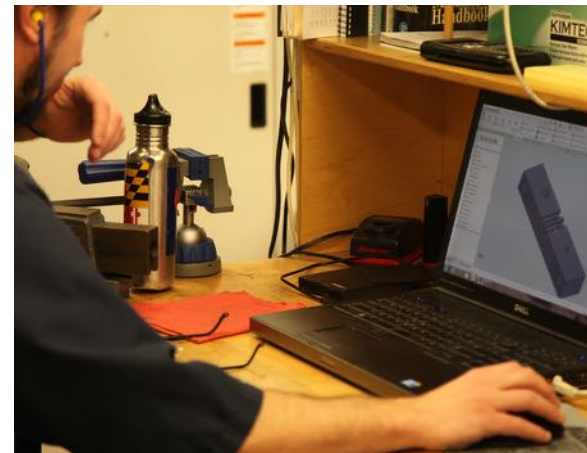
IIDF capabilities and services include: Microprocessor-based instrumentation; data acquisition software; LabView programming; multi-Layer printed circuit boards; wire electric discharge machining; CNC Lathe and 2,3,4

Axis Mills; CAD design modeling; optical systems; ultra-high vacuum (UHV) chambers; tungsten inert gas welding and brazing for UHV; precision grinding; electro polishing; electroplating; exotic materials processing; cryogenics; lab equipment and appliances repair; refrigeration servicing glassblowing; vacuum dewar evacuation; metallizing and special coatings; and vacuum leak detection.

<http://cires.colorado.edu/iidf>



CIRES Integrated Instrument Design Facility's staff. Left to right: Ken Smith, Yehor Novikov, Jim Kastengren, Don David, Kenny Wine, Danny Warren, Wayne Winkler. Photos: Robin L. Strelow/CIRES



Danny Warren designing a part with SolidWorks CAD software.

Tooling for Computer Numerically Controlled (CNC) milling machine.



Danny Warren setting up a CNC to machine the part designed above.

Communications

CIRES is committed to communicating the institute's scientific discoveries to the scientific community, decision-makers, and the public. The CIRES communications group fosters public awareness of Earth system science for the benefit of society through its use of trusted and engaging communications products. 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 2016 reporting period (June 1, 2015 to May 31, 2016), communications efforts included 56 news releases (highlights follow), media relations, videos, social media, blogs, 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: *Scientific American*, *Smithsonian Magazine*, the *Washington Post*, *Newsweek*, UPI, *Christian Science Monitor*, *The Economist*, *Popular Science*, CBS News, *atlantic.com*, *newyorker.com* and many other local, national, and international media outlets.



Recovery of Lamont ocean bottom seismometer and absolute pressure gauge package after one year on the seafloor offshore Gisborne, New Zealand. Photo: Elizabeth Brenner/Scripps Institution of Oceanography

News releases

June 1, 2015

The ebb and flow of Greenland's glaciers: New CU Boulder-led paper could improve understanding of Greenland's contribution to sea-level rise

July 2, 2015

Surveillance tech reveals greater ice sheet detail, and more

August 26, 2015

Home Sweet Microbe: Dust in your house can predict geographic region, gender of occupants

August 31, 2015

Better daily sea ice forecasts for the Arctic following CU Boulder-led innovation

September 1, 2015

NOAA's Science On a Sphere® animations coming to your desktop

September 4, 2015

Abdalati to co-lead high-profile effort to set nation's satellite science agenda

September 15, 2015

Arctic sea ice reaches fourth lowest minimum

September 29, 2015

Science of the people, by the people: CIRES Director Abdalati highlights citizen science at White House event

October 16, 2015

NOAA's NGDC turns 50

October 29, 2015

Warming waters a major factor in Gulf of Maine cod collapse

November 2, 2015

Less ice, more water: Parts of Arctic Ocean shifting rapidly to conditions very different from last century

December 2, 2015

Antarctic ozone hole a record low in October

December 3, 2015

A dispatch from the Paris climate conference

December 7, 2015

Crowdsourcing old weather records means more data for research

December 10, 2015

Cloudy with a Chance of Warming: Clouds can increase warming in the changing Arctic region more than scientists expected

December 15, 2015

Accidental Geoengineering?: Airline traffic may help create an icy haze that's brightening U.S. skies

January 4, 2016

Greenland's "sponge" affected by atmospheric warming: Changing climate limits the ability of the ice sheet to retain meltwater

January 25, 2016

Rapid, Affordable Energy Transformation Possible: NOAA, CIRES study: Sun and wind could provide most U.S. electricity by 2030

February 29, 2016

History on Ice: New insights from reviewing 60 years of crevasse research

March 14, 2016

Antarctica's Upside-Down Rivers: Warming ocean water undercuts Antarctic ice shelves

March 30, 2016

Rethinking Induced Seismicity: New study suggests fracking itself, not just wastewater injection, may cause earthquakes

April 11, 2016

Islands Face A Drier Future: Today's global climate models do not capture the effects of climate change on islands' aridity

April 26, 2016

One oil field a key culprit in global ethane gas increase

April 27, 2016

Will droughts turn the Amazon into a giant source of carbon emissions?

May 5, 2016

World's shallowest slow-motion earthquakes detected offshore of New Zealand

May 11, 2016

North Dakota's Bakken oil and gas field leaking 275,000 tons of methane per year

May 19, 2016

Climate change's likely role in kidney disease epidemics

May 27, 2016

Arctic sea ice loss likely not a factor in recent Northern Hemisphere cold winters

Webcasts, photos, social media, and blogs

CIRES communications provides webcasting services for institute seminars, workshops, and meetings; develops short education 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/CIREStweets>

<http://www.twitter.com/CIREStweets>

<https://www.flickr.com/photos/cires-photos>

<http://ciresblogs.colorado.edu>

Videos

June 2015

CIRES: Science at Every Scale

January 2016

Shrinking Satellites

January 2016

Greenland's "Sponge" Affected By Climate Change

January 2016

Rapid, Affordable Energy Transformation Possible

<http://www.youtube.com/user/ciresvideos>



Spheres science magazine

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

During this reporting period, we produced the Space Perspectives edition of *Spheres*. At CIRES, we're working to understand Earth's systems by looking at changes in weather and climate, air quality, water resources, and the atmosphere, just to name a few. While much of our information comes from research our scientists do on the ground, we're also collecting data from space—from satellites and from other planets. By looking beyond our own planet, we can better grasp what's happening here on Earth.

<http://cires.colorado.edu/spheres>

Diversity & Undergraduate Research

Educating undergraduate students and involving them in hands-on research are both part of CIRES engagement on campus. Our institute also oversees and participates in diversity programs designed to encourage involvement in atmospheric and other Earth sciences. The next three pages describe a few of last year's highlights.

Research Experience for Community College Students (RECCS)

In the summer of 2014, CIRES and the Institute of Arctic and Alpine Research (INSTAAR) received funding from the National Science Foundation to provide three years of the RECCS program, which gives summer research experiences to undergraduates from underserved communities. With this grant, CIRES and INSTAAR offer 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>

RECCS Students

Jess Barber

Mentor: Theo Barnhart (INSTAAR)

Project: Terrestrial based leaf area index compared to aerial lidar measured leaf area index for the Boulder Creek Critical Zone Observatory (CZO)

Scott-Wesley Bean

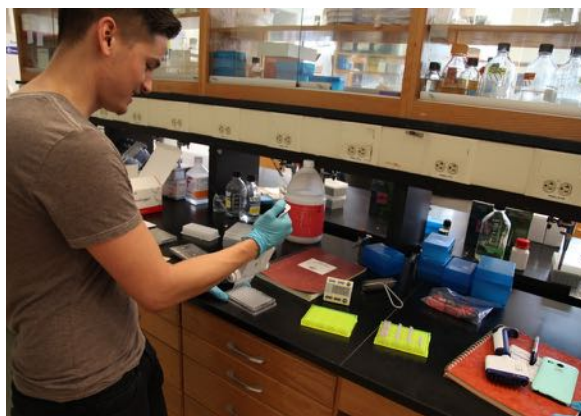
Mentor: Noah Fierer, Tess Brewer (CIRES)

Project: Effect of resuscitation factors on spore-forming and non-spore-forming soil bacteria

Michaela Brannum

Mentor: James McCutchan (CIRES)

Project: Nitrogen or phosphorus: The limiting factor on algae growth in Colorado lakes



Research Experience for Community College Students (RECCS) intern Scott-Wesley Bean. Photo: Robin L. Strelow/CIRES

Amanda Espinoza-Martinez

Mentor: Michael Gooseff (INSTAAR)

Project: Stream water temperature changes along the Gordon Gulch Creek

Brett Lindgen

Mentor: David Barnard (INSTAAR)

Project: Solar radiation and the forest canopy

Sean Ross

Mentor: Suzanne Anderson (INSTAAR)

Project: Weathering of the Boulder Creek Granodiorite as observed in a deep core, outcrops, and rock exposed by debris flows

Randall Rouse

Mentor: Theo Barnhart (INSTAAR)

Project: Evaluating the effects that slope intensity and directional orientation have on tree height and leaf area



Research Experience for Community College Students (RECCS) intern Michaela Brannum. Photo: Robin L. Strelow/CIRES

Taylor Schoenfeld

Mentor: Charles Shobe, Gregory Tucker (CIRES)

Project: Determining how different processes affect the trend of downstream fining of fluvial sediment grains in Chalk Creek, Colorado

Shala Wallace

Mentor: Brian Harvey (Geography)

Project: Climate growth relationships vary between different species and size classes?

Research Experiences in Solid Earth Sciences (RESESS)

RESESS at Unavco in Boulder, Colorado, is a summer research internship program aimed at increasing the diversity of students in the geosciences.

<http://recess.unavco.org>

RESESS Students

Crystal Burgess

Project: Detection of diagenesis in paleosol carbonate nodules using optical and cathodoluminescence microscopy (continued from previous year)

CIRES research mentor: Karen Alley

Enrique Chon

Project: Spatial and temporal analysis of soil moisture observations from the Russian River basin (continued from previous year)

CIRES research mentor: Anne Sheehan

Deanna Metivier

Project: Understanding the use of climate information in state wildlife action plans (continued from previous year)

CIRES research mentor: Heather Yocum

Significant Opportunities in Atmospheric Research and Science (SOARS)

SOARS is a learning community and mentoring program for promoting ethnic and gender equity in the atmospheric and related sciences. The National Center for Atmospheric Research created and administers the highly regarded four-year mentorship and research program for protégés majoring in an atmospheric or related field.

<http://www.ucar.edu/soars>

SOARS Protégés

Gabriela De la Cruz Tello

Project: Links between changes in atmospheric circulation and the extent of oceanic oxygen minimum zones

CIRES Mentor: Kris Karnauskas

William Evonosky

Project: Interactive ion-neutral dynamics in the ionosphere

CIRES Mentor: Tzu-Wei Fang

Meghan Mitchell

Project: Validating the WRF-Chem model using high resolution Doppler Lidar data from a Utah 2012 field campaign

CIRES Mentor: Yelena Pichugina

Alan Grochov Negron

Project: Emissions from oil and natural gas extraction upstream of the refinery at high spatial and temporal resolution

CIRES Mentor: Brian McDonald, Amy Solomon

Nkosi Muse

Project: Ingesting geospatial data into the National Weather Service's hazard services for flood warnings

CIRES Mentor: Kevin Manross, Lesley Smith



Ann Marie Prue and CIRES RESESS intern Crystal Burgess investigate carbon-rich mudstone at a road cut. Morrison, Colorado, June 2015. Photo: Benjamin Gross/UNAVCO

Diversity and Undergraduate Research

Zoraida Perez-Delgado

Project: Satellite and model analysis of coral reefs in the Western Indian Ocean: 2001-2007

CIRES Mentor: Dustin Swales

Awolou Sossa

Project: Understanding the rainfall pattern over West Africa

CIRES Mentor: Brant Liebmann, Tanya Peevey

Rosa Vargas-Martes

Project: Exploring the synoptic differences between MJO initiation events identified by multiple algorithms

CIRES Mentor: Leslie Hartten

Undergraduate Research Opportunities (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://www.colorado.edu/suep/about-urop>

UROP students

Michael Dooley

Project: Photochemical properties and surface thermodynamics of fatty acids

CIRES mentor: Veronica Vaida

Matthew Egleston

Project: Understanding the mechanisms by which *E. coli* can adapt to disruption of the pathway for the synthesis of pyridoxal-5-phosphate

CIRES mentor: Shelley Copley

Alix Knight

Project: Cultivating methylotrophs

CIRES mentor: Noah Fierer

Hunter Layton

Project: The effect on antibiotics on wild tobacco hornworms

CIRES mentor: Noah Fierer

Kyle Marchiori

Project: Surviving mass extinction

CIRES mentor: Max Boykoff

Selected 2015 Awards

The breadth and number of achievements by CIRES researchers and staff speak to the quality of research conducted at CIRES. From lifetime achievement awards to recognition of emerging new talent, CIRES scientists are among the best at what they do. Among the premier awards CIRES scientists received in 2015 were a Presidential early-career award for Gijs de Boer and a U.S. Department of Commerce Gold Medal for distinguished performance by two NOAA-led teams including CIRES and other scientists.

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.

Science and Engineering

Carrie Bell (NCEI) for developing an innovative way to display sonar data intuitively, making oceanic data accessible for diverse users.



Carrie Bell. Photos: Robin L. Strlow/CIRES



Rick Tisinai



Hillary Peddicord



Barry Eakins

Brian Lerner (CSD) for building one of the world's quickest and most automated whole air sampling analysis systems for atmospheric chemistry.

Richard McLaughlin, Andrew Rollins, Troy Thornberry, and **Laurel Watts** (CSD) for developing a sensitive new SO₂ instrument, allowing investigation of science questions previously impossible to tackle.

Service

Gabrielle Accatino, Catherine Rasco, and **Rick Tisinai** (CSD) for their innovative and high-impact IT design and development in support of the 2015 CSD Review.

Jonathan Joyce and **Hilary Peddicord** (GSD) for developing Science On a Sphere Explorer™, an educational software package that encourages exploration and discovery.

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 U.S. Department of Commerce Medals. CIRES recognizes their extraordinary achievements with CIRES Gold, Silver, and Bronze Medals and Technology Transfer awards.

CIRES Gold Medal for scientific/engineering achievement

Curtis Alexander, Ming Hu, Eric James, Jaymes Kenyon, Terra Ladwig, Bill Moninger, Joe Olson, Tanya Smirnova, Craig Tierney, and **Xue Wei** who work in NOAA's Global Systems Division were part of a NOAA team honored with a U.S. Department of Commerce (DOC) Gold Medal for the success of High-Resolution Rapid Refresh, the first stormscale model to give forecasters and decision-makers fast, local weather guidance. NOAA and CIRA recipients were: Stan Benjamin, John Brown, David Dowell, Georg Grell, Brian Jamison, Haidao Lin, Bob Lipschultz, Ed Szoke, and Steve Weygandt. The Gold Medal is presented by the Secretary of Commerce for distinguished performance.

CIRES Bronze Medal for superior performance

Barry Eakins, Jennifer Jencks, and **Elliot Lim** were part of a NOAA team honored with a DOC Bronze Medal for planning and establishing a multi-departmental U.S. Extended Continental Shelf Project Office to define and document U.S. territorial limits. NOAA recipients were: Capt. Andy Armstrong, Robin Warnken, and Meredith Westington. The Bronze medal for superior performance

Selected 2015 Awards

is the highest award conferred by the Under Secretary of Commerce for Oceans and Atmosphere.

CIRES Technology Transfer Award

Betsy Andrews, Derek Hageman, and Anne Jefferson, CIRES scientists in ESRL's Global Monitoring Division, collaborated with NOAA colleagues on the design of a new instrument, the Continuous Light Absorption Photometer, for long-term, research-quality measurements of atmospheric aerosol. NOAA recipients were John Ogren, Patrick Sheridan, and James Wendell. Brechtel Manufacturing, Inc. is now making a commercial version of the instrument.

Administrator's Award

Leon Benjamin and Gopa Padmanabhan, CIRES scientists in ESRL's Global Systems Division, along with colleagues at the Cooperative Institute for Research in the Atmosphere (Colorado State University) were part of a NOAA team awarded with the NOAA Administrator's Award for the group's extraordinary collaboration and leadership to ensure the Meteorological Assimilation Data Ingest System (MADIS) was successfully transferred to operations. NOAA and other recipients were Leigh Cheatwood-Harris, Randy Collander, Jim Frimel, Kevin Kelleher, Tom Kent, Michael Leon, Greg Pratt, John Schneider, Amenda Stanley, Daniel Velasco, and Michael Vrencur.



Anne Jefferson



Gijs de Boer

Other State, Federal, and International Awards

Curtis Alexander, Ming Hu, Tanya Smirnova, Joe Olson, Eric James, James Kenyon, Terra Ladwig, Bill Moninger, Craig Tierney and Xue Wei of CIRES were part of a multi-institution team that won the Governor's Award for High-Impact Research in the category of sustainability. With colleagues from CIRA (Haidao Lin, Brian Jamison and Ed Szoke) and led by NOAA's Stan Benjamin, John Brown, Steve Weygandt, David Dowell, and Georg Grell, the team developed an innovative weather model and transitioned it into National Weather Service offices across the country, saving lives and property. The High-Resolution Rapid Refresh (HRRR) model, developed during several years of intense research, is now giving emergency managers, pilots, and wind farm operators a more accurate depiction of hazardous weather, including critical details in rapidly changing and evolving weather events.

Gijs de Boer, a CIRES scientist working in the Physical Sciences Division of NOAA's Earth System Research Laboratory, is one of 106 recipients of the Presidential Early Career Awards for Scientists and Engineers (PECASE), announced in 2016.

Gabriela Anat Adler Katz (CSD)

Israel National Postdoc Award for Women in Science, awarded by the Weizmann Institute of Science to outstanding female Ph.D. graduates from all Israeli institutions of higher learning.

Patrick Alken, Nir Boneh, Arnaud Chulliat, Rich Fozzard, Stefan Maus, Brian Meyer, Manoj Nair, Neesha Schnepf, and Adam Woods (CIRES in NCEI) and NOAA's John Cartwright and Susan MacLean Governor's Award for High Impact Research—Foundational Science and Technology (CO-LABS)

This team of CIRES and NOAA geomagnetic experts has produced a diversity of remarkable science in 2014 and 2015, including mission-critical representations of Earth's magnetic field used daily by millions of people for military, mobile phone, and other navigation needs (including Google and Apple); and edgy innovations that may some day transform our ability to detect tsunamis and navigate more accurately through cities or under ice.

Lisa Dilling, Eric Gordon, Jeffrey Lukas (WWA) Governor's Award for High-Impact Research—Honorable Mention (CO-LABS)

The CIRES Western Water Assessment delivers actionable science to people, communities, governments, and other



Governor's Award for High Impact Research—Foundational Science and Technology award winners. Photo: CU Boulder

organizations seeking to build resilience to climate change and variability. With a focus on the Intermountain West (Colorado, Utah, and Wyoming) and relying on applied research, this NOAA-funded program has built powerful and effective collaborations to generate policy-relevant science that's both useful and used.

Linyin Cheng (PSD)

AGU Natural Hazard Focus Group Graduate Research Award. This award recognizes a promising young scientist engaged in studies of natural hazards and risks and is given in recognition of outstanding contributions achieved during their Ph.D. (or highest equivalent terminal degree) research.

David Costa and Darren Jackson (PSD)

NASA Group Achievement Award for outstanding achievements of the Hurricane and Severe Storm Sentinel (HS3) airborne mission to investigate the factors influencing hurricane intensity change.

Anne Gold (Education and Outreach)

The University of Colorado Boulder Chancellor's Award for Excellence in STEM Education.

Xiangbao Jing (GSD) and **William Rowland** (NCEI)

NASA Group Achievement Award for outstanding effort in developing and testing the DSCOVER ground system under extenuating circumstances with limited resources and time.

Tomoko Matsuo (SWPC)

Selected as a member of International Space Science Institute (ISSI) Working Group "Ionospheric Multi-Spacecraft Analysis Tools" in 2015-2017 to review the state of the field and make recommendations for future research directions.

Carrie Morrill (NCEI)

Kavli Fellow, National Academy of Sciences and Kavli Foundation. Selection to participate in the Kavli Frontiers of Science Symposium which "brings together outstanding young scientists to discuss exciting advances and opportunities in a broad range of disciplines." Outstanding Science and Research Employee of the Year NOAA's National Environmental Satellite, Data and Information Service (NESDIS) for our key role in implementing a broad-spectrum of use-inspired innovations in the World Data Center for Paleoclimatology, thus supporting the NOAA mission of sharing knowledge and information with others.

Allen Pope (NSIDC)

Science Communication Award, International Glaciological Society & Association of Polar Early Career Scientists

Juan Rodriguez (NCEI)

Robert H. Goddard Exceptional Achievement for Engineering Team to GOES-R Space Environment In-Situ Suite (SEISS) Development

Lesley Smith (Education and Outreach)

Appointed chair of the Colorado Science Education Network.

Christopher Williams (PSD)

NASA Group Achievement Award, to the Global Precipitation Measurement (GPM) Post-Launch Team, "For exceeding all expectations for GPM operations, data processing, algorithm performance, science impact, and education and public outreach within one year after launch."

Lynn Yarmey (NSIDC)

Elected to the EarthCube Leadership Council by community of peers.



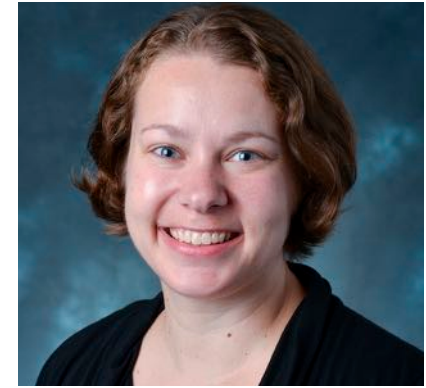
Anne Gold. Photo: David Oonk/CIRES



Allen Pope. Photo: Robin L. Strlow/CIRES



Lesley Smith. Photo: David Oonk/CIRES



Lynn Yarmey. Photo: CU Boulder

Events

Analytical Chemistry Seminars

Paul Ziemann and Jose Jimenez Chemistry of organic compounds in the atmosphere and indoor air (9/15)

Veronica Vaida and Eleanor Browne Building molecular complexity with sunlight at aqueous interfaces (10/15)

Henning Finkenzeller and Rainer Volkamer CE-DOAS at its detection limit (10/15)

John Birks Portable air pollution monitors and the global ozone (GO3) Project (10/15)

Harald Stark High-resolution mass spectrometry: Peak fitting and aerosol partitioning (10/15)

Doug Day Particle size resolution of the Aerodyne aerosol mass spectrometer (10/15)

Noah Fierer Diversity of bioaerosols in indoor and outdoor air across the U.S. (11/15)

Hyungu Kang Size-dependent molecular-level characterization of secondary organic aerosol from NO₃ initiated Δ-carene oxidation using nanospray desorption electrospray ionization high-resolution mass spectrometry (11/15)

Nolan Kane The genetics of terpenoid production in cannabis (11/15)

Eve-Lyn Hinckley Immediate fates of the world's oldest pesticide in California's most lucrative crop (11/15)

Barbara Dix Parameterization and evaluation of airborne halogen oxide measurements in the tropical transition layer and lower stratosphere (12/15)

Pedro Campuzano Jost SOA derived from isoprene epoxydiols: Insights into formation, aging and distribution over the continental U.S. from two NASA aircraft campaigns (12/15)

Abigail Koss Measurement of volatile organic compounds in the atmosphere using NO⁺ chemical ionization mass spectrometry (2/15)

Benjamin Nault Chemistry in one of the coldest places in the atmosphere: Impacts of updated NO_x lifetime and fate on lightning NO_x emission rates (2/16)

Jason Schroder Insights into submicron aerosol composition and sources from the WINTER Aircraft Campaign over the eastern U.S. (2/16)

Ingrid Mielke-Maday Investigating hydrocarbon emissions in oil and gas basins using mobile platforms (2/16)

Katie Primm Supercooling and ice formation of perchlorate and chloride brines under Mars-relevant conditions (2/16)

rate and chloride brines under Mars-relevant conditions (2/16)

Lucas Algrim Effect of a functional group on SOA yields and particle composition from OH radical initiated reactions of alkanes in the presence of NO_x (3/16)

Demetrios Pagonis Chemistry of multifunctional hydroperoxides in secondary organic aerosol (3/16)

Shuichi Ushijima Heterogeneous efflorescence by mineral dust particles (4/16)

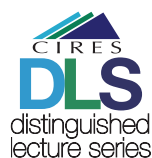
Ronald C. Cohen On the lifetime of nitrogen oxides in the continental boundary layer (4/16)

Megan Claffin Effects of atmospheric conditions on the composition of secondary organic aerosol formed from the oxidation of isoprene and monoterpenes (4/16)

William C. Keene Marine aerosol production, chemical processing, and feedbacks (4/16)

CSTPR Noontime Seminars

Deserei Crow, Adrienne Kroepsch, Elizabeth Koebele, Lydia Dixon Assessing wildfire mitigation outreach strategies in the wildland-urban interface (9/15)



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.

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David Keith

Moderate, temporary, and responsive solar geoengineering (9/15)



Jan Marco Müller

The quest for evidence: An insider's view on science and politics in Europe (10/15)



Barbara Finlayson-Pitts

Particle formation from sulfur compounds in a coastal urban area: Now and then (11/15)



Steve Running

Is terrestrial net primary production a planetary boundary? (4/16)

Jan Marco Müller Chief scientific adviser in the European Commission: Results of an experiment (9/15)
Sam Schramski Climate change in an Amazon town: Media and environmental perceptions in ever-rising waters (12/15)
Ines Lörcher Climate change from the audience's perspective (2/16)
Lucy McAllister Coming to the rescue? Tech firms and the harms of the electronics commodity chain (3/16)
Reiner Grundmann Media coverage of climate change in a comparative perspective (3/16)
Sam Schramski A real polémica: An approach to scientific controversy and its uncertain reach (3/16)
Lesley Henderson Communicating plastic pollution: The (conflicting) values of media producers, scientists, & lay publics? (4/16)
Maxwell Dalaba Prices, peers, and perceptions (P3): Improved cookstove research in northern Ghana (5/16)

Cryospheric and Polar Processes Seminars

Kevin Schaefer Using Interferometric Synthetic Aperture Radar (InSAR) to remotely sense active layer thickness in permafrost regions (9/15)
Matthew Hoffman Validation of the dynamic response of ice sheet models to changes in outlet glacier discharge (9/15)
Joseph A. MacGregor A synthesis of the thermal state of the bed of the Greenland ice sheet (9/15)
Ted Scambos The coldest place on earth (9/15)
Katja Friedrich The great Colorado flood of September 2013 (10/15)
Karl Rittger Mapping snow and snow melt with MODIS, Landsat, and other satellites for the CHARIS project (10/15)
Matthew Druckenmiller Communicating why sea ice matters: New directions for the Study of Environmental Arctic Change (SEARCH) (10/15)
Jeff Thompson Perspective from the periphery: Linking vegetation phenology and cryospheric change in Greenland (11/15)
Drew Slater Will the terrestrial Arctic turn to mush? (11/15)

Rob Massom Satellite-based fast ice studies in Antarctica (1/16)
Lora Koenig Scratching the surface: Studies of accumulation and melt over the ice sheets (2/16)
Garrett Campbell Sea ice in the 1960s from satellites (2/16)
Julienne Stroeve Variability in the Antarctic marginal ice zone and pack ice in observations and NCAR CESM (3/16)
Andrew Barrett How much water do glaciers and snow cover contribute to runoff from High Mountain Asia? (3/16)
Allen Pope Progress on a Landsat 8 mosaic of Antarctica (3/16)
William Colgan New paradigm for attributing recent Greenland ice loss (3/16)
Amanda Lynch Linkages between Arctic summer circulation regimes and regional sea ice anomalies (4/16)
Ted Scambos The continuing evolution of the Larson B ice shelf system: Cape disappointment (4/16)

Education & Outreach Events

RECCS Summer Internship (6/15)
NAGT Earth Educators Rendezvous (7/15)
Colorado's Changing Energy Budget Workshop (11/15)
Colorado Science Conference Booth (11/15)
CU Outreach Conference Booth (1/16)
CU Volunteer Fair Booth (1/16)
Mysterious Microbes Webinar Series (1/16, 2/16, 3/16)
Mysterious Microbes Workshop (6/16)

Reading the IPCC Report

16 presentations from CIRES, NCAR, CU Boulder and NOAA scientists involved in creating the IPCC report spoke and took questions about individual segments of the report.
Jerry Meehl Points of departure (8/15)
Ben Livneh Freshwater (9/15)
Joanie Kleypas Ocean systems (9/15)
James Syvitski Coastal systems (9/15)
Linda Mearns Regional context (9/15)

Leiwen Jiang Human settlements (10/15)
Brian O'Neill Emergent risks and key vulnerabilities (10/15)
Paul Chinowsky Key economic sectors and services (10/15)
William Travis Food security (10/15)
Garvin Heath Energy systems (10/15)
John O'Loughlin Human security (11/15)
Michele Betsill National and sub-national policies and institutions (11/15)
Jennifer Berry Light-absorbing impurities and spectral albedo of the Juneau Icefield (11/15)
Kevin Jansen Chemical and physical alterations of acid-treated aluminosilicate clay minerals and impacts on heterogeneous ice nucleation (11/15)
Mary Hayden Human health (11/15)
Helena Chum Agriculture, forestry, and other land use (12/15)

Miscellaneous

Winona LaDuke Indigenous women telling a new story about energy and climate (12/14)
Roger Bilham Geology Colloquium: The disastrous Nepal 2015 earthquake: What happened and what's next
Performance, Art and Music for a RESILIENT BOULDER (10/15)
Craig Rodger Zombie satellites, killer electrons, and physics in space! (10/15)
Happy 50th, NGDC/NCEI (10/15)
Kris Karnauskas: NCAR Climate & Global Dynamics Seminar: Climate change on tropical islands: Dynamics and impacts (10/15)
Jan Marco Müller FOSEP Talk: The challenge of shaping a society that embraces innovation and why Europe differs from the US (10/15)
Jeff Lukas, Louisville Climate Change Symposium: Climate change and Colorado water (10/15)
Jeff Lukas, Klaus Wolter, Nezette Rydell, and Martin Hoerling, WWA & NOAA PSD El Niño panel discussion and webinar (10/15)
Jan Marco Müller INSTAAR Seminar: Policy—Should it be based on fact or fiction? Joint Research Centre European

Commission (10/15)

CGA Student Speaker Series:

Aleya Kaushik Investigating climate in the atmospheric surface layer using stable water isotopes (11/15)

Deserai Anderson Crow Colorado's floods and fires: Risk mitigation and disaster recovery through a policy lens (11/15)

Vineel Kumar, Reddy Yettella, Shane Grigsby, Mike McFerrin, Glenn Grant (12/15)

John Melack CWEST Seminar: John Melack Ecosystem processes in Amazon floodplains: Linking hydrology and ecology (1/16)

Benjamin Hale ENVS Colloquium: The lingering value of technological artifacts: A clog in the e-waste stream (2/16)

CGA Travel Award Winner Lunchtime Seminar (2/16)

Rebecca Rapf Sunlight-driven, water-mediated synthesis

and self-assembly of model amphiphiles under prebiotic conditions

Brett Palm Secondary organic aerosol formation from ambient air in an oxidation flow reactor at GoAmazon2014/5

Magali Barba: Post-seismic deformation of Mojave earthquakes using full-resolution InSAR time-series analysis

Mas Yanto: Hydrologic modeling and parameter estimation under data scarcity for Java Island, Indonesia

Panel Discussion: AAAS (2/16)

Lorenzo Polvani ATOC Distinguished Lecture: Stratospheric ozone and southern hemisphere climate change (2/16)

Maxwell Boykoff ENVS Colloquium: Maxwell Boykoff Navigating climate change: Communication and cultural

politics in the 21st century (2/16)

Reed Maxwell CWEST Seminar: Reed Maxwell Connections in the hydrologic cycle: How anthropogenic stresses impact feed-backs, sensitivity, and sustainability (2/16)

Indigenous Peoples and Climate Justice (3/16)

Sarah A Krakoff Tribal self-determination, cultural survival, and climate justice

Heather Lazrus Rising voices of indigenous people in weather and climate science and policy

Kyle Whyte Indigenous climate justice, collective continuance, and settler colonialism

CGA Lunch Seminar: Use your online presence to get a job and further your career goals (3/16)

Comedy for Climate Change Standing Up for Climate: An Experiment with Creative Climate Comedy (3/16)

Panel Discussion: Power Dialog (4/16)

Panelists: William S. Becker, Suzanne Tegen, David Ciptet, Rosemarie Russo, Stephanie Malin

Moderators: Kristen Averyt, Michelle Gabrielloff-Parish

Lauren E. Hay CWEST Distinguished Seminar Series: Hydrologic modeling on a national scale (4/16)

Creative Climate Communications with 7News' Mike Nelson (4/16)

Eric Lindstrom Ocean Observing from NASA's Perspective (4/16)

CIRES Visiting Fellows: Special Seminar (4/16)

Paul Carini Census of the dead: Relic DNA obscures molecular analyses of soil microbial communities,

Ben Green Further evidence of two different MJO flavors in high-resolution coupled model simulations

Adam Schneider A "flood of troubles": Evidence for and historical implications of environmental influences upon the outcome of Valens's first Gothic War (367-369 C.E.) on the lower Danube

CIRES Rendezvous (5/16)

NSIDC 40th Anniversary (5/16)

Uwe Karst, CIRES Visiting Fellow Seminar: An image says more than a thousand words: Mass spectrometric imaging and complementary techniques in pharmaceutical and biomedical analysis (6/16)

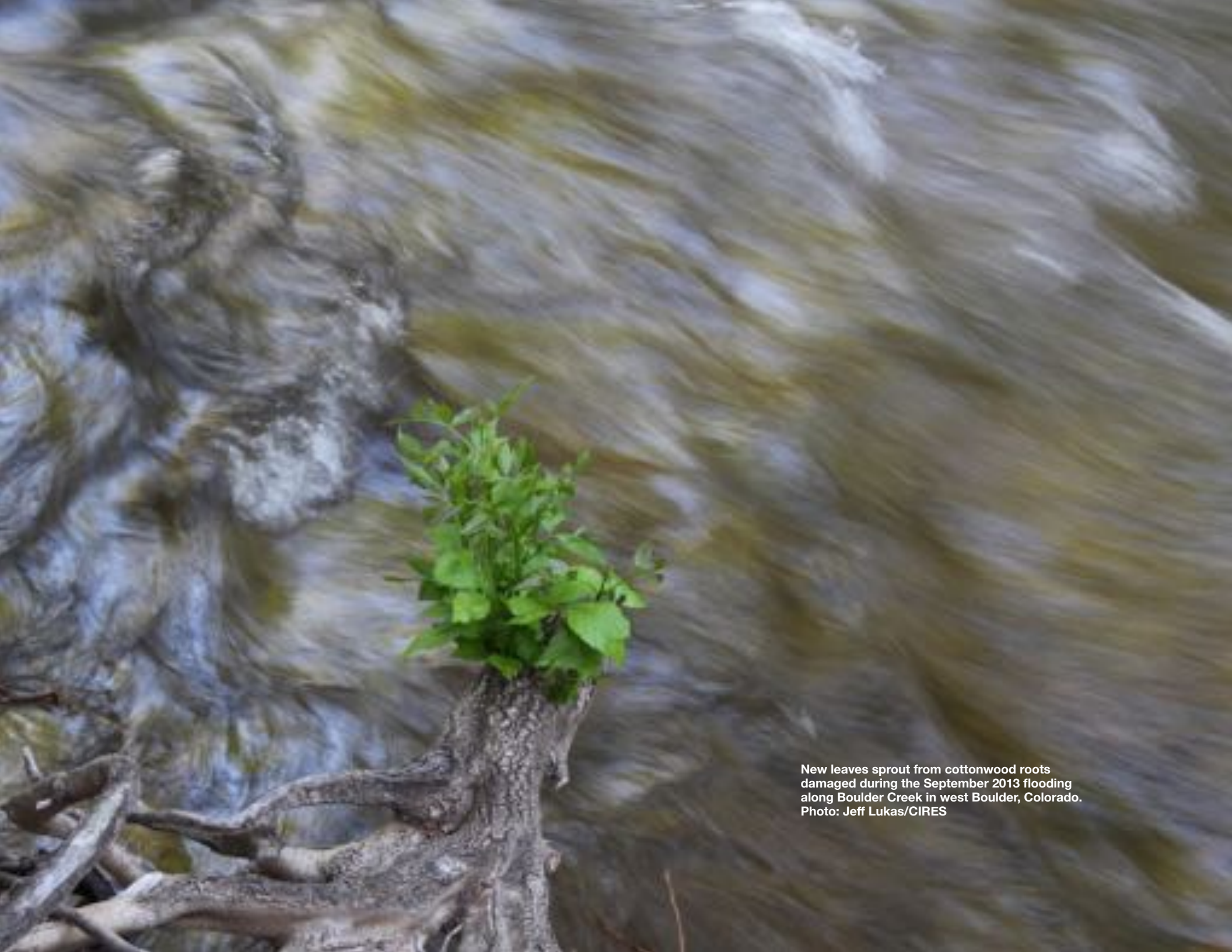
Anniversaries



The National Geophysical Data Center (now the National Center for Environmental Information) celebrated its 50th anniversary in October, 2015. Photo: Charles Anderson/NOAA



Director Mark Sereze addresses the audience at the National Snow and Ice Data Center's 40th anniversary luncheon in May, 2016. Photo: Robin L. Strelow/CIRES



New leaves sprout from cottonwood roots damaged during the September 2013 flooding along Boulder Creek in west Boulder, Colorado.
Photo: Jeff Lukas/CIRES

Project Reports

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Key acronyms in this section

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
NOAA	National Oceanic and Atmospheric Administration
OAR	NOAA Office of Oceanic and Atmospheric Research
PSD	NOAA ESRL Physical Sciences Division
SWPC	NOAA NWS Space Weather Prediction Center

- Office of Oceanic and Atmospheric Research (OAR)
- National Environmental Satellite, Data, and Information Systems (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 and analyzed results from several intensive regional field studies conducted to enhance understanding of air quality and climate, using a variety of measurement platforms and locations. The results from these field studies are improving scientific understanding of emissions, atmospheric chemistry, and transport to support development of effective mitigation strategies and improve the ability of models to estimate future climate and air quality.

Using in situ measurements from the NOAA twin otter aircraft during the TOPDOWN (Twin Otter Projects Defining Oil/Gas Well Emissions) 2014 experiment, upwind and downwind of the Bakken oil and gas field in North Dakota, we quantified methane emissions from oil and natural gas extraction in this region. The methane leak rate was significantly lower than had been reported using satellite remote sensing data. These measurements help improve emissions inventories and provide accurate data for policy makers.

We performed rapid-response airborne and mobile van chemical sampling of methane from



Bakken Formation well pad with flares in North Dakota. Photo: Jeff Peischl/CIRES

the massive release of natural gas from the Aliso Canyon underground storage facility in California. The analysis of these measurements quickly quantified the leak rate to the atmosphere, which helped document human exposure, formulate intervention strategies, and quantify the efficacy of control measures. Further, this study is valuable for assessing the climate and air quality impacts of major unanticipated chemical releases.

The climate and air quality impacts from oil and natural gas operations also depend on emissions of ozone precursor species, nitrogen oxides, and volatile organic compounds (VOC). We have shown how emissions from oil and gas activities in the Denver-Julesburg Basin affect ozone formation, using measurement from the Boulder Atmospheric Observatory (BAO) during the 2014 Front Range Air Pollution and Photochemistry Experiment (FRAPPÉ). Using measurements from the 2012, 2013, and 2014 Uintah Basin Wintertime Ozone Studies (UBWOS), we have detailed the wintertime atmospheric impacts of nitrogen oxide and VOC emissions in a basin with extensive oil and gas development.

Additional accomplishments include the modification and construction of new reactive nitrogen, ozone, and particle instruments for operation aboard the NASA DC-8 aircraft in support of the NASA Atmospheric Tomography mission. We have deployed instruments on the NASA DC-8 in support of the Korea-US Air Quality Study (KORUS-AQ), an international cooperative air quality field study in Korea. We have sampled atmospheric emissions from agricultural sources in northeast Colorado from a mobile van and used these measurements to elucidate the diurnal and seasonal variability of emissions from feedlots. Quantifying these emissions improves air quality models and informs mitigation plans.

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 the magnitude, spatial, and temporal variability of important chemical species emitted by various sources is vital to the management of pollution within large urban air-sheds, and to predictions of air quality and climate change. California's South Coast Air Basin (SoCAB) is home to more than 17 million, and perennially exceeds the national air quality standards for ozone. This project combines regional photochemical transport modeling, aircraft, surface, and remote sensing measurements made during an intensive field study, and a relatively new method to estimate vehicle emissions of odd-ni-

Project Reports: Air Quality in a Changing Climate

trogen (NO_x) and carbon monoxide (CO) in California's SoCAB. These two species are key ingredients to ozone formation and associated poor air quality.

In contrast to emission inventories produced by the U.S. EPA and the California Air Resources Board (CARB), the Fuel-based Inventory for Vehicle Emissions (FIVE), developed and published by Brian McDonald (CIRES), is used to specify CO and NO_x vehicle emissions within regional photochemical model simulations over SoCAB during the summer of 2010. The FIVE method relies on intensive roadside monitoring programs and tunnel studies to derive ambient emission factors for gasoline- and diesel-powered vehicles. A notable feature of FIVE is the separate spatial and temporal mapping of on-road gasoline and diesel emissions, utilizing highway traffic count, weigh-in-motion, and fuel sales data. It also accounts for weekday/weekend differences in vehicle emissions, and is applied to 1-km horizontal resolution grids for Los Angeles and 6 other US cities.

The WRF/Chem regional photochemical transport model, using the FIVE-based emissions, is critically evaluated against several pollutants and meteorological parameters, focusing on the large differences seen between weekdays and weekend oxidation conditions induced by the differences in (vehicular) NO_x and CO emissions.

The results of this work were published (Kim, S.-W., et al., JGR) in early 2016. Utilizing the newly developed FIVE emission inventory, the simulated NO_x and CO mixing ratios agree with the observations from the airborne, ground based in-situ, and remotely sensed measurements from the field study. The simulations also reproduce the weekly cycles of the chemical species. Both the observations and model simulations indicate that decreased NO_x on weekends leads to enhanced photochemistry and ozone increases in the basin.

GSD-04: Improve Regional Air Quality Prediction

■ CIRES Lead: Ravan Ahmadov ■ 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

During the last report year CIRES staff worked on several projects related to improving air quality prediction.

The Weather Research & Forecasting-Chem model was updated to the 3.8 version, which was released to a large users' community. The new version of the model includes an updated dust scheme based on the University of Cologne parameterization, a new secondary organic

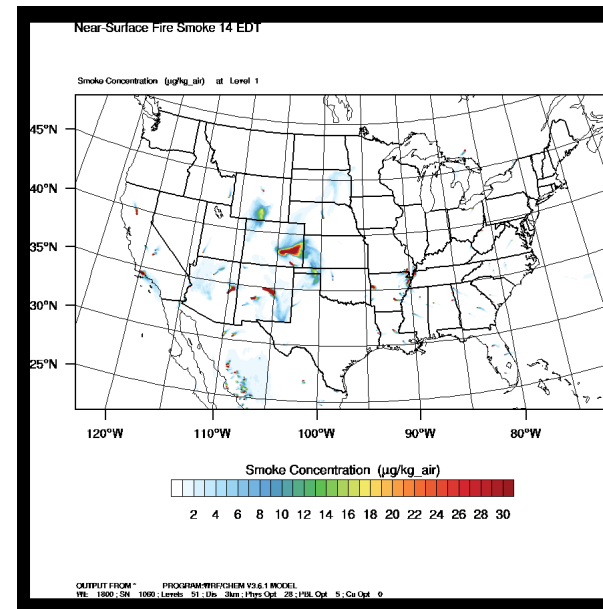
aerosol scheme with direct and indirect feedback mechanisms, several bug fixes, and other updates. CIRES has continued to support the large WRF-Chem user community by providing an annual WRF-Chem tutorial, providing a guidance to modelers, and answering questions sent to the WRF-Chem help desk. CIRES has been providing continuous support to update and test the WRF-Chem model for the next release (expected in August

2016) in a strong collaboration with NCAR.

A significant amount of work has been done by CIRES in developing and testing a new modeling system—High-Resolution Rapid Refresh (HRRR)-Smoke. HRRR-Smoke has been developed to simulate the emissions and transport of particulate matter from wildfires in real time in high spatial resolution (3km). The fire emissions in HRRR-Smoke are calculated using the fire detection and characterization data from the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on the Suomi National Polar-orbiting Partnership satellite. Fire Radiative

Power (FRP) data from VIIRS determine fire size and are then applied in HRRR-Smoke to calculate injection heights using a plume rise model. For HRRR-Smoke a new version of the Prep_Chem_Source tool and plume rise parameterization have been developed in order to simulate fire emissions and plume rise using the VIIRS FRP data.

One of the major accomplishments was setting up HRRR-Smoke to run in real time by CIRES at NOAA/ESRL/GSD for the entire CONUS domain (3km horizontal grid resolution). HRRR-Smoke is initialized every day at 00 and 12UTC using input files for the meteorology from the real-time HRRR experimental runs. The model is then run to produce 36 hour forecasts. The forecast smoke fields are visualized in real-time and graphics are provided via a web-site at: <http://rapidrefresh.noaa.gov/HRRRsmoke/>



Example of a High-Resolution Rapid Refresh Smoke forecast. Image: CIRES/NOAA

The dynamics and physics packages and settings for the meteorology of HRRR-Smoke were based on the experimental version of the HRRR model, which is run in real-time (<http://rapidrefresh.noaa.gov/hrrr/>), and is also supported by CIRES staff. Since HRRR-Smoke includes anthropogenic emissions of other particulate matter species, and includes an aerosol aware microphysics scheme, it also allows us to investigate aerosol impacts on Numerical Weather Prediction.

Another development by CIRES was the simulation of fire emissions and smoke fields by HRRR-Smoke for the August 2015 case. Such a model product allows to evaluate and further improve the HRRR-Smoke modeling system for wildfires over the United States.

In collaboration with ESRL/GSD, the CIRES scientists have made progress in developing a fully coupled global general circulation model (e.g. FIM) and chemical transport model (FIM-Chem), which include incorporating different gas-phase mechanisms and sophisticated aerosol modules, to improve air pollution predictions, and apply data assimilation methodologies to improve chemical weather forecasts. This includes incorporating different gas-phase mechanisms and aerosol mechanisms, such as the organic aerosol formation mechanism within FIM-Chem.

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

The Synthesis Report of the United Nations' *Montreal Protocol on Substances that Deplete the Ozone Layer* was completed in October 2015. The 1987 Montreal Protocol is an international agreement to protect the ozone layer from ozone-depleting substances such as chlorofluorocarbons and halons. *The Synthesis Report* describes and synthesizes the major findings from the 2014 reports of the Protocol's three assessment panels: Scientific Assessment Panel, Technology and Economic Assessment Panel, and Environmental Effects Assessment Panel. Together, these three panels were established by the Protocol to periodically assess the state of understanding regarding science of the ozone layer, technological approaches to its protection, and effects of depletion of the ozone layer. The 2014 reports of the panels and the 2015 *Synthesis Report* were the most recent in the series of quadrennial reports. CIRES played significant roles in authoring, reviewing, coordinating, and editing

the 2014 report of the Scientific Assessment Panel, and in editing the 2015 *Synthesis Report* of the three panels. *The Synthesis Report* was delivered to decisionmakers at the November 2015 Meeting of the Parties to the Montreal Protocol in Dubai. Its findings will help the Parties evaluate options for potential future measures to protect the ozone layer, which plays a critical role in shielding the earth surface from harmful amounts of ultraviolet radiation.

A CIRES scientist is leading a major international effort to produce an assessment regarding ozone in the lower atmosphere, the Tropospheric Ozone Assessment Report (TOAR). Tropospheric ozone (O₃) is important both as an air pollutant and as a greenhouse gas. It is formed as a secondary pollutant when volatile organic compounds (VOCs) and nitrogen oxides (NO_x) react in the atmosphere. The multi-year effort to produce the TOAR assessment is being

organized under the auspices of the International Global Atmospheric Chemistry (IGAC) project, with support from NOAA and the World Meteorological Organization. The TOAR assessment will be the first global "state-of-the-science" assessment on the topic of ozone in the lower atmosphere. It specifically aims to provide the research community with an up-to-date scientific assessment of tropospheric ozone's global distribution and trends from the surface up to the tropopause (the boundary between the troposphere and the stratosphere). The first drafts of the assessment's seven chapters were produced in 2015 and discussed at a peer-review meeting held in Beijing in January 2016. The chapters will be revised and further reviewed in 2016, with completion and publication anticipated for late 2016/early 2017.

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 past decade due to advances in hydraulic fracturing and directional drilling. CIRES scientists are studying the emissions of trace gases and fine particles to the atmosphere that are associated with this industrial activity, and how these emissions affect climate and air quality. CIRES scientists made measurements of methane from research aircraft in multiple oil and gas production regions. Methane emissions were derived from mass balance, by comparing the methane observations upwind and downwind from a production area, and also by inverse modeling. For the Bakken in North Dakota, annual emissions of 275,000 tons of methane were reported, which was significantly less than a previous study based on satellite remote sensing data. CIRES scientists also focused on emissions of volatile organic compounds (VOC) and black carbon aerosol associated with oil and gas production. VOC emissions were found to be quantitatively and qualitatively different between different production regions, possibly reflecting differences in raw oil and gas composition, differences in production methods, or other external factors. Black carbon aerosol emitted from flaring in the Bakken was quantified and found to be less than 1% of the total black carbon emissions in the United States. Finally, using aircraft measurements, the accidental methane release from the Aliso Canyon gas well blowout northwest of Los Angeles, California was quantified to be 97,100 tons.

Atmospheric emissions from agriculture are important to air quality and climate, yet their representation in models is incomplete. Using research aircraft and an instrumented van,





Aerial image of Aliso Canyon natural gas storage facility shot from UC Davis scientist Stephen Conley's airplane, which provided the first and, so far, only estimates of methane emissions from an ongoing leak at the facility in the San Fernando Valley. Photo: Stephen Conley/UC Davis

CIRES scientists are measuring the emissions of methane, ammonia, nitrous oxide, and other trace species including VOCs from animal feedlots and dairies. Measurements of VOCs allowed the distinction between sources from animal waste, and feed storage and handling in a single feedlot.

An increasing focus in CIRES' research is on biomass burning emissions, as wildfires have become a larger factor in air quality, especially in the western U.S. Initial measurements from research aircraft and an instrumented van were used to characterize smoke from agricultural and forest fires, and from wood burning stoves. Emissions of radical precursor gases like nitrous acid, a species that is prone to measurement artifacts, were quantified using chemical ionization mass spectrometry. Emissions of nitrogen-containing VOCs were found to depend strongly on the nitrogen content of the fuel, which has implications for atmospheric chemistry and health effects.

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

■ CIRES Lead: Dimitris Papanastasiou ■ NOAA Lead: Jim Burkholder
NOAA Theme: Climate Adaptation and Mitigation

Goals & Objective

This project will use specific laboratory techniques to measure the rates, reaction pathways, and product distributions of homogeneous and heterogeneous processes that play a role in air quality, climate, and stratospheric ozone depletion.

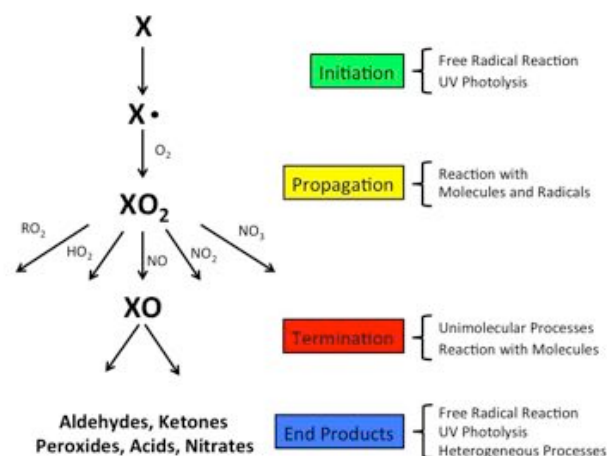
Accomplishments

Atmospheric lifetimes, ozone depletion and global warming potential of halocarbons in the atmosphere:

The observation of $\text{CCl}_2\text{FCCl}_2\text{F}$ (CFC-112), $\text{CCl}_3\text{CClF}_2$ (CFC-112a), and CCl_3CF_3 (CFC-113a) in the atmosphere was recently reported. The potential impact of CFC-112, CFC-112a, and CFC-113a, on stratospheric ozone and climate was not, however, well characterized. CIRES scientists performed laboratory studies and atmospheric model calculations to define the atmospheric lifetime, ozone depletion potential (ODP), and global warming potential (GWP) of CFC-112, CFC-112a, CFC-113a, as well as CCl_2FCF_3 (CFC-114a) [Davis, et al., 2016]. UV photolysis was expected to be the predominant atmospheric loss process for these compounds and the UV absorption spectra of these CFCs were measured over an atmospherically relevant wavelength (192.5–235 nm) and temperature range (207–323 K). 2-D atmospheric model calculations were used to evaluate the atmospheric loss processes, lifetimes, and ODPs. Global annually averaged steady-state lifetimes (years) were determined to be 63.6, 51.5, 55.4, and 105.3 for CFC-112, CFC-112a, CFC-113a, and CFC-114a, respectively. These long-lived CFCs are potent ozone depleting substances with model calculated ODPs of 0.98, 0.86, 0.73, and 0.72 for CFC-112, CFC-112a, CFC-113a, and CFC-114a, respectively. The CFCs were also shown in this study to be potent greenhouse gases with GWPs comparable to those of the most abundant CFCs present in the atmosphere.

CIRES scientists performed laboratory studies to evaluate the impact of the recently observed $\text{CF}_3\text{CH}_2\text{Cl}$ (HCFC-133a) on stratospheric ozone and climate [McGillen, et al., 2015a]. The

Atmospheric Degradation



A trace gas (X) in the atmosphere undergoes transformation processes leading to a variety of stable end-products. This project aims to better understand the key processes that define the atmospheric lifetime, fate and products of trace gases and their impact on climate, air quality and stratospheric ozone. Image: CIRES and NOAA

Project Reports: Climate Forcing, Feedbacks, and Analysis

atmospheric abundance HCFC-133a has increased over the past 20 years to a 2012 mixing ratio of 0.37 ppt (parts per trillion). In this study, the UV absorption spectrum of HCFC-133a and the rate coefficient for its reaction with the hydroxyl (OH) radical were measured. A 2-D atmospheric model was used to evaluate the relative importance of the atmospheric loss processes, its lifetime, and ODP. The global annually averaged steady-state lifetime was determined to be 4.45 years, with the main degradation pathway being reaction with OH radicals in the troposphere. Its ODP was determined to be relatively small, 0.017, which is consistent with values for other HCFCs with atmospheric lifetimes

Impact on stratospheric ozone and climate of degradation products of CFCs and replacement compounds:

1. Tetrafluoromethane, CF_4 , and its sources are a concern because of its atmospheric persistence (its atmospheric lifetime is estimated to be 50,000 years), and a significant global warming potential of ~6600 (100 year time horizon). In this study, a previously uncharacterized atmospheric source of the persistent greenhouse gas CF_4 was identified in the UV photolysis of trifluoroacetyl fluoride, $\text{CF}_3\text{C}(\text{O})\text{F}$, which is a degradation product of several halocarbons currently present in the atmosphere [Jubb, et al., 2015]. CF_4 quantum yields, were determined at 193, 214, 228, and 248 nm and a 2-D atmospheric model was used to estimate the contribution of this photochemical source to the global CF_4 budget. Although the CF_4 photochemical production was found to be relatively minor, the identified mechanism demonstrates that long-lived products with potential climate impacts can be formed from the atmospheric breakdown of shorter-lived source gases.
2. Trifluoroacetyl chloride, $\text{CF}_3\text{C}(\text{O})\text{Cl}$, is formed in the atmospheric degradation of hydrochlorofluorocarbons (HCFCs), chlorofluorocarbons (CFCs), and brominated compounds. The atmospheric fate of $\text{CF}_3\text{C}(\text{O})\text{Cl}$ is determined pre-dominantly by wet deposition/hydrolysis and UV photolysis in the troposphere, and UV photolysis in the stratosphere. The possible formation of CF_3Cl , as a photolysis product, is of particular interest, since CF_3Cl is a long-lived ozone depleting substance. In this study, quantum yields in the UV photolysis of $\text{CF}_3\text{C}(\text{O})\text{Cl}$ at 193, 248, 254, and 280 nm were determined [McGillen and Burkholder, 2015b]. The CF_3Cl quantum yield was determined to be minor (<0.001) at the wavelengths studied. Photolysis of $\text{CF}_3\text{C}(\text{O})\text{Cl}$ in the troposphere and lower stratosphere is expected to mainly form CF_3CO radicals.

References:

- Davis, M.E., Bernard, F., McGillen, M.R., Fleming, E.L., and Burkholder, J.B., UV and infrared absorption spectra, atmospheric lifetimes, and ozone depletion and global warming potentials for $\text{CCl}_2\text{FCCl}_2\text{F}$ (CFC-112), $\text{CCl}_3\text{CClF}_2$ (CFC-112a), CCl_3CF_3 (CFC-113a), and CCl_2FCF_3 (CFC-114a), *Atmos. Chem. Phys. Discuss.*, doi:10.5194/acp-2016-180, in review, 2016.
- McGillen, M.R., F. Bernard, E.L. Fleming, and J.B. Burkholder, HCFC-133a ($\text{CF}_3\text{CH}_2\text{Cl}$):

OH rate coefficient, UV and infrared absorption spectra, and atmospheric implications, *Geophys. Res. Lett.*, 42, 6298, 2015a.

Jubb, A.M., McGillen, M.R., Portmann, R.W., Daniel, J.S., and Burkholder, J.B., An atmospheric photochemical source of the persistent greenhouse gas CF_4 , *Geophys. Res. Lett.*, 42, 9505, 2015.

McGillen, M.R., and Burkholder J.B., Gas-phase photodissociation of $\text{CF}_3\text{C}(\text{O})\text{Cl}$ between 193 and 280 nm, *Chem. Phys. Lett.*, 639, 189, 2015b.

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

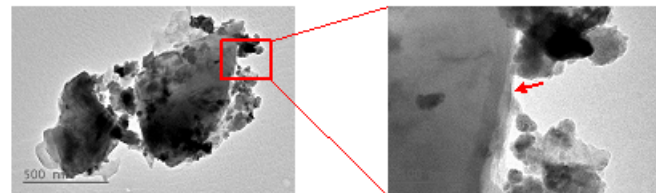
This project will investigate the origins, transformations, and fate of aerosols in the atmosphere, including both direct and indirect (interactions with clouds) radiative effects.

Accomplishments

Aerosol formation, composition, properties

Aerosol optical properties in the southeastern United States: We completed three related analyses of aerosol optical properties in the southeastern United States based on data of field studies during the summer of 2013. We placed quantitative limits of the aerosol production aloft, hygroscopicity of organic aerosol, and sensitivity of aerosol optical depth to microphysical parameters.

Optical absorption during forest fires: We completed the technical analysis of aerosol optical absorption during wildfire plumes observed during the aircraft field studies in the summer of 2013. This data has been used as part of a large effort to investigate aerosol optical transformations during wildfire aging. We intercompared optical absorption measured by independent methods: photoacoustic spectroscopy, filter-based photometer, and difference of extinction and scattering.



Scanning electron microscopy images of a mineral dust particle that was coated with a very thin layer of organic material visible at particle the edge (arrow). Image: Karl Froyd/CIRES

Open-path aerosol extinction measurements: Previously, we developed an instrument for the measurement of ambient aerosol extinction using an open-path between two cavity mirrors

rather than drawing a sample into the instrument. We have designed a prototype of this instrument for deployment on an aircraft external to the fuselage.

Organosulfate formation: Organosulfates constitute a small ubiquitous fraction of organic aerosol mass over North America. We compared our airborne measurements of organosulfate abundance in the southeast U.S. to simulations using a detailed chemical transport model (Marias et al., 2016).

Aging of mineral dust: We performed laboratory studies to investigate how mineral dust becomes coated with organics upon ageing during atmospheric transport. By measuring size, composition, and morphology of coated dust particles, we calibrated the response of an airborne instrument to the abundance of coating material. Using this calibration, we estimated the amount of organic material on dust in the atmosphere at several locations. Additionally, we compared measured and simulated airborne dust concentrations in the southeast U.S. (Kim et al., 2015).

Secondary organic aerosol (SOA) formation in fog: Based on field experiments, we show that the chemical processing and oxidation processes depend on droplet sizes in fog, with highest rates in smallest droplets (Chakraborty et al., 2016).

Representation of clouds in models

Co-variability in aerosol/clouds/meteorology to address radiative effects of aerosol-cloud interactions: We explored how aerosol affects cloud reflectance and sunlight absorption, using inputs for aerosol and meteorology. To quantify aerosol-cloud radiative effects, we use process models, with observationally-based inputs for aerosol and meteorology varying simultaneously in space and time. This approach advances aerosol-cloud interactions studies and their implications for the warming or cooling effects of clouds (Feingold et al., 2016).

Large scale wind speed trends and cloud properties: Observed and projected changes in large scale wind speed, with associated cloud response, constitutes a cloud-climate feedback mechanism with potential to impact Earth's radiation budget, formation of precipitation, and aerosol effects on clouds. Higher wind speed leads to thicker clouds, which reflect more solar radiation (cooling). We found that clouds that exceed a certain thickness are unable to grow by turbulence production from radiative cooling (Kazil et al., 2016).

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

■ CIRES Lead: Troy Thornberry ■ NOAA Lead: Ru-Shan Gao
NOAA Theme: Climate Adaptation and Mitigation

Goals & Objective

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

Accomplishments

Analysis of black carbon (BC) measurements in gas flaring from oil production in the Bakken Formation (North Dakota) was completed and the results published in *Environmental Science and Technology Letters* in October 2015. Laboratory studies were conducted to optimize the method for measurement of BC in aqueous solutions with the Single Particle Soot Photometer (SP2), critical for the accurate determination of BC in snow and ice samples, and a manuscript is in preparation. SP2 instruments were deployed in a study at the Storm Peak Laboratory during fall 2015 to constrain the role of BC in ice cloud nucleation, and in air quality studies on board the NASA DC-8 during the KORUS-AQ mission in South Korea in spring 2016 to measure BC pollution loadings, mixing state, and hygroscopicity.

Laboratory studies to characterize the response of the Wideband Integrated Bioaerosol Sensor (WIBS) instrument to various types of bioaerosol were concluded and manuscript reporting the results of the characterization studies was submitted to Atmospheric Measurement Techniques in January 2016. Additional laboratory work to better understand and improve the calibration of the WIBS fluorescence response were conducted. A manuscript describing the results is in preparation. Measurements using the WIBS instrument in the NOAA ESRL CSD van to examine the diurnal and seasonal cycles of feedlot emissions continued.

The Printed Optical Particle Spectrometer (POPS) instrument design and performance were described in a manuscript published in *Aerosol Science and Technology* in January 2016. A number of POPS instruments were produced and two were launched on balloon sondes from Kunming, China, in August 2016 to profile the Asian Tropopause Aerosol Layer that forms during the Asian summer monsoon. During April 2016, POPS were



Andrew Rollins installs an SO₂ instrument on a NASA high-altitude research aircraft, preparing for the start of a field experiment based in Houston. Photo: R. Gao/NOAA

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deployed on light aircraft flying from La Réunion Island in the southern Indian Ocean to investigate oceanic aerosol sources, and from Oliktok Point, Alaska, to study aerosol-cloud interactions in the Arctic.

During summer 2015, the prototype laser-induced fluorescence (LIF) SO₂ instrument was converted into a flight-capable instrument. In September-October 2015 the instrument was deployed on the NASA WB-57 high altitude research aircraft during the Volcano-plume Investigation Readiness and Gas-phase and Aerosol Sulfur (VIRGAS) mission in flights from southern Texas over the Gulf of Mexico and eastern Pacific Ocean. These flights produced the first in situ SO₂ measurements in the tropical upper troposphere and lower stratosphere and will be used to constrain the SO₂ flux to the stratosphere and its contribution to the radiatively important stratospheric sulfate aerosol layer.

The NOAA Water and Ozone instruments were also flown on the NASA WB-57 during the VIRGAS mission in order to characterize the air masses the aircraft encountered. A manuscript describing analysis of data from the NASA Airborne Tropical Tropopause Experiment (ATTREX) mission deployments in 2013 and 2014 that examines the efficiency of the microphysical processes regulating dehydration in the tropical tropopause layer (TTL) was published in *Geophysical Research Letters* in March 2016. ATTREX data have also been used to develop a new ice water content-optical extinction relationship for TTL cirrus that will improve lidar retrievals of tropical cirrus IWC.

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

■ CIRES Lead: Betsy Andrews ■ NOAA Lead: Patrick Sheridan

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.

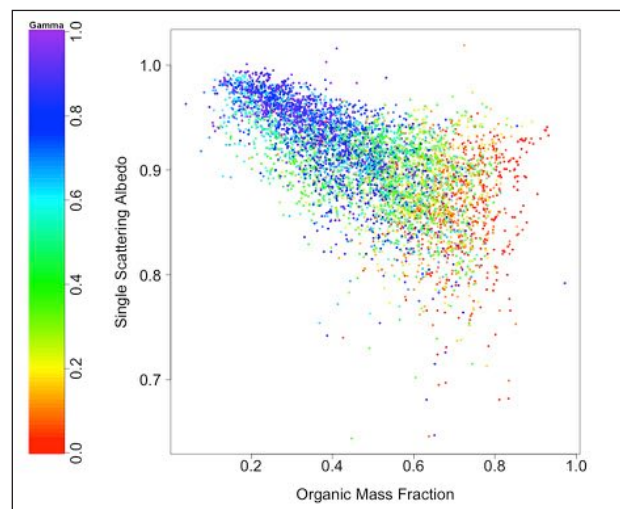
Accomplishments

The aerosol hygroscopic growth uncertainty, measurement statistics, and correlations with other aerosol and chemical properties were evaluated from long-term measurements at the Department of

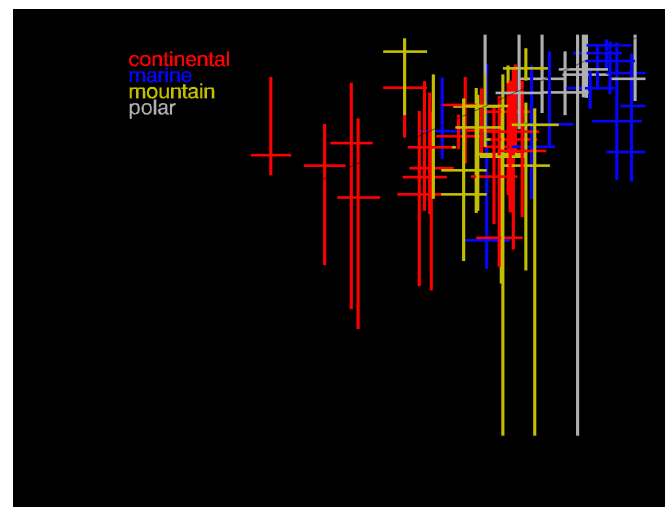
Energy (DOE) Southern Great Plains site in Oklahoma. The findings were presented at the 2015 and 2016 DOE Atmospheric Systems Research (ASR) meetings in Virginia.

Aerosol measurements were conducted at a surface site in the Brazilian state of Amazonia as part of the DOE GoAmazon campaign. The measurements spanned two years, 2014-2015. The intent of the campaign was to study the evolution of pollution aerosol from Manaus in the Amazon rainforest and its impact on cloud formation. The measured aerosol optical properties indicated higher aerosol loading and darker, larger, less hygroscopic in the dry season when smoke was the dominant aerosol.

The primary accomplishments from the first year of the project to evaluate global models with in-situ aerosol optical measurements include: a) collection and processing of long-term aerosol data from approximately 35 NOAA network surface sites, as well as similar data sets from 30 surface sites outside the network; b) acquisition of simulated aerosol properties from the output of approximately 10 global models; and c) comparisons of modeled and measured properties on various spatial and temporal scales. One major finding is that models tend to under-predict single scattering albedo relative to the observations—this appears to be driven more by an under-prediction of aerosol scattering than an over-prediction of aerosol absorption. Models simulations also suggest that the atmospheric aerosol is larger than what is



Aerosol sub-micron single scattering albedo at 550 nm versus the organic mass fraction. Data are colored by the aerosol hygroscopic fit parameter, gamma, where $B_{sp}(RH) = (1 - RH/100)^{-\gamma}$ (Bsp is aerosol scattering at 550 nm, RH is relative humidity at which Bsp is measured). Image: A. Jefferson/CIRES



Comparison of measured and modelled aerosol single scattering albedo, colored by site category (continental, marine, mountain, polar). Range on x-axis indicates uncertainty in measured single scattering albedo; range on y-axis indicates range of simulations from 7 different global models. Image: E. Andrews and AeroCom modelling community modellers and GAW aerosol monitoring network scientists.

observed in the in-situ measurements. These findings were presented at several international meetings and a paper is in progress. Additionally, a proposal was submitted to DOE in January 2016 to fund a comparison of modeled and measured aerosol hygroscopicity.

Our research on Arctic aerosol under the aegis of the International Arctic Systems for Observing the Atmosphere (IASOA) consortium continues. Self-consistent, benchmark aerosol optical property data sets for six Arctic sets have been developed. Some of the data appeared in Uttal et al. (2015). These data sets also form the basis for an Arctic aerosol climatology manuscript (Schmeisser et al.) and an aethalometer data treatment manuscript (Backman et al.). Both manuscripts are nearing completion and should be submitted this year. Results from this research have been presented at several international meetings and workshops. In conjunction with the quality control for the Arctic aethalometer measurements, quality control was also performed on the long-term aethalometer measurements made at the South Pole. The South Pole aethalometer data were included in Sheridan et al.'s (2016) South Pole climatology paper.

References:

- Sheridan, P.J., Andrews, E., Schmeisser, L., et al. "Aerosol Measurements at South Pole: Climatology and Impact of Local Contamination," *Aerosol and Air Quality Research*, 16, 855-872, doi: 10.4209/aaqr.2015.05.0358, 2016.
- Uttal, T., Starkweather, S., Drummond, J.R., et al., "International Arctic Systems for Observing the Atmosphere (IASOA): An International Polar Year Legacy Consortium," *Bull. Amer. Meteor. Soc.*, doi: <http://dx.doi.org/10.1175/BAMS-D-14-00145.1>, 2015.

GMD-04: Studies of Greenhouse Gas Trends and Distributions

■ CIRES Lead: Gabrielle Petron ■ 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 (CO₂, CH₄ and N₂O) and the large suite of minor one (CFCs, HFCs, 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

Our calibrated long-term measurements of long-lived greenhouse abundances in the atmosphere continue to reveal major year-to-year variability in the global budgets of carbon dioxide (CO₂) and methane (CH₄).

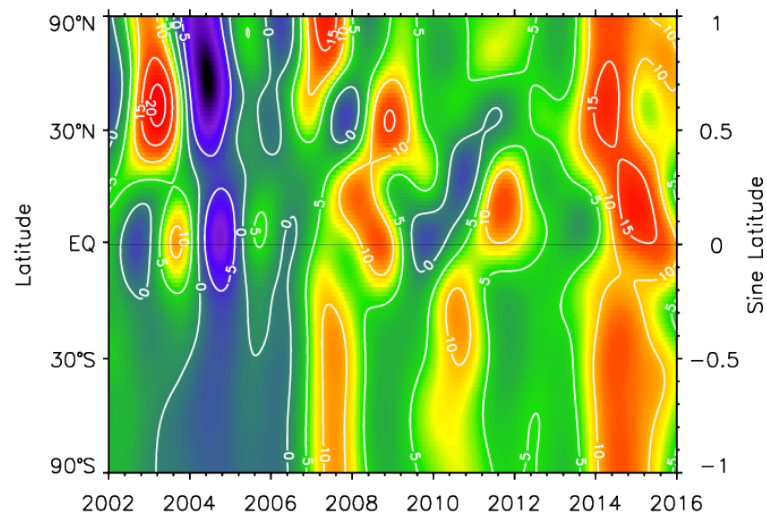
2015 had the largest annual increase in global CO₂ (2.99 ppm/yr) since the beginning of the measurement record in 1959. This is presented on the web at <http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html>.

<http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html>.

Atmospheric CH₄ has been on the rise since 2007 after a period of leveling off between 1999 and 2006. The annual increase in CH₄ reached over 10 ppb/yr in 2014 and 2015. Global methane trends based on our measurements are now updated monthly at this new webpage http://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/#global_growth.

We updated the NOAA Annual Greenhouse Gas Index to include our 2015 GHG measurements and infer the direct impact of different gases on global radiative forcing. This is available at <http://www.esrl.noaa.gov/gmd/ccgg/aggi.html>.

We released a new version of CarbonTracker-CO₂, called CT2015. Weekly CO₂ net fluxes over the land and ocean were optimized using long-term calibrated atmospheric measurements of CO₂ from 2000 to 2014 from our laboratory and from a few other groups. Detailed information and conveniently packaged modeled data and observations are available at: <http://www.esrl.noaa.gov/gmd/ccgg/carbontracker> and <http://www.esrl.noaa.gov/gmd/ccgg/obspack/>



Contour plot of zonally averaged CH₄ growth rate (ppb/yr) from 2002 to 2016, based on measurements from NOAA's cooperative global air sampling network. Red contours indicate where and when atmospheric CH₄ has increased the most. Image: CIRES and NOAA

Earth System Dynamics, Variability, and Change

PSD-20: Develop Stochastic and Scale-Award Parameterizations Informed by Observations

This is a new project.

■ CIRES Lead: Prashant Sardeshmukh ■ NOAA Lead: Cecilia Penland

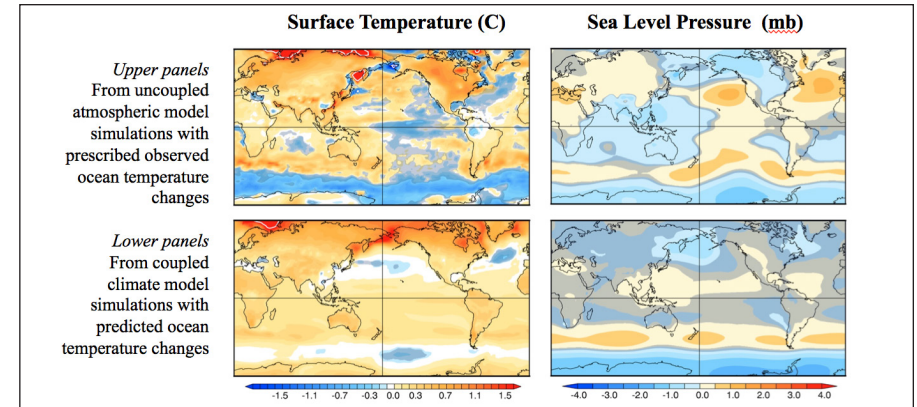
NOAA Theme: Science and Technology enterprise

Goals & Objective

Research addressing the inadequate representation of feedback from unresolved and sub-grid scale processes in forecast models seek to more accurately portray the full probability distribution function (PDF) of resolved processes in the model, the probability of extremes, and the full range of possibilities in an ensemble prediction system.

Accomplishments

Although the human influence on 20th century global warming is well established, the influence on the atmospheric circulation, especially on regional scales, has proved harder to ascertain. And yet assertions are often made to this effect, especially in the media whenever an extreme warm or cold or dry or wet spell occurs. We have addressed this issue using the longest global atmospheric circulation dataset currently available at daily resolution, the 20th Century Reanalysis (20CR) dataset spanning the period 1871 to the present, as well as atmospheric general circulation model (GCM) simulations of the period with prescribed observed evolving sea surface temperatures (SSTs) and radiative perturbations, and also fully coupled atmosphere-ocean climate model simulations with prescribed radiative perturbations only. We generated the 20CR dataset and atmospheric GCM simulations ourselves, and used the coupled model simulations from the Coupled Model Intercomparison Project version 5 (CMIP5) that formed the basis of the recent 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). We assessed trends in the atmospheric circulation and storminess around the globe, and changes in the indices of some important modes of atmospheric circulation variability such as the North Atlantic Oscillation (NAO), the Pacific North American pattern (PNA), the tropical Pacific Walker Circulation (PWC), the Annular Antarctic Oscillation (AAO), and the Global Overturning Circulation (GOC, which is expected to slow down with global warming). Given the skewed and heavy-tailed character of the probability density functions (PDFs) of these indices, we assessed changes in the entire PDFs and not just in their means and standard deviations, using both raw histograms and fitted Stochastically Generated Skewed (SGS) PDFs discovered by us, whose particular relevance in studies of extreme weather statistics was highlighted in a paper published in the *Journal of Climate* (Sardeshmukh, Compo, and Penland, 2015). The paper shows that without properly accounting for the distinctively skewed and heavy-tailed aspects of the observed PDFs, the detection and attribution of sig-



Responses to observed radiative forcing changes over 1874-2010 of surface temperature (sea surface temperature over the oceans, 2-meter air temperature over land) and sea level pressure (1943-2010 minus 1874-1942 December-February averages). The upper panels show the mean responses obtained in 56 uncoupled NOAA atmospheric model simulations, in which the changing observed SSTs were prescribed over the oceans, and the lower panels show the mean responses in 62 CMIP5 atmosphere-ocean coupled model simulations in which the SSTs were predicted. Note the opposite-signed sea level pressure responses over the eastern Northeastern Pacific, North America, and the North Atlantic, which likely result from the CMIP5 models not adequately capturing the spatial pattern of the SST responses. Image: Sardeshmukh, Compo, Penland, and McColl (2016, to be submitted)/CIRES

nificant changes in extreme weather and climate statistics can be compromised and lead to wrong conclusions. With this in mind, we also investigated changes in the risks of extreme daily temperatures, and found that in many regions of the globe, the risk of extreme warm temperatures has remained nearly unchanged despite the mean warming, primarily because of a reduction of the temperature variability in those regions.

PSD-22: Predictive Understanding of Tropical-Extratropical Coupling, Moisture Transport and Heavy Precipitation

This is a new project.

■ CIRES Lead: Darren Jackson ■ NOAA Lead: George Kiladis

NOAA Theme: Science and Technology Enterprise

Goals & Objective

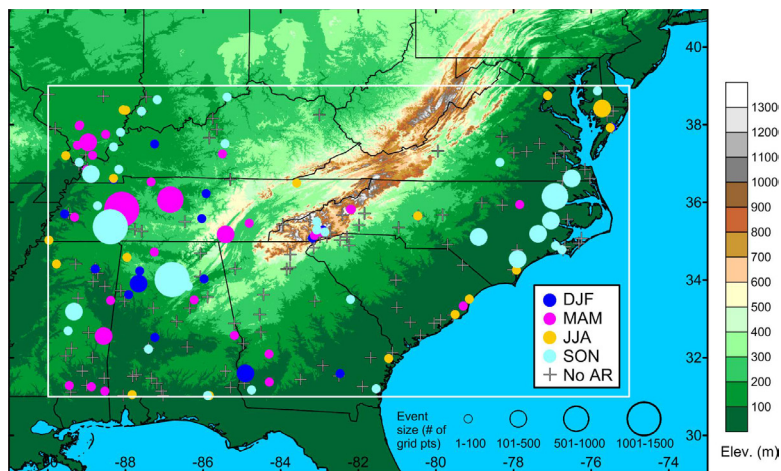
Research under this project aims to improve our understanding and predictions of tropi-

cal-extratropical linkages, moisture transport, and heavy precipitation.

Accomplishments

Six CIRES scientists in the Physical Sciences Division (PSD) investigated the impact land-falling atmospheric rivers (AR) have on heavy precipitation on the west and southeast U.S. coasts. Observations from instruments installed by PSD as a part of the National Oceanic and Atmospheric Administration (NOAA) Hydrometeorology Testbed (HMT) were utilized for two studies on the West Coast. One study showed that the fractional contribution of shallow precipitation during AR events is twice as large in the northern Sierra than for the southern Sierra due to uninterrupted flow through an orographic gap in the coastal mountains east of San Francisco, California. In a separate but complementary study, HMT observations, satellite cloud and water vapor imagery, and reanalysis data were used to diagnose three mesoscale frontal waves that induced enhanced precipitation during a long-lived AR event impacting the coastal range north of San Francisco and the northern Sierra. A third published study examined the skill four different reanalysis products have for characterizing AR landfalls along the West Coast and results found good agreement between the reanalysis products and satellite observations.

A 10-year climatology of ARs (2002-2011) was developed for the southeast U.S. for the



Season of occurrence of heavy precipitation events matched with ARs within 250 km and 24 hours are plotted over terrain. Location indicated by a circle is the center point of heavy precipitation. Circle size indicates size of precipitation event defined by the number of grid points in the precipitation data with heavy precipitation. Black “+” signs indicate heavy precipitation events in which no AR was matched. (from Mahoney et al. 2016)

first time and the impacts on heavy precipitation in the southeast U.S. was investigated. The figure shows the location of heavy rain events in the Southeast over a 10-year period from 2002-2011 and the events that were associated with ARs. The key finding here was that 41% of the heavy precipitation event in this region were associated with AR events. This percentage is significantly less than the AR relationship with West Coast heavy precipitation events. While orographic influence associated with ARs is a dominant forcing mechanism on the West Coast, the Southeast has a suite of forcing mechanisms that may or may not require AR conditions to initiate heavy precipitation.

PSD-23: Lead the Planning and Execution of Large-Scale National and International, Multi-Institutional Field Campaigns to Observe and Understand the Coupled Behavior of the Atmosphere Over Land, Oceans, Ice, and Snow

This is a new project.

■ CIRES Lead: Matt Newman ■ NOAA Lead: Allen White
NOAA Theme: Science and Technology Enterprise

Goals & Objective

This project encompasses the planning and execution of large-scale national and international, multi-institutional field campaigns to observe and understand the coupled behavior of the atmosphere over land, oceans, ice, and snow.

Accomplishments

The NOAA El Niño Rapid Response (ENRR) Field Campaign

Forecasts by the summer of 2015 indicated a strong El Niño was very likely during winter 2015-16. This lead time was sufficient to identify an exceptional scientific opportunity to accelerate advances in understanding and predictions of an extreme climate event and its impacts while the event was ongoing. Acting on this opportunity, NOAA initiated the El Niño Rapid Response (ENRR) project. The ENRR efforts led by PSD included an observational field campaign, whose primary objective was to determine the initial tropical atmospheric response linking El Niño to its global impacts. The campaign conducted intensive observations in a data-sparse region over the central Pacific Ocean near the heart of El Niño. NOAA's Gulfstream IV (G-IV) was deployed from Hawaii for 22 flights between January 19 to March 9 to obtain wind, temperature, moisture, and precipitation profiles through use of dropsondes, tail Doppler radar, and flight level observations. Flight routes over the central tropical Pacific, shown in the figure, sampled organized tropical convection and poleward convective outflow. The G-IV mission concluded with three flights in five days examining the cascade of linked dynamical processes between the tropics and extratropics that culminated in a landfalling storm with heavy precipitation along the West

Project Reports: Earth System Dynamics, Variability, and Change

Coast of the United States, March 10-13. The G-IV data were augmented by twice-daily radiosonde launches from Kiritimati (Christmas) Island, up to 8 times/day radiosonde launches from the NOAA Research Vessel Ronald H. Brown in the eastern tropical Pacific during a TAO mooring survey, and scanning X-band radar positioned in Santa Clara, California. During the campaign, the ENRR project also coordinated with the NOAA Sensing Hazards with Operational Unmanned Technology (SHOUT) program, which conducted three extratropical North Pacific flights with the unmanned NASA Global Hawk.

CAPRICORN (Clouds, Aerosols, Precipitation, Radiation, and Atmospheric Composition over the Southern Ocean)

PSD, in collaboration with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Bureau of Meteorology, installed the NOAA seagoing air-sea flux system on a new research vessel, the R/V *Investigator* to investigate the coupling of air-sea fluxes and boundary layer clouds. The ship spent about 40 days at sea south of Tasmania studying a large ocean eddy there, making direct measurements of clouds and the exchange (or flux) of heat, water, and momentum between the atmosphere and the ocean

plus bulk meteorological variables (such as sea surface temperature, wind speed, air temperature, humidity) that can be used to estimate similar exchanges in weather and climate models. Surface waves and CO₂ fluxes were also measured. For CAPRICORN, the principal scientific objective of the flux observations was to expand the very sparse database of direct flux measurements in the Southern Ocean. It is expected that these observations will add significantly to efforts to demonstrate the accuracy of the NOAA Coupled Ocean-Atmosphere Response Experiment (COARE) bulk flux algorithm in the Southern Ocean and to allow verification of gridded flux products such as the Woods Hole Oceanographic Institution's OAFflux product.

PSD-24: Interpret Weather and Climate Extremes to Explain and Improve the Prediction of High-Impact Weather and Climate Events

This is a new project.

■ CIRES Lead: Judith Perlwitz ■ NOAA Lead: Martin Hoerling
NOAA Theme: Science and Technology Enterprise

Goals & Objective

Research in this arena focuses on interpreting weather and climate extremes to better explain and predict high-impact weather and climate events.

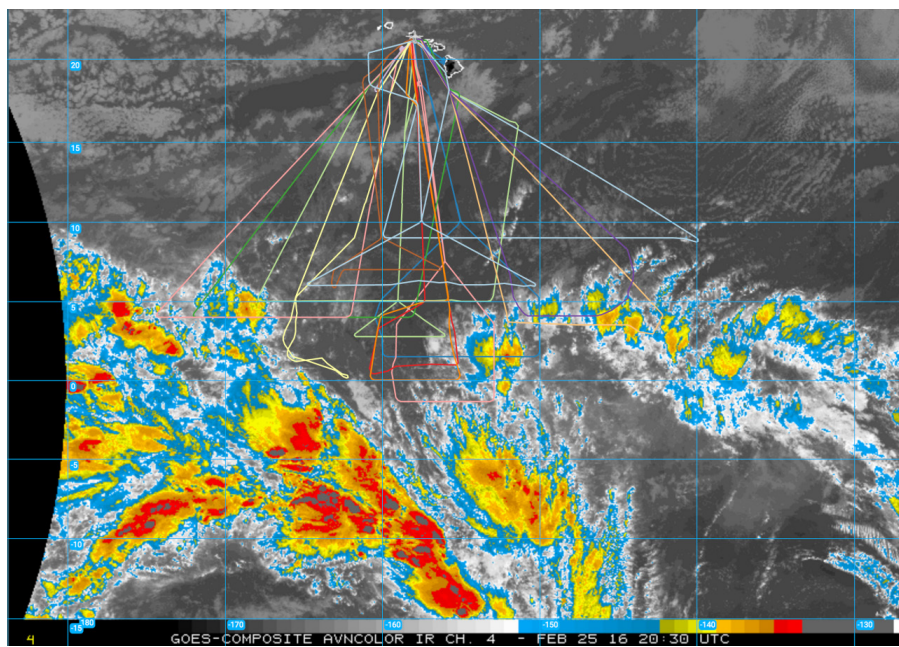
Accomplishments

What History Tells Us About 2015 US Daily Rainfall Extremes

Three extreme rainfall events occurred over the contiguous United States in 2015 associated with damages in excess of \$1 billion: 1. Drought-ending May rains and flash-floods in Texas and surrounding states; 2. Near land-falling Hurricane Joaquin in early October associated with catastrophic flooding in South Carolina; and 3. Unseasonable December rains that inundated the Mississippi basin. Recognizing the *a posteriori* nature of case study selections, we present a large-scale assessment of the observed occurrences of extreme daily rainfall (≥ 20 -yr return threshold exceedances) over the entire contiguous United States during 2015.

We found that this elevated number of occurrences in 2015 appears “unusual” only when viewed in the context of a stationary climate. However, it was not that unusual if one considers the upward trend that relates strongly to global mean temperatures, and the fact that nine out of the top ten years of most extensive extreme event coverage occurred since 1990. However, seasons and regions experienced the most abundant extremes were not foreshadowed by long-term trends.

We submitted a publication on this topic to the Bulletin of the *American Meteorological Society Special Issue on Explaining Extreme Events* of 2015 from a climate perspective.



Tracks of all ENRR flights from Jan 22, 2016 to Feb 25, 2016, overlaid on satellite image from Feb 25, 2016. Image: CIRES and NOAA



Cars and houses are seen covered by floodwaters in southwest Houston, Texas on May 26, 2015. Torrential rains have killed at least eight people in Texas and Oklahoma, including two in Houston where flooding turned streets into rivers and led to nearly 1,000 calls for help in the fourth-most populous U.S. city. Photo: Reuters

<http://www.gospelherald.com/articles/55873/20150604/texas-floods-2015-update-death-toll-rises-to-31-as-more-bodies-recovered-victims-identified.htm>

Detailed analysis of the Texas/Oklahoma record-breaking rainfall of May 2015

Multiple factors/conditions can lead to or affect occurrences of extreme weather and climate events. For instance, a strong El Niño is known to have the tendency to increase late-spring precipitation in the southern Great Plains of the U.S.; and long term heat waves can increase the probability in intensifying the severity of a drought event. Exploring the role of different contributing factors in extreme events is important for a better physical understanding and prediction of extreme event occurrences. We have conducted a conditional analysis for the Texas and Oklahoma (TX/OK) record-breaking rainfall of May 2015 in order to investigate changes in the extreme precipitation induced by El Niño and anthropogenic forcings, respectively, and made attributions for this extreme event.

Our results indicate the condition of an El Niño state in May 2015 is the principle factor contributing to this record rainfall. It had a much greater bearing on both the likelihood and intensity of appreciable breaking the prior TX/OK May rainfall record than the condition of anthropogenic forcings in extreme rainfall over the last century.

PSD-26: Next Generation Global Prediction System

This is a new project.

■ CIRES Lead: Phil Pegion ■ NOAA Lead: Jeff Whitker

NOAA Theme: Science and Technology Enterprise

Goals & Objective

Research contributing to the development of a next-generation global prediction system capable of dramatically improved global numerical weather predictions on time scales of one to thirty days through research to support model development, improve model physics, advance data assimilation, conduct testing and evaluation, develop enhanced ensemble prediction system development, and apply statistical post-processing.

Accomplishments

The Next Generation Global Prediction System (NGGPS) project involves replacing the current Global Forecast System (GFS) run operationally at the National Weather Service (NWS) with a global non-hydrostatic dynamical core. The new model will be an entire, wholesale change of the modeling system run in operations, which has never been done for the global model at the NWS.

Currently, the project is in the process of selecting a replacement dynamical core. The selection process started with Phase 1 in the summer of 2015. At that time,

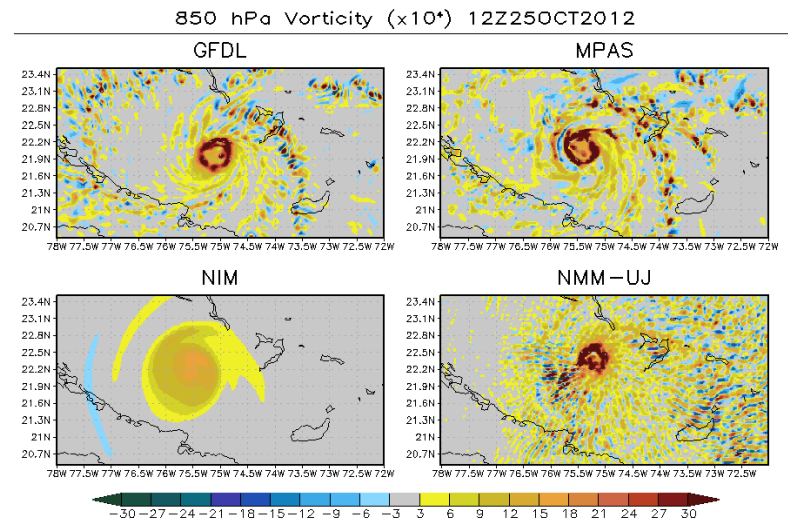


Figure 1: 850-hPa relative vorticity [10^{-4} s^{-1}] from a 30-hour, global 3km resolution forecast centered around Hurricane Sandy. Image: CIRES and NOAA

there were five candidate models that performed a series of tests, both in an idealized setting and with real data. A combination of metrics was used to down select to two models that would undergo more rigorous testing in Phase 2. Due to the sensitivity of the selection process, the participants in the NGGPS Dycore Test group are required to sign a confidentiality agreement, and no results from the Phase 2 testing is allowed to be disclosed to outside parties, but the testing plan is public. The role of CIRES in this project is to perform the evaluation of the Phase 1 and Phase 2 tests. Results from the real data tests in Phase 1 are shown in Figures 1 and 2. Figure 1 shows a 30-hour forecast of the vorticity field around Hurricane Sandy, and Figure 2 shows a 27-hour forecast of cloud water over central Oklahoma during a time of severe thunderstorms. These two tests run with a global resolution of 3 km and each model chose its own physics. Both tests show large differences in the models' results, with NIM being overly smooth, and NMM-UJ showing a large amount of variability near the grid scale. FV3 and MPAS show a more realistic representation of both Hurricane Sandy and the severe thunderstorms in Oklahoma.

Beside evaluating the rests of the Phase 2 tests, CIRES is directly involved in setting up and performing the cycled data assimilation test for the two models that were selected for Phase 2, MPAS and FV3. This consisted of developing a common working framework for the two models such that the data assimilation tests can be evaluated in a controlled setting. The Phase 2 tests are designed to directly compare the performance of the dynamics core, and for these tests, both models are run with the GFS physics and are compared to a comparable GFS run at the same resolution.

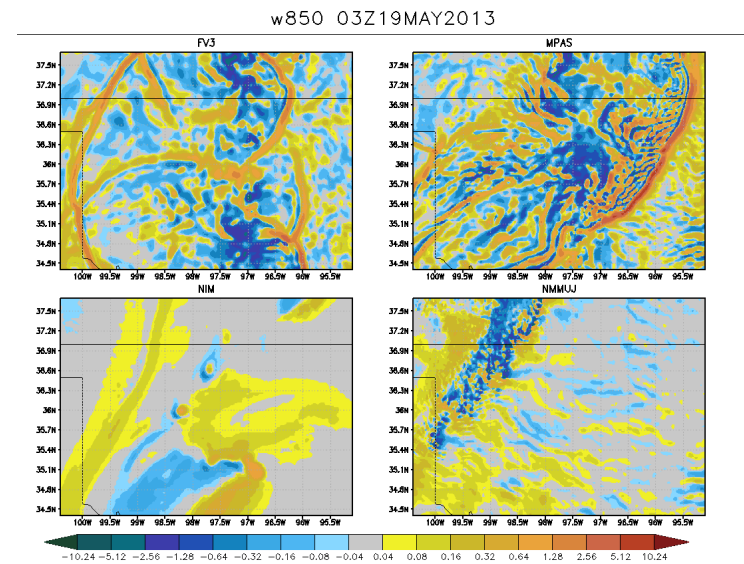


Figure 2: Integrated Cloud water [Kg m²] from a 27-hour, global 3km resolution forecast zoomed in over central Oklahoma. Image: CIRES and NOAA

Management and Exploitation of Geophysical Data

NCEI-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

The CIRES project team supporting the Enhancing Data Management Systems and Web-Based Data Access project have focused on a diverse set of efforts during 2015. As a result of our work, the team received an NCEI team excellence award, finishing first out of the 12 teams nominated within NCEI. Equally satisfying was the selection of our common ingest software as a solution across locations within NCEI. The full scope of our work is described below.

Early in the year we focused on a distributed software system that allows multiple federal partner agencies to coordinate on submitting and analyzing data related to determining the U.S. Extended Continental Shelf (ECS) boundaries. The team upgraded the ECS data management application to include usability changes requested by the ECS team, a new security implementation, and a simplified framework that should make the application much more supportable and enhanceable moving forward.

Next we focused on data ingest software for the NCEI which included:

Generic Archive: The team accomplished a major change to common ingest, moving from stream-by-stream code implementation to configurable streams using composable modules. The new system provides a roughly 90% reduction in time required to create and deploy a new stream to production. The system also has end-to-end testing and a major reduction in duplicated code.

Passive Acoustic Data (PAD): As the first configurable stream the agile team implemented data transformation and aggregation engines. The team created a new stream for PAD ingest and successfully delivered the system to acceptance for a National Marine Fisheries release date.

Crowdsourced Bathymetry (CSB): Implemented a GeoJSON data to database loader to prototype CSB data ingest requirements and created a new stream to process CSB data.

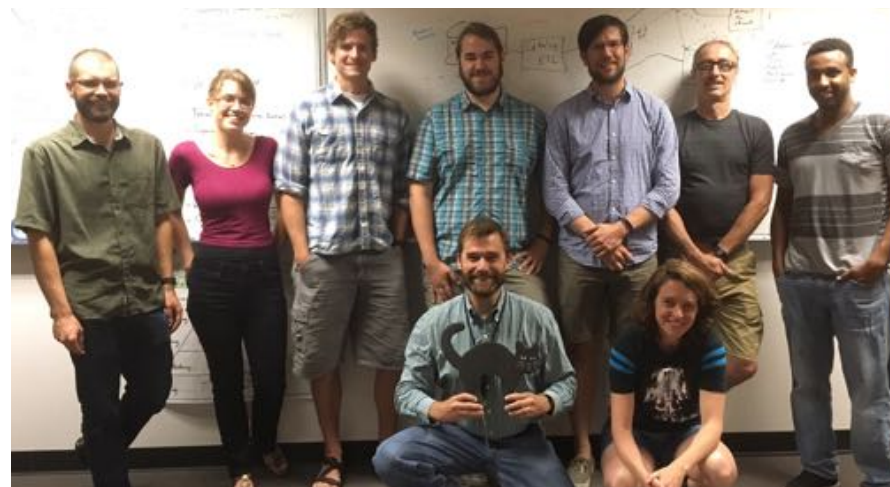
University Rolling-deck-to-Repository (R2R): Developed system to support data manager ingest of R2R data to the archive. This included creating a ingest client (file-submitter) that submits files from a directory into the ingest system and a transformation engine to change

the path and filename to a configurable value. The team created a new stream with these new capabilities to process R2R data in production.

International Ocean Drilling Program (IODP): Implemented a new engine for file validation and created a new stream to ingest IODP data in production.

NOAA's GOES-R satellite Level Zero Storage Segment (LZSS) ingest: Implemented a new ingest stream for ingesting LZSS data into the archive in support of the GOES-R mission.

In the final part of the year we focused on data extraction software to allow public access to data from the NCEI. Specifically our work focused on an effort in support of Hurricane Sandy recovery and future mitigation strategies. During 2015 the team did major cleanup and refactoring of the NCEI extract system (NEXT) to drastically reduce redundant code and improve test coverage. The team also created a new catalog system for capturing meta-data information as part of ingest and created a new search index to significantly improve performance and reduce complexity for serving search, discovery and ordering of Sandy data. By the end of 2015, the NEXT system could support adding new data set extract in 10-30% of the previous effort required.



From left to right: Brendan Billingsley, Arianna Jakositz, Christopher Esterlein, Waverly Hinton, Aaron Caldwell, Michael Anstett, Semere Ghebrechristos. Front row: David Neufeld, Erin Reeves. Photo courtesy David Neufeld/NOAA

Project Reports: Management and Exploitation of Geophysical Data

NCEI-02: Enhancing Marine Geophysical Data Stewardship

■ CIRES Lead: Carrie Bell ■ NOAA Lead: Jennifer Jencks
 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 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 the National Geophysical Data Center (NGDC), interactive databases. NCEI provides long-term archiving, stewardship, and delivery of data to scientists and the public by using standards-compliant metadata, spatially enabled databases, a robotic tape archive, and standards-based web services. Since June 2015, 146 multibeam swath sonar surveys (352,355 nautical miles) and 114 new 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 expanded it to incorporate additional sonar systems. These efforts resulted in the archive of an additional 9.7 TB of water column sonar data bringing the total volume to 25.8 TB. 136 Digital Object

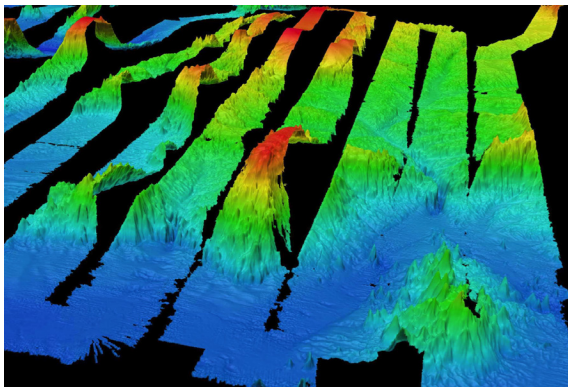


Figure 1. Image of the sea floor northwest of the U.S. islands of Kingman Reef and Palmyra Atoll, surveyed by the NOAA ship *Ronald H. Brown* in January and February 2016. The presumably inactive channel in the middle right of the image funneled sediments that eroded from nearby islands, seamounts and guyots to the sediment plain in the lower left. Kingman Reef and Palmyra Atoll are to the right. Image: CIRES and NOAA

Identifiers (DOIs) were minted in 2015 for the corresponding cruises; each DOI provides a permanent citation of the associated dataset. Improvements were made to the functionality and performance of the project's data access portal (<http://www.ngdc.noaa.gov/maps/water-column-sonar/index.html>), including automatic delivery of data orders less than 100 GB.

In 2015, the one year pilot project to establish the framework for stewarding NOAA Fisheries passive acoustic data was completed. NCEI staff along with NOAA Fisheries partners are working to expand the pilot to a full archive.

Marine geophysical data archived at, and publicly available by, NCEI currently support two specific, ongoing U.S. mapping efforts: the Extended Continental Shelf (ECS) project

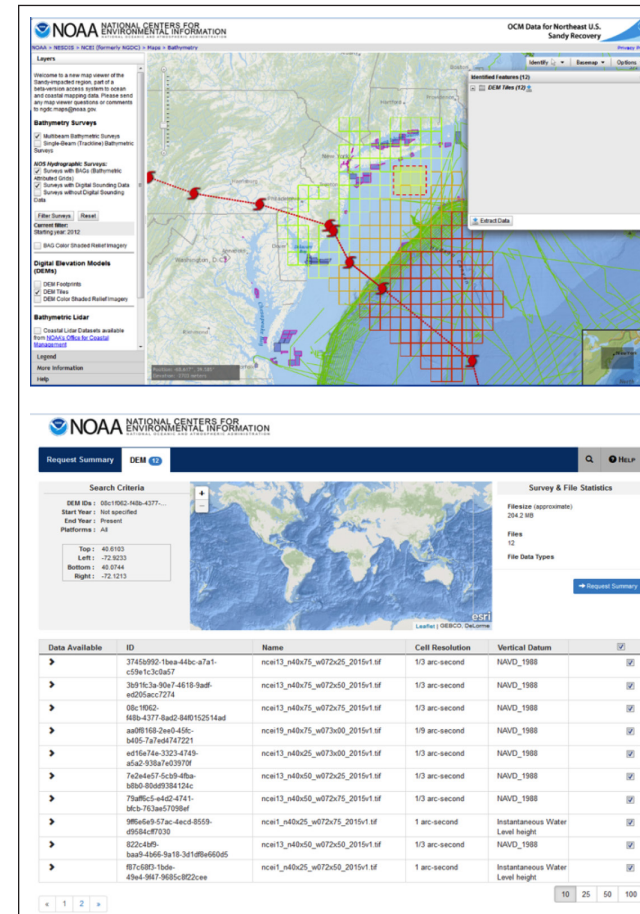


Figure 2. NCEI's OCM map viewer (top). Grey inset box identifies the 12 available DEM tiles that fall within a user-specified region of interest (red dashed-outline box). The DEM ordering client (bottom), which lists NCEI's available DEM tiles, along with brief metadata. The selection boxes on the right permit the user to refine their DEM data request prior to placing an order.

and the Integrated Ocean and Coastal Mapping (IOCM) program. Marine geophysical data from three recent ECS project surveys of the U.S. ocean floor were archived at NCEI, in support of this project, with CIRES staff participating in two of these surveys in the last year (Figure 1).

The public-facing OCM data viewer (http://maps.ngdc.noaa.gov/viewers/north-east_ocm/) developed by CIRES staff now shows the footprints of the high-resolution digital elevation models (DEMs) of the northeast coast of the U.S. Users can query a region of interest to determine which NCEI DEMs are available for download (Figure 2). The ordering client permits users to refine their DEM data request by selecting just those of interest. After submitting a DEM data request, users can, if they choose, track the status of their request. The resulting download includes the DEM tiles, separated into subdirectories by cell size, along with ISO-compliant metadata.

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

■ CIRES Lead: CarrieBell ■ NOAA Lead: Jennifer Jencks

NOAA Theme: Science and Technology Enterprise

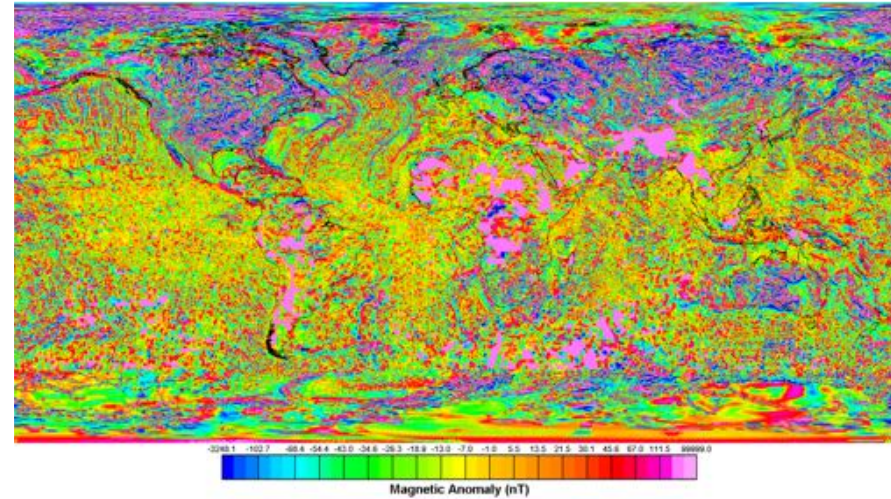
Goals & Objective

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.

Accomplishments

Over the past year, the CIRES geomagnetism team developed a new version of the Earth Magnetic Anomaly Grid at 2-arcmin resolution (EMAG2). The new EMAG2 represents a significant upgrade compared to the previous EMAG2, released in 2009. It includes more than 11 million new marine and airborne trackline data and several new precompiled grids. It is based on a new processing methodology that is more faithful to the data and relies on a more accurate global model of the large-scale crustal field inferred from data collected at low altitude during the last two years of the German CHALLENGING Minisatellite Payload (CHAMP) satellite mission. Magnetic anomaly maps such as EMAG2 are widely used in geophysical exploration and the geological sciences. They are inverted to derive high-resolution geomagnetic models such as NOAA's Enhanced Magnetic Model (EMM) and High Definition Geomagnetic Model (HDGM), which are used by government and industry for accuracy-sensitive navigation purposes. The new grid is fully traceable to the original data, allowing more frequent updates in the future.

Another achievement of the geomagnetism team was the development and release of a real-time component for the 2016 version of NOAA's HDGM. The new model, HDGM-RT2016, improves HDGM by accurately modeling the magnetic fields originating in the Earth's magnetosphere in real-time, including during adverse space weather conditions, using a combination of satellite and ground data. HDGM-RT2016 was developed in



Earth Magnetic Anomaly Grid at 2-arcmin resolution (EMAG2), version 3 (2016). EMAG2 includes more than 75-million marine and airborne trackline data points, and 38 pre-compiled anomaly grids. Here it is represented at 4 km altitude. Areas with no data are shown in light pink. Image: CIRES and NOAA

partnership with industry and provides time-varying reference magnetic data for directional drilling. The main field part of HDGM-RT2016 was derived from the latest data acquired by the European Space Agency (ESA) Swarm satellite mission. Swarm consists of three identical satellites flying in near-polar orbits, near 500 km altitude, including two satellites flying side-by-side in a gradient configuration and a third satellite in a different local time. Swarm has been providing high-accuracy magnetic measurements since its launch in 2013.

The geomagnetism team continued developing new models and tools to improve data-based descriptions of the external magnetic fields, to be later implemented in the EMM and HDGM models. This includes a new global, climatological model of the mid- and low-latitude ionospheric magnetic field derived from a combination of Swarm and ground-based data. Swarm data were also used together with CHAMP data to investigate the gravity and diamagnetic current systems in the F-region of the ionosphere.

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

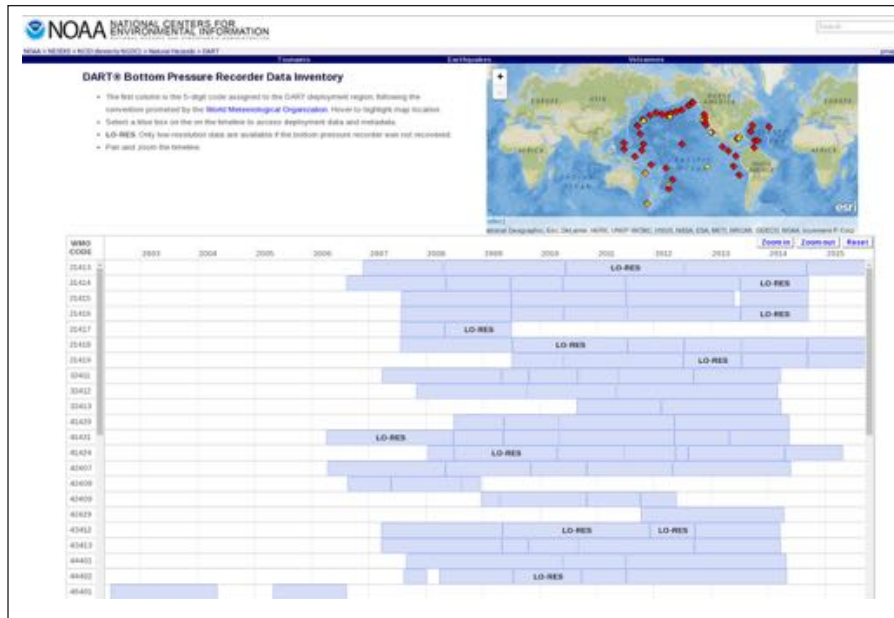
■ CIRES Lead: Kelly Stroker ■ NOAA Lead: Emily Rose

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

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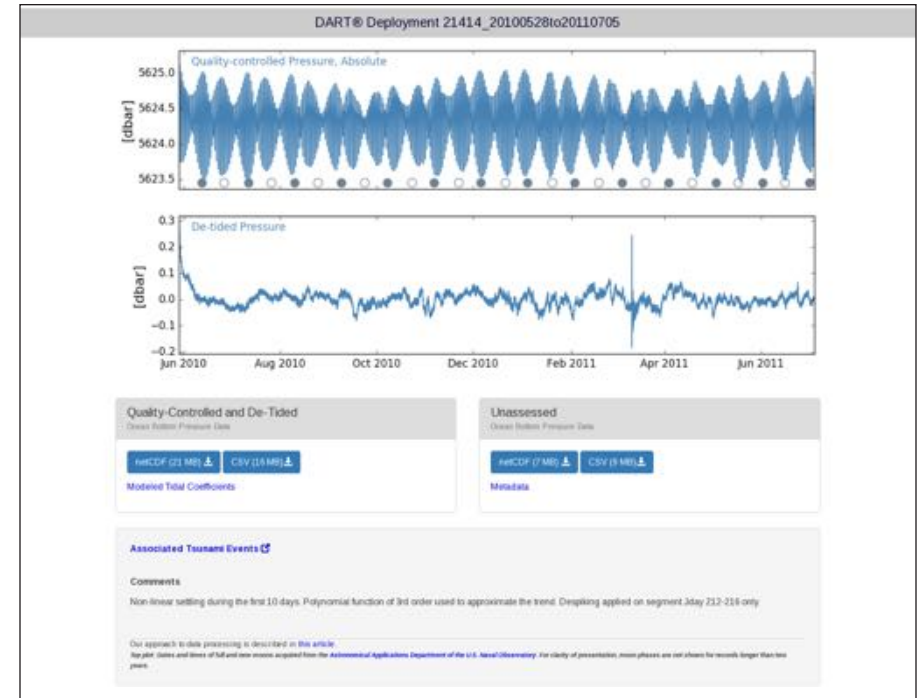
DART® data inventory viewed through an interactive timeline. Temporal extents of data coverage are immediately apparent to the user.

that can be integrated into hazard assessments and coastal elevation models at local, regional, national, and global scales.

Accomplishments

For the Natural Hazards Event Databases, NCEI hired a CIRES data scientist to work directly with the Historical Hazards lead scientist to manage the foremost authoritative databases on global tsunami, earthquake, and volcanic eruption events. The National Tsunami Hazard Mitigation Program (NTHMP) meeting was hosted by NCEI/CIRES staff in Boulder along with a joint NTHMP/USGS tsunami workshop. This meeting, held February 1-5, 2016, brought together over 60 U.S. Coastal State and Territory hazard scientists, emergency managers, and Federal (NOAA, U.S. Geological Survey, Federal Emergency Management Agency) partners working to reduce the impact of tsunamis through improved warning products, modeling, evacuation planning, education, and outreach. The book edited by NCEI/CIRES staff, *Pacific Tsunami Warning System, A Half-Century of Protecting the Pacific, 1965-2015*, was selected as one of the 2015 American Library Association's Notable Government Documents and announced in the *Library Journal* newsletter.

Building digital elevation models (DEMs) for the National Tsunami Warning Centers and



The DART® deployment page linked from the timeline providing a graphic of the data and links to data products created by NCEI.

the National Tsunami Hazard Mitigation Program (NTHMP) continues to be a priority task at NCEI. Over the last year, CIRES staff at 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. DEM Developers, Kelly Carignan and Matthew Love, were invited to provide digital elevation model (DEM) training to scientists in British Columbia from April 18-22, 2016 at the University of Victoria (UVic). This DEM training session brought together ten participants from ONC, UVic, GeoBC, Canadian Hydrographic Service (CHS), and Alberni-Clayoquot Regional District (ACRD). The training was written up in Ocean Networks Canada's newsletter:

<http://www.oceannetworks.ca/canadian-first-noaa-brings-tsunami-digital-elevation-model-training-victoria-bc>

In January 2016, CIRES/NCEI staff successfully finished the Hurricane Sandy Digital Elevation Modeling project, with funding provided through the Disaster Relief Appropria-

tions Act of 2013. During 2015-16, high resolution, 1/9 arc-second spatial resolution digital elevation models representing the topography and nearshore bathymetry for northern New Jersey, New York, and Connecticut were completed. These data can now be discovered and accessed in the Hurricane Sandy web mapping viewer for ocean and coastal mapping data: http://maps.ngdc.noaa.gov/viewers/northeast_ocm/

Nearly 3.6 TB of coastal lidar data was archived from June 2015-May 2016. Noteworthy data submissions include post-Hurricane Sandy topographic-bathymetric lidar data for an area stretching from northern South Carolina to Long Island, New York as well as the first phase of the North Carolina Statewide Lidar Mapping Initiative. CIRES/NCEI staff hosted staff from the NOAA Office for Coastal Management in February 2016 to discuss ways in which to improve efficiencies in archiving workflow and data documentation, as well as the potential for archiving related ancillary products (i.e. DEMs, shoreline vectors, etc.) associated with lidar data submissions.

A crucial element to plan for many coastal natural hazards impacts is water-level data. CIRES staff at NCEI ingest, process, archive, and disseminate tide gauge data and deep ocean-bottom pressure recorder (BPR) data from several NOAA agencies. In 2015, there was one notable tsunami event where water level data was requested and processed: the September 16, 2015, magnitude 8.4 Chile earthquake. For the water level data archive, improvements included a redesign of the online data visualization and extraction tool, expanding the range of types of water level data archived and available online, and continued development of data processing algorithms. In an effort to promote data interoperability and compatibility with open source software tools, we migrated all existing water level data to netCDF, thus making use of common tools for data visualization and exploration. For the first time, Deep Ocean Assessment & Reporting of Tsunamis (DART®) ocean bottom pressure data products (quality-controlled, de-tided data, and modeled tidal constituents) are available online. User discovery of DART® data and products was greatly improved through a visual, timeline inventory, with links to deployment pages, including time-series plots and data access links. The data inventory timeline has also proven immense value as a data curation tool, identifying gaps in data coverage and prompting our data provider to locate and submit for archive 13 data packages to fill those gaps.

NCEI-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 management duties are still waiting to be transferred to the appropriate branches of NCEI as the data center consolidation continues. Management of Space Weather Data



Image of Jeju Island oblique VIPIR site. Photo: Justin Mabie/CIRES

continues in a status-quo capacity. Management of ionosonde data has continued. Two oblique field sites were installed in Korea at Jeju Island and Icheon and these sites will begin collecting data when the radar receivers are delivered. Analysis of experimental data collected from the Wallops Island, Virginia Vertical Incidence Pulsed Ionospheric Radar (VIPIR) site continues and publications are being drafted for peer review. The work journals of C. A. Schott have been digitized and a copy was delivered to the Geophysical Center of the Russian Academy of Sciences and the data is available to public upon request.

NCEI-07: Remote Sensing of Anthropogenic Signals

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

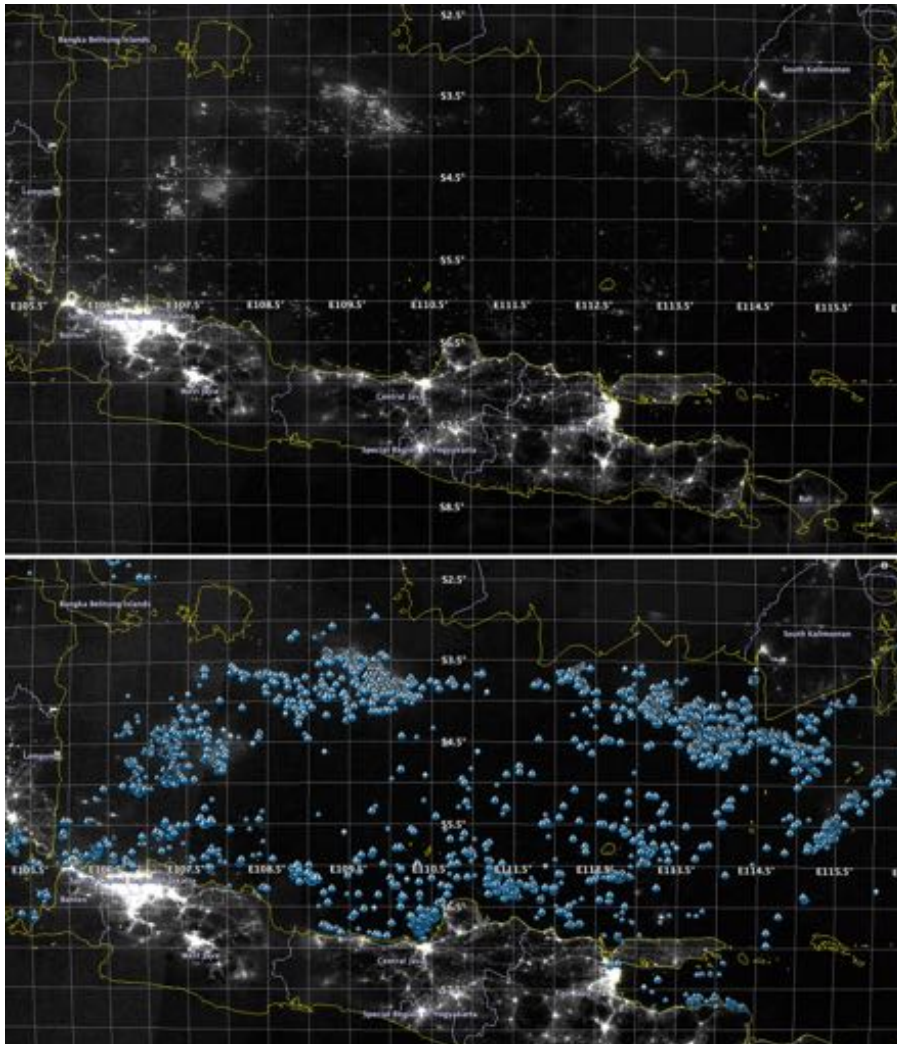
NOAA Theme: Science and Technology Enterprise

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 2 of a Visible Infrared Imaging Radiometer Suite (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 2 is a major improvement over Version 1, which functioned only in the dark half of the lunar cycle. This new version utilizes an additional VIIRS longwave thermal band to distinguish moonlit clouds from lit fishing boats. VBD Version 2 is currently operational over approximately one-third of the globe, from the Indian Ocean east to the Gulf of Mexico. CIRES staff is continuing algorithm development to address the large number of false detections that occur due to the



VIIRS Boat Detection V2.0 product over the Java Sea from June 10, 2016. The top panel shows a mosaic of the nighttime VIIRS Day/Night Band data. The bottom panel shows an overlay of the VIIRS boat detections using blue boat symbols. Images: CIRES and NOAA

South Atlantic Anomaly and aurora.

This year CIRES staff has pulled the remaining VIIRS data from the NOAA Comprehensive Large Array-data Stewardship System (CLASS) archive and completed processing of all archived 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 using the VIIRS Nightfire product. Flare locations were identified using global Nightfire composites. Updated calibration coefficients were obtained by regressing the estimated gas flaring volumes from the Cedigaz reports against the Nightfire-derived radiant heat values for those countries. These coefficient, were then used to obtain preliminary country-level estimates of gas flaring volumes for 2012-2015.

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

■ CIRES Lead: Juan Rodriguez ■ NOAA Lead: William Denig

NOAA Theme: Science and Technology Enterprise

Goals & Objective

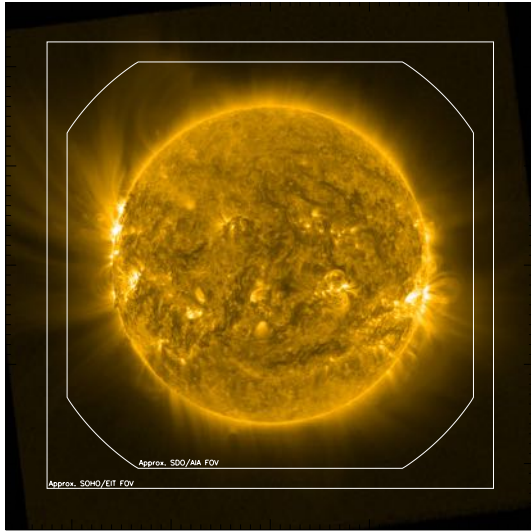
This project will develop the algorithms and products necessary to support use of the GOES-R satellite data for describing space weather with particular attention to damaging solar storms.

Accomplishments

Led the development of space weather data processing and archiving systems within NCEI for several NOAA operational observing and forecast systems. This effort was dominated by development of processing systems for the next-generation Geostationary Operational Environmental Satellites (GOES). (The first satellite of the \$11 billion GOES-R series is scheduled to launch in late 2016.) The GOES-R space weather instruments are the Solar Ultraviolet Imager (SUVI), the Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS), the Space Environment In-Situ Suite (SEISS), and the Magnetometer.

Designed and directed the development of the GOES-R Satellite Product Analysis and Distribution Enterprise System (SPADES) and planned for GOES-R data archiving and dissemination. SPADES serves as a demonstration for the operational real time processing system that the National Weather Service will implement for GOES-R space weather products. Performed successful Initial Operating Capability (IOC) review for SPADES. Oversaw development and testing of SPADES data ingest and control segments.

Developed and deployed a cutting edge search and retrieval portal for Deep Space Climate Observatory (DSCOVR) science users. Designed a DSCOVR database and developed code



A composite of images from the Atmospheric Imaging Assembly on NASA's Solar Dynamics Observatory and the Sun Watcher EUV solar imager on ESA's PROBA2 satellite shows approximately what we expect to see in images of the solar corona in the 171 Å passband using the Solar Ultraviolet Imager on GOES-R. The fields-of-view of other well-known solar extreme-ultraviolet imagers, including AIA and EIT on SOHO, show the extent of the corona seen by previous space observatories. SUVI images will have a large 53 arcminute field-of-view, which will allow scientists to study large scale phenomena—particularly those associated with solar flares and eruptions—in an unprecedented region of the corona. Image: NASA

science algorithm software.

Developed EXIS X-Ray Sensor (XRS) proxy data to cover a variety of solar flare activity levels. Developed SUVI extreme ultraviolet (EUV) proxy data from images from the Atmospheric Imaging Assembly on NASA's Solar Dynamics Observatory and the Sun Watcher EUV solar imager on the European Space Agency's (ESA) Project for On-Board Autonomy (PROBA)-2 satellite (see figure).

Rewrote most of the EXIS L2 algorithm software in Python and tested it with the new proxy data.

to ingest data into this database.

Oversaw development of a data access website for Wang-Sheeley-Arge (WSA)-Enlil, the solar wind model data used in NOAA space weather forecasting. Developed monitoring scripts to detect missing data for several data sets (GOES 13-15, Polar Operational Environmental Satellites (POES), and WSA-Enlil model data). Retrieved missing data (POES) and updated files and databases for reprocessed data (GOES 13-15 X-ray sensor data).

Procured official archive approval for hydrogen-alpha and magnetogram images generated by the Global Oscillating Network Group (GONG).

Participated in detailed planning of calibration and validation for GOES-R Post Launch Test (PLT) and Post Launch Product Test (PLPT). Developed software tools for post-launch calibration and validation of GOES-R space weather instruments.

Continued development of Level 2 (L2) data processing algorithms and integration of L2 algorithms into SPADES. Developed and tested interfaces to selected L2

Oversaw instrument calibration and characterization activities by SEISS instrument vendor. Traveled to instrument calibrations and Technical Interchange Meetings (TIMs), reviewed calibration data books and requirement verification reports, and performed consistency checks with calibration data needed by ground processing algorithms.

Validated "diagonal bowtie matrix" algorithm for SEISS Magnetospheric Particle Sensor (MPS-HI) L1b data affected by channels whose energy responses overlap.

Developed software for the creation of daily SEISS Level 0 (L0) netCDF files for use during calibration and validation and subsequent reprocessing.

Attended GOES-R Magnetometer flight operations training at NOAA Satellite Operations Facility (NSOF). Attended the GOES-R spacecraft stray fields test and spacecraft dipole test at Lockheed Martin, pertinent to the on-orbit performance of the Magnetometer. Attended GOES-R Backup Magnetometer Preliminary Design Review at NASA Goddard Space Flight Center (GSFC).

Under the GOES-R Visiting Scientist project, visited the United Kingdom Met office in Exeter and hosted scientists from the Royal Observatory of Belgium.

Published (or had accepted for publication) over ten papers in refereed journals. Delivered presentations at several scientific conferences and workshops (e.g., Geospace Environment Modeling (GEM) workshop, Solar, Heliospheric, and Interplanetary Environment (SHINE) workshop, European Space Weather Week, AGU Fall Meeting, Boulder Solar Day, Space Weather Workshop, American Astronomical Society Solar Physics Division Annual Meeting).

NCEI-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

A key accomplishment of this task is the final installation of the advanced ionosonde at the South Korean Jang Bogo Antarctic Research Station. Terry Bullett and colleague Bob Livingston joined the Korean Polar Research Institute to make antenna repairs and install the new second generation radar electronics. Nine months of data were added to the archive, as well as real time data products.

Two receive antenna arrays were installed by team member Justin Mabie at two Korean Space Weather Agency locations, Icheon and Jeju. This is a key step to establishing a network of oblique propagation ionosphere experiments in Asia.

A discovery was made by team member Justin Mabie that it is possible to use the high-resolution data from the Vertical Incidence Pulsed Ionosphere Radar to detect and measure the acoustic waves generated by large, ground-based noise sources. In particular, the sound

Project Reports: Management and Exploitation of Geophysical Data



The Korean Polar Research Agency Space Weather Team group photo after successfully installing the ionosonde, neutron monitor, and scintillation receiver to the Jang Bogo Space Weather Observatory. Photo: Chang-Sup Lee/KOPRI

wave from an orbital rocket launch is shown to create an ionosphere plasma displacement around 200 km altitude. This may be important for making thermosphere measurements below satellite altitudes.

This project has provided ionosonde data required to study energy transport from the oceans into space. This effort has obtained direct evidence of the correlation of deep ocean wave activity with atmospheric gravity waves in the ionosphere-thermosphere system. Principle investigator Nikolay Zabotin has lead the effort to publish these convincing results.

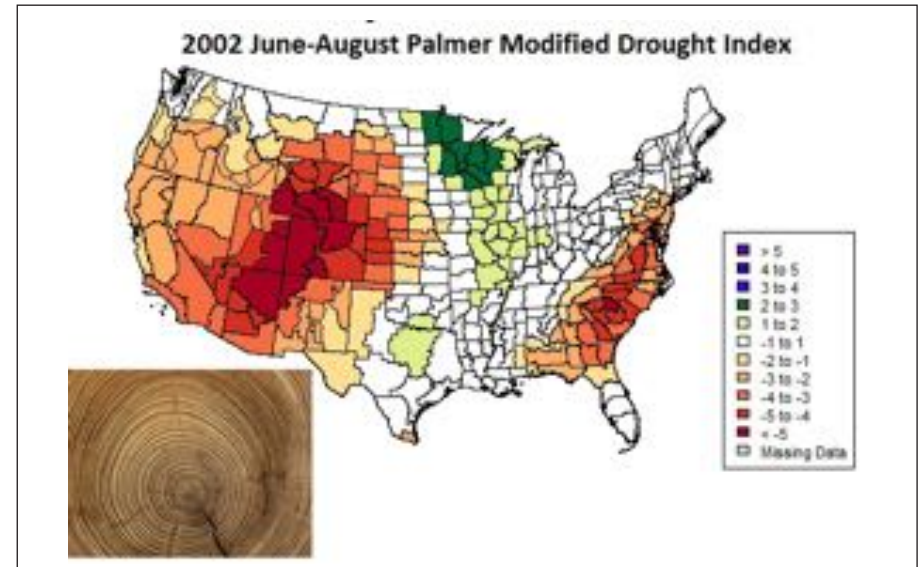
In an increasingly challenging national-international data exchange and information technology security environment, team member Jim Manley was able to obtain 60 real-time ionosonde data streams from across the globe and maintain real-time public access to the data archive.

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

■ CIRES Lead: Carrie Morrill ■ NOAA Lead: Eugene Wahl
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.



The Palmer Modified Drought Index for summer 2002, showing drought (orange) and wet (green) conditions for the 344 U.S. Climate Divisions. We are using tree ring width data to extend these annual maps back two millennia. Image: CIRES and NOAA

Accomplishments

In conjunction with NOAA's National Integrated Drought Information Service (NIDIS), we are developing the Living Blended Drought Product. This product seamlessly blends hydroclimate information inferred from the width of the annual tree rings over the past two millennia with the shorter, but continuously-updated instrumental record. Integrating these two datasets will place recent droughts into a longer-term perspective and will enable research to understand and predict hydroclimate changes in the continental United States. This year, we completed recalibrations of the tree ring width data with the newly-developed Palmer Modified Drought Index (PMDI) from instrumental data. We also mapped the tree ring data into the 344 United States Climate Divisions, extending the original presentation of information from a half-degree grid to societally-relevant geographic areas. We will release the final product in summer 2016, following completion of PMDI reconstructions for the last two millennia and of mapping functions.

We also began a two-year project to create and apply comprehensive controlled vocabularies for describing the measurements we archive as part of the World Data Service for Paleoclimatology. The heterogeneity of paleoclimate measurements 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. Expanding on initial working versions built last year, we have now formulated comprehensive vocabularies for four of nine archive types and that adhere to international standards and best practices in library and information science. We have convened committees of subject matter experts to inspect these vocabularies and guide us in terminology. We have assigned controlled terms to more than 1500 individual studies archived at the World Data Service, making significant progress toward describing nearly all of our datasets using standard terminology.

Lastly, we have developed a new dataset of past lake level changes and new methodologies to support quantitative paleohydrologic model-data comparisons. Unlike the modern observational record, paleoclimate evidence offers an “out-of-sample” test of climate models because these models have not been tuned to reproduce paleo results. Climate changes recorded in the paleo record are also larger than those of the observational record, allowing assessment of model skill against a wider range of climate states. However, paleo model-data comparisons are often qualitative (“wet” vs. “dry”), limiting the rigor of the test. Our new dataset maps the areal extent of lakes in the western United States during extreme wet conditions at the Last Glacial Maximum (~21,000 years ago), which we are now quantitatively comparing to climate model output through the development of hydrologic models that translate past climate change to lake area.

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

■ CIRES Lead: Scott Woodruff ■ NOAA Lead: Huai-min Zhang
NOAA Theme: Climate Adaptation and Mitigation

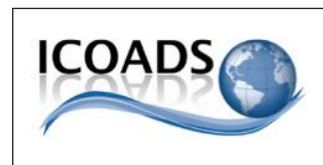
Goals & Objective

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

Accomplishments

International Comprehensive Ocean-Atmosphere Data Set (ICOADS) development and coordination activities:

During this period, we completed most of the planning and processing for Release 3.0 (R3.0), our upcoming major delayed-mode ICOADS update (1662-2014), to be made publicly available by the end of June 2016. This intensive development and production work included four “beta” processing runs, the results of which we shared with our international partners for feedback. In conjunction with R3.0, we are finalizing operationalization of a new “preliminary” Global Telecommunication System (GTS) product, created through blending marine GTS receipts from NOAA’s National Centers for Environmental Information (NCEI) with those from NOAA’s National Centers for Environmental Prediction (NCEP). This new near-real-time (NRT) product will replace NCEP-only GTS data



New ICOADS logo.

presently used to update ICOADS monthly, and thus regularly extend the R3.0 data and products past 2014. To publicize and describe R3.0, we wrote a journal paper—Freeman, E., S.D. Woodruff, S.J. Worley, S.J. Lubker, E.C. Kent, W.E. Angel, D.I. Berry, P. Brohan, R. Eastman, L. Gates, W. Gloeden, Z. Ji, J. Lawrimore, N.A. Rayner, G. Rosenhagen, and S.R. Smith, 2016: “ICOADS Release 3.0: A major update to the historical marine climate record”—which has now been accepted, and will be published on-line by the *International Journal of Climatology* in conjunction with R3.0. Additional ongoing documentation work included more fully describing the latest version of the International Maritime Meteorological Archive (IMMA) common observational format. In addition, I continued serving as the Interim Chair for the ICOADS Steering Committee (ISC) operating under our international Letter of Intent (LOI), until transitioning to ex officio status in August 2015.

Participation in international activities:

Continuing participation during this period in Joint WMO (World Meteorological Organization)-IOC (Intergovernmental Oceanographic Commission) Technical Commission on Oceanography and Marine Meteorology (JCOMM) and related activities, including:

- The Fifth session of the JCOMM Expert Team on Marine Climatology (ETMC), 22-25 June 2015, Geneva.
- The 3rd CLIOTOP (Climate Impacts on Oceanic Top Predators) Symposium (14-18 Sept. 2015, San Sebastián, Spain), and the Second Meeting (19 September) of the JCOMM/CAGM (Commission for Agricultural Meteorology of WMO) Task Team on Weather, Climate and Fisheries, as a Task Team member representing JCOMM.

NCEI-13: U.S. Extended Continental Shelf Project

This is a new project.

■ CIRES Lead: Barry Eakins ■ NOAA Lead: Robin Warnken
NOAA Theme: Science and Technology Enterprise

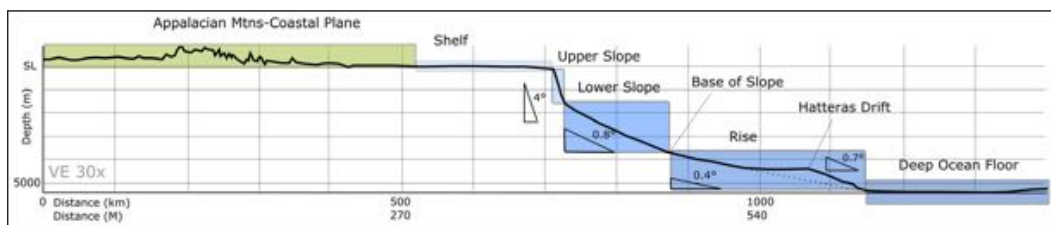
Goals & Objective

Data and products from this project will help establish a new U.S. maritime seabed area.

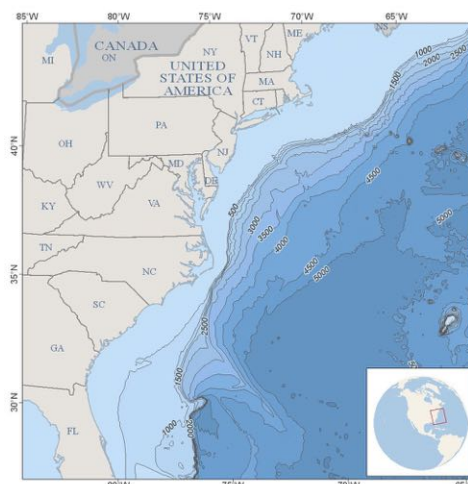
Accomplishments

CIRES members of the U.S. Extended Continental Shelf (ECS) Project Office devel-

Project Reports: Management and Exploitation of Geophysical Data



Annotated regional bathymetric profile across the Central Atlantic continental margin. Average seafloor gradients of the various components of the margin (upper slope, lower slope, rise, deep ocean floor) are illustrated by triangles. The base of the Atlantic continental slope is located between the lower slope and the rise. Vertical exaggeration: 30x. Image: CIRES and NOAA



Bathymetric map of the U.S. Atlantic continental margin. Cartographic elements within the geospatial database will underlie all maps and figures created in support of the U.S. ECS project. Image: CIRES and NOAA

oped geographic information system (GIS) analysis methods, cartographic content, and preliminary scientific documentation for those regions where the United States will delineate ECS. These products need to be scientifically justifiable, robust, and conform with Article 76 of the United Nations Convention on the Law of the Sea, and the Scientific and Technical Guidelines of the Commission on the Limits of the Continental Shelf (CLCS).

The GIS work included developing robust methods for identifying the base of the slope of the continental margin, drawing bathymetric profiles, and determining the locations of the maximum change in gradient at its base. These methods were utilized to develop base-of-slope polygons and example foot-of-slope points for the U.S. ECS regions. The GIS work also included designing the geospatial data model that will be used for storing, maintaining, and retrieving key ECS data assets for delineating formula lines and generating cartographic content. Prototype long, regional bathymetric profiles, with continental margin components identified, were also developed (Central Atlantic regional profile).

A system for producing that cartographic content and figures was developed, including constructing a database of geographic names, and designing map templates and styles. An initial set of regional maps was created of the U.S. ECS regions (map of the U.S. Atlantic continental margin).

Preliminary documentation on the continental margin for the U.S. ECS regions was also developed. This documentation included physiographic and geologic background, descriptions of GIS methods, description of the base of the continental slope, and accompanying graphics. The GIS methods, regional maps, and preliminary documentation were presented and reviewed at the annual, multi-agency U.S. ECS Project meeting in

May 2016.

A variety of structural layouts were created for organizing the ECS data and products that will be included as Part III of the U.S. Submission to the CLCS.

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

■ CIRES Lead: Florence Fetterer ■ NOAA Lead: Eric Kihn

NOAA Theme: Science and Technology Enterprise

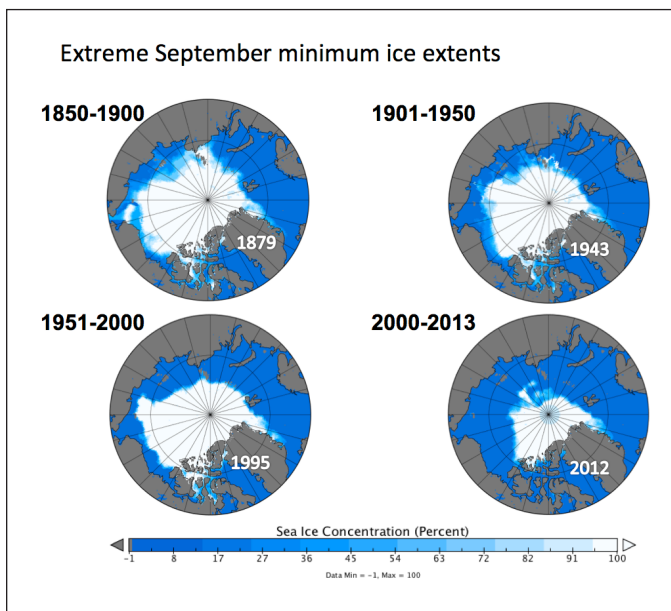
Goals & Objective

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

Accomplishments

One new data collection was published, and several others were updated. More information can be found at <http://nsidc.org/noaa/news.html>. Most notable:

1. Data set G10010, Gridded Monthly Sea Ice Extent and Concentration, 1850 Onward was published. Observations from historical sources are the basis of this product that begins in 1850. In 1979, these sources give way to a single source: concentration from satellite passive microwave data. The historical observations include those from ships, compilations by naval oceanographers, analyses by national ice services, and others. The data product fills a need for ice concentration fields that predate the satellite era and have realistic variability throughout the record.
2. MASAM2: Daily 4 km Arctic Sea Ice Concentration, <http://nsidc.org/data/G10005> has been made into a near-real-time daily update product. This product meets a need for greater accuracy and higher resolution in ice concentration fields that are used to initialize



Ice concentration fields for the smallest annual minimum ice extent for years within three 50-year periods and the most recent 14 years. Data are from Gridded Monthly Sea Ice Extent and Concentration, 1850 Onward. The image shows that the diminishing Arctic ice extent of the last decade has no precedent in the previous 150 years.

NSIDC-04: Support the activities of the NCEI Arctic Team

This is a new project.

■ CIRES Lead: Florence Fetterer ■ NOAA Lead: Eric Kihn
NOAA Theme: Science and Technology Enterprise

Goals & Objective

This project will support NCEI and NOAA's mission in the Arctic by coordinating NCEI broad Arctic observational, modeling, and research data products, and online data services.

Accomplishments

2016 saw the formalization of the NCEI Arctic Action Team, a small group of NCEI Federal employees and affiliates who are subject matter experts in areas of Arctic data. The Team recognizes that NCEI Arctic projects, activities, and programs are inherently cross-center throughout NOAA, yet often lack interaction and strategic coordination across the centers. At the same time, the Arctic is a high priority for NOAA. The new NCEI-wide Arctic Action Team, led by Hernan Garcia, seeks to integrate efforts and requirements between Arctic projects, activities, and programs in order to efficiently enable environmental intelligence. NOAA@NSIDC plays an active role on the team, participating in frequent teleconferences for information sharing and planning. One activity of the team in 2016 will be to stand up a prototype digital Arctic atlas. This will highlight NCEI Arctic data, and initially use data for which web services are already enabled. A major accomplishment has been the success of a Big Earth Data Initiative (BEDI) program proposal that will allow us to provide web services for the Sea Ice Index so that this popular data product can be featured in the data portal prototype.

an operational sea ice forecast model. It is now being used in the NOAA ice modeling research group for hindcast studies of Beaufort Sea ice forecasting.

3. The [Glacier Photograph Collection Search and Order](#) interface was enhanced and the metadata fields were fine-tuned and improved to increase the discoverability of the photos.
4. The [Submarine Upward Looking Sonar Ice Draft Profile Data and Statistics](#) data set has been updated with data from 1960, 1969, and 1970. These pre-satellite-era data are a significant and important addition to the slim record of sea ice thickness that researchers have to work with for this time period.
5. In collaboration with the National Ice Center, a 1km version of the Multisensor Analyzed Sea Ice Extent product was released.
6. Two NOAA@NSIDC data sets, the [Sea Ice Index](#) and the [Multisensor Analyzed Sea Ice Extent](#), appeared in an exhibit at the Arctic Matters Day, 14 January 2016, at the National Academy of Sciences building in Washington, DC.

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 vertical distribution of ozone and aerosols, observe the wind and turbulence structure in the vicinity of wind farms, and investigate plankton densities in the Gulf of Mexico.

We used the Tunable Optical Profiler for Aerosol and Ozone (TOPAZ) ozone lidar to make semi-routine, twice-weekly ozone and aerosol profile measurements in the Boulder,



NOAA Doppler wind lidar (in foreground) deployed during WFIP2 near a wind farm along the Columbia River. Photo: Aditya Choukulkar/CIRES

Colorado area as part of the NASA-funded Tropospheric Ozone Lidar Network (TOLNet) operations. TOLNet consists of six ozone lidar stations that cover the contiguous United States and southern Canada. As part of the TOPAZ observations in Boulder, we characterized with high spatio-temporal resolution the ozone and aerosol distribution in the lower atmosphere during a period in late August 2015 when the Colorado Front Range was impacted by forest fire smoke plume that originated in the Pacific Northwest. We also successfully upgraded the TOPAZ lidar data acquisition system, which significantly increased TOPAZ's measurement range from 2 km to at least 6 km. This will allow us to better document ozone transport mechanisms with important implications for ground-level air quality, such as stratospheric intrusions and long-range transport of ozone from Asia.

We analyzed the data collected during the Experimental Planetary boundary layer Instrumentation Assessment (XPIA) field campaign to validate various lidar-based complex flow measurement strategies. We found that observations with multiple wind lidars had the lowest uncertainties and highest update rates, but limited spatial coverage. Single wind lidar observations combined with the Optimal Interpolation technique can cover larger areas with reasonable update rates, but have higher uncertainty. We also deployed two scanning wind lidars in the Columbia River Gorge in Oregon as part of the second Wind Forecast Improvement Project (WFIP2). The objective of this study is to improve wind forecasts in complex terrain for wind energy applications. We optimized the lidar scan strategies and data processing algorithms to provide precise measurements of wind speed and direction, atmospheric turbulence, as well as boundary layer height during WFIP2.

The NOAA oceanographic lidar was deployed on a NOAA Twin Otter aircraft for a three-week study in the Gulf of Mexico to characterize the vertical and horizontal distribution of plankton layers in the upper ocean, test new instrumentation, and work toward a calibrated lidar for future studies. 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 plankton layers in the Gulf of Mexico.

PSD-19: Improving Wind and Extreme Precipitation Forecasting

This is a new project.

■ CIRES Lead: Laura Bianco ■ NOAA Lead: Kelly Mahoney

NOAA Theme: Science and Technology Enterprise

Goals & Objective

Observation-based research to improve understanding of how variations in wind energy and precipitation extremes are influenced by onshore transport associated with winter storms, complex topography, and large scale climate forcings influence on circulation and moisture pathways.

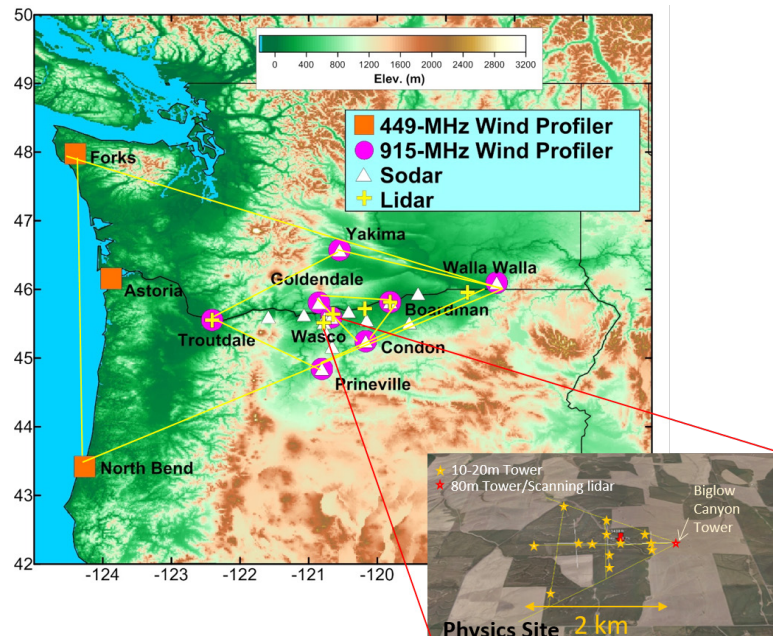
Accomplishments

For the second Wind Forecast Improvement Project (WFIP2) a wide array of instruments has been deployed to improve the skill of NOAA's forecast models at predicting weather that impacts wind energy generation around the Columbia River Gorge (see figure).

The project began in October 2015 and the deployment will last for 18 months (until March 2017). Our goal is to build on the WFIP2 framework to study multiple aspects of water vapor transport, precipitation, and evaporation locally, and both upstream and downstream from the study site. Specifically, we will augment the number and types of instruments deployed during WFIP2, conduct analyses on high-resolution model simulations already planned for WFIP2, diagnose and analyze other relevant PSD datasets, and perform new model experiments to address multiple science questions.

Specific science issues to be addressed include:

- additional exploratory techniques for measuring humidity profiles with the synergetic use of microwave radiometers (MWRs) and wind profiling radars (WPRs);
- study of the large-scale dynamics and moisture transport upstream and downstream of the Columbia Gorge;



Schematic representation of the WFIP2 instruments deployment (yellow lines illustrate the telescopic approach taken for this study). Image: CIRES and NOAA

- model assessment of quantitative precipitation forecasting (QPF) performance in selected extreme precipitation events;
- examination of numerical weather prediction (NWP) and regional model fluxes and balances using local moisture and energy budgets determined at the physics site by the full set of observations including estimates of the surface fluxes, moisture and heat flux convergence, and precipitation.

Some additional instruments have been deployed during spring 2016 (an S-band radar and a disdrometer in Troutdale, Oregon, to measure precipitation, and a soil moisture pit in Wasco, Oregon); others will be deployed in summer 2016. Several meetings to determine the milestones and coordinate the effort between the people involved in this project have occurred.

PSD-21: Develop and Prototype Experimental Regional Arctic Sea Ice Forecasting Capabilities

This is a new project.

■ CIRES Lead: Amy Solomon ■ NOAA Lead: Janet Intrieri

NOAA Theme: Science and Technology Enterprise

Goals & Objective

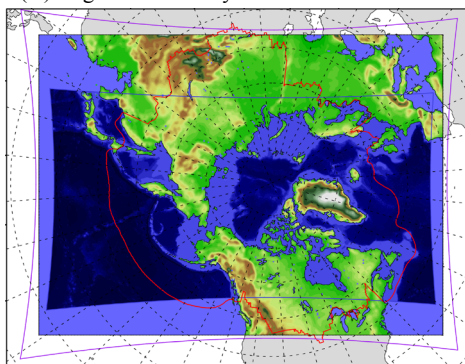
Improve predictions of Arctic sea ice on an extended weather scale (0-4 weeks) through the application of enhanced observation-based understanding to identify critical (large-scale and local) physical processes, characterize process-level model deficiencies, and improve model representation of key processes.

Accomplishments

The NOAA Earth System Research Laboratory Physical Sciences Division adapted the Regional Arctic System Model (RASAM) for short-term Arctic sea ice forecasting. RASAM is a limited-area, fully coupled ice-ocean-atmosphere-land model (Maslowski et al. 2012). It includes the Weather Research and Forecasting (WRF) atmospheric model, the LANL Parallel Ocean Program (POP) and Community Ice Model Version 5 (CICE5) and the Variable Infiltration Capacity (VIC) land hydrology model configured for the pan-Arctic region. The ocean and sea ice models used in RASAM are regionally configured versions of those used in CESM, while WRF replaces the Community Atmospheric Model (CAM). These components are coupled using a regionalized version of the CESM flux coupler (CPL7), which includes modifications by Roberts et al. (2014) important for resolving the sea ice pack's inertial response to transient (i.e. weather) events. RASAM's domain covers the entire Northern Hemisphere marine cryosphere, terrestrial drainage to the Arctic Ocean and its major inflow and outflow pathways, with optimal extension into the North Pacific and Atlantic oceans to model the passage of cyclones into the Arctic (see figure A). RASAM's standard configuration includes a 50 km polar stereographic atmosphere and land grid, with ~9 km (eddy permitting) resolution mesh for the sea ice and ocean.

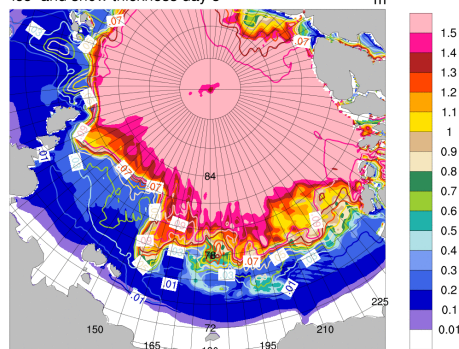
Project Reports: Regional Sciences and Application

(A) Regional Arctic System Model Domain



(A) The Regional Arctic System Model (RASM) domain includes all Arctic drainages and mid-latitude storm tracks and is used primarily for climate simulations. (B) The RASM-ESRL model is focused on the Arctic basin and is used for short-term forecasting. RASM-ESRL is initialized with 3-hourly GFS forecasts or analyses and sea ice concentrations reset to AMSR2 sea ice extent. Image: CIRES and NOAA

(B) RASM-ESRL Domain
ice and snow thickness day 5



The Earth System Research Laboratory version of the Regional Arctic System Model (RASM-ESRL) is RASM modified for short-term forecasts (see figure B). In order to optimize the model for short-term forecasts the dynamic level ocean model was replaced with a mixed-layer ocean model, the VIC land model was replaced with the NCAR Community Land Model, the horizontal domain was limited to the

Arctic, and all components were run with 10km horizontal resolution. This model includes a bulk double-moment cloud microphysics scheme for droplets and frozen hydrometeors that allows both size and number of hydrometeors to vary in response to environmental conditions (Morrison et al. 2009).

Daily 5-day forecasts with RASM-ESRL were run for the 2015 freeze-up season, initialized with GFS atmosphere and Advanced Microwave Scanning Radiometer 2 (AMSR2) sea ice analyses and forced by 3-hourly GFS forecasts at the lateral boundaries (see <http://www.esrl.noaa.gov/psd/forecasts/seaice/> for current experimental forecasts). These daily forecasts have been validated with observations of surface fluxes and vertical profiles of cloud ice and liquid at land sites, and with observations of surface fluxes and sea ice characteristics from recent ocean campaigns and ice mass balance buoys. The forecasts were used for guidance on the research vessel Sikuliaq during the SeaState campaign and by the National

Weather Service Ice Desk for operations. These relatively short forecasts are currently being used to validate and improve simulations of synoptic evolution, atmospheric boundary-layer structure, and surface energy fluxes over sea ice and the adjacent ocean.

PSD-25: Linking Weather, Climate and Environmental Tipping Points

This is a new project.

■ CIRES Lead: James Scott ■ NOAA Lead: Michael Alexander
NOAA Theme: Climate Adaptation and Mitigation

Goals & Objective

This research aims to accelerate the development and broaden the application of coupled climate system analysis and modeling to understand tipping points that could affect the stability and sustainability of managed and unmanaged resources.

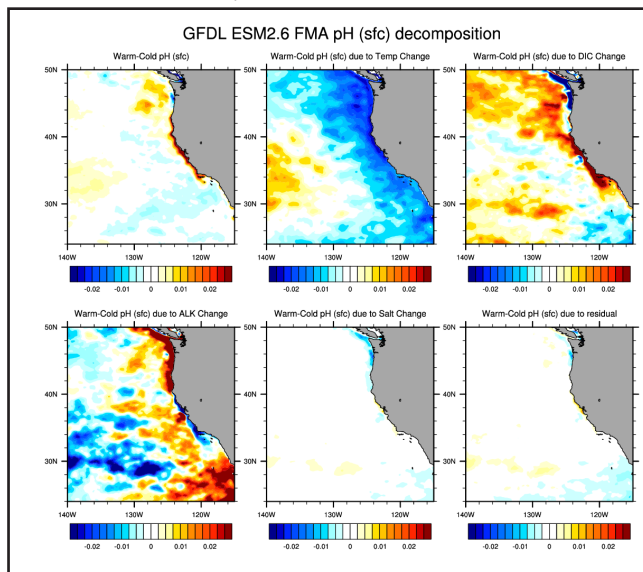
Accomplishments

We used a prototype, fully coupled global Earth System Model (ESM2.6), developed by NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), including an ocean bio-geochemistry component run at 10 km resolution, to investigate the impact of El Niño (ENSO) on the California Current System (CalCS) surface pH and dissolved oxygen (DO). Coastal upwelling ecosystems, such as the CalCS, support some of the world's most productive fisheries due to the seasonal wind-driven upwelling of nutrient rich waters. The upwelled waters fuel the biological production in the CalCS but are also more acidic and less well oxygenated than the surrounding surface waters. Although the CalCS is accustomed to seasonal fluctuations in pH and DO, several observational studies suggest that in the last decades, the ecosystem has become more acidic and hypoxic, particularly in the nearshore 100 km. The topic of how ENSO influences the physics and ultimately the biogeochemistry of the CalCS is very complex. We focus on the various manifestations of a typical ENSO on the CalCS in terms of changes in pH and DO in the GFDL ESM2.6. ENSO modifies surface heat fluxes through surface warming or cooling, and the large-scale atmospheric dynamics of the North Pacific, leading to changes in the CalCS' source waters and to changes in upwelling depth and intensity. We found that ENSO influences pH and DO through two rather different processes: the most intense pH signal is limited roughly to the first 100 km along the coast, indicating that changes in upwelling and thus the supply of dissolved inorganic carbon (DIC) rich bottom waters to the surface is the main driver for pH variability. On the other hand, the DO signal is more widespread to the offshore regions, mirroring the sea surface temperature (SST) patterns, indicating a temperature-dependence of DO through the O₂ solubility.

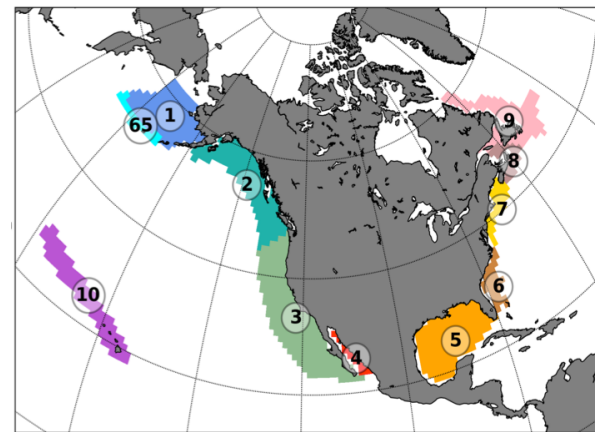
Through our initial SEED project entitled "Seasonal to Decadal-Scale Climate Predictions for Marine Resource Management" we explored the forecast skill of the National Centers for Environmental Prediction (NCEP) CFS2 and Geophysical Fluid Dynamics Laboratory (GFDL) CM2.5 FLOR models in predicting monthly SST anomalies in Large Marine Eco-

systems (LMEs), with a focus on seven LMEs in U.S. waters. Variability in the ocean state, especially SST, is known to strongly influence marine ecosystems and be a useful indicator of ecosystem state changes. The CFSv2 and FLOR forecast systems both exhibit regional forecast skill, out several months to a year in many regions, but forecasts were less successful in other regions and differences in forecast skill between CFSv2 and FLOR were common. In most previous studies climate forecasts are better using a multi-model ensemble than from any individual model. In addition, the spread among the prediction systems provides a measure of uncertainty in the forecasts. The North American Multi-Model Ensemble

(NMME) is an experimental multi-model seasonal forecasting system consisting of coupled models from US modeling centers including NOAA/NCEP, NOAA/GFDL, IRI, NCAR, NASA, and Canada's CMC (Kirtman et al. 2014). We used the NMME to assess the skill of the 14 different individual models and to determine if using the ensemble mean from the NMME improved predictions of the SSTs in U.S. coastal LMEs compared to the individual models.



This figure shows the change in pH between El Nino and La Nina conditions in the California Current System as simulated by the GFDL ESM2.6 model. The total change in pH is shown in the top left. The contribution to pH change is broken into different constituents: temperature change (top center), dissolved inorganic carbon change (top right), alkalinity change (bottom left), salinity change (bottom center), and the residual (bottom right). Image: NOAA/GFDL and NOAA/ESRL/PSD



Large Marine Ecosystems studied. 1: East Bering Sea (EBS), 2: Gulf of Alaska (GoA), 3: California Current (CC), 5: Gulf of Mexico (GoM), 6: South-east U.S. Continental Shelf (SEUS), 7: Northeast U.S. Continental Shelf (NEUS), 8: Scotian Shelf (SS), 9: Newfoundland-Labrador Shelf (NL), 10: Insular Pacific Hawaiian (IPH), 65: Aleutian Islands. Image: NOAA/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

We had a banner year with Science On a Sphere® (SOS) and SOS Explorer™ (SOSx)! SOS

was installed in 17 new locations across seven countries and two versions of SOSx were released, an exhibit version and a free version.

In November, the SOS Users Collaborative Network met at the Oregon Museum of Science and Industry for a workshop that is hosted every 18 months. Right before the workshop, CIRES and collaborators released version 5.0 of the SOS software that included a new visual playlist editor, a splitter, greater support for translations, a new kiosk, and automated alignment software. The release was received with great praise at the SOS workshop. At the same time as the workshop, a traveling SOS was part of the U.S. Pavilion at UN Climate Change Conference in Paris, France, where CIRES employee Beth Russell gave daily SOS presentations. We also set up the traveling SOS exhibit at four other events including the American Meteorological Society Annual Meeting and the USA Science and Engineering Festival.

We also conducted quarterly SOS Education Forum webinar meetings between network educators to promote more creative use of the sphere in museum education. To reach local educators, we held a teacher workshop that introduced teachers to the brand new SOS Explorer. The teachers provided valuable feedback and even created a tour that was adapted for use in the Lite version that was released to the public.

In order to provide a free resource for teachers and home users, we released SOS Explorer Lite in September. There have been over 1700 downloads of the software since then. After accomplishing this major milestone, we began working on an exhibit version for museums and schools that uses a touchscreen to control the display. We released the first version of this exhibit SOSx in April and have one set up in the lobby of the David Skaggs Research Center. We are now exploring the best ways to get SOSx into the hands of educators and the public around the world.

TerraViz™ has added significant new capabilities, several of which are technical breakthroughs that make TerraViz stand out from competing visualization engines. The High Impact Weather Prediction Project (HIWPP) program was concluded and we delivered a final version of NOAA's Earth Information System (NEIS) application. Over the past year, NEIS visualization capabilities were significantly enhanced to display and animate ultra high-resolution (80k+) images. There were also technical enhancements which optimized several existing visualizations to support multi-model comparisons. For SOSx we added touch input, multi-display, and globalization (translation support) capabilities.



The brand new SOS Explorer exhibit on display in the lobby of the David Skaggs Research Center.
Photo: Will von Dauster/NOAA

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

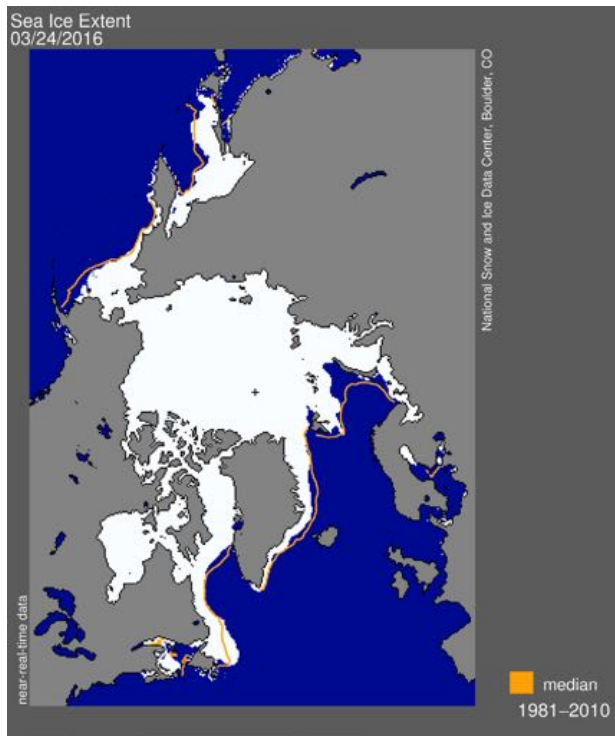
■ CIRES Lead: Florence Fetterer ■ NOAA Lead: Eric Kihn
NOAA Theme: NOAA Engagement Enterprise

Goals & Objective

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

Accomplishments

Sea Ice Index accomplishments fell into two broad categories over this reporting period. Maintaining and updating the Sea Ice Index code base is invisible to the thousands of users who view the product site or download data every month. A more visible accomplishment has been timely and thorough documentation of changes, and communication with the data product's users when there has been some change in the product. In May 2016, Sea Ice Index processing had to be suspended because of the degradation of brightness temperature



The Sea Ice Index daily image for March 24, 2016. Ice on this day reached its seasonal maximum extent in the Arctic. This maximum was a new record low for the satellite era; a fact described and discussed by scientists on the Arctic Sea Ice News and Analysis site (<http://nsidc.org/arcticseaicenews/2016/03/another-record-low-for-arctic-sea-ice-maximum-winter-extent/>) The site relies on Sea Ice Index data for communicating with public about Arctic sea ice. Image: NSIDC

data coming from the F17 satellite upon which the Sea Ice Index's input data sources depend. A banner on the Sea Ice Index product page announced the stoppage, and a message to all registered users provided further explanation. The earlier bad data was removed from the site. We demonstrated rapid response when alerted to the bad data by the science team. The popularity of the sight and its use in products like the Climate.gov dashboard demands this.

The product code has been modularized and updated, and runs now on a Virtual Machine server. This means that processing can be more easily resumed on another server if it is interrupted for some reason.

NSIDC-02: Update and Maintain Education Resources for the Cryosphere

This project was completed in early 2015.

Space Weather Understanding and Prediction

NCEI-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.

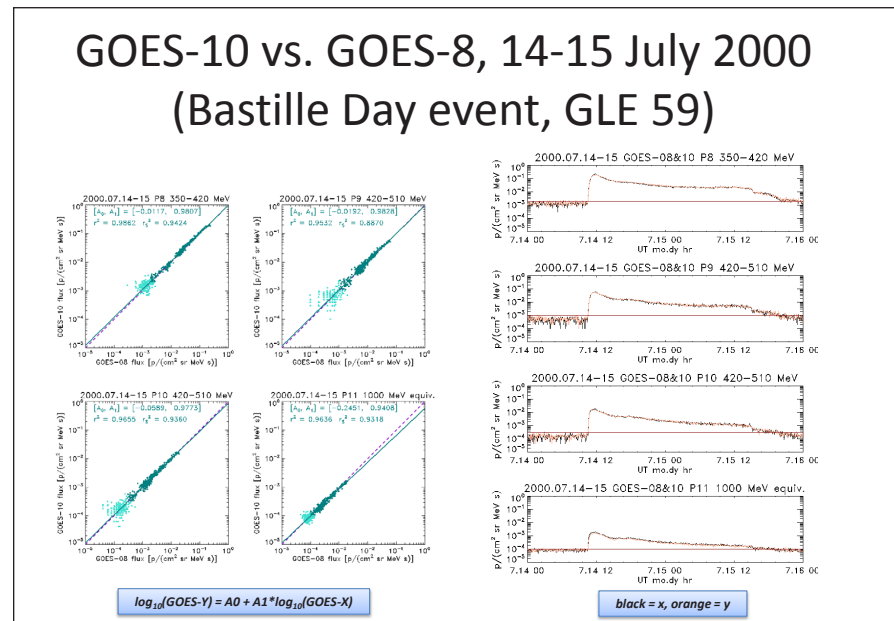
Accomplishments

During this year, CIRES contributed to the Satellite Anomaly Information Support project in several areas:

1. CIRES helped organize the Spacecraft Anomalies and Failures (SCAF) workshop held in Chantilly, Virginia, 6-7 October 2015. CIRES recommended speakers in the area of attributing anomalies to the space radiation environment.
2. With the National Centers for Environmental Information (NCEI), CIRES contrib-

uted to a poster presentation at the 14th International Conference on Space Operations (SpaceOps 2016) on the attribution of anomalies experienced by the Cross-track Infrared Sounder (CrIS) on the Suomi-NPP satellite to the space environment (Sedares et al., 2016). In the course of the work, CIRES and NCEI concluded that the anomaly resolution team should focus any further investigation of potential space environmental root causes on internal charging by radiation belt electrons and on single event upsets (SEUs) caused by highly-energetic penetrating ions.

3. CIRES contributed to an NCEI oral presentation at the 14th Spacecraft Charging Technology Conference (SCTC) held at the European Space Research and Technology Centre (ESTEC) in Noordwijk, Netherlands (Redmon et al., 2016). In this study, NCEI used a parametric charge accumulation model to determine whether a series of anomalies on the Polar Orbiting Environmental Satellites (POES) could be attributed to >800 keV electron fluxes as originally put forward by NOAA. Our findings tended to discount that hypothesis. CIRES was primarily responsible for the calculation of the factor used to convert raw counts from the POES Medium Energy Proton and Electron Detector (MEPED) P6 channel to >800 keV electron fluxes.
4. One of the longest series of space-borne measurements of the highest energy solar energetic particles (SEPs) is provided by the High-Energy Proton and Alpha Detectors (HEPADs) on GOES 4-15. These observations are commonly combined with ground-based neutron monitor observations to estimate the solar proton spectrum above 500 MeV. This important data set has a reputation as being difficult to interpret. In order to better understand and possibly to resolve this situation, CIRES started a cross-comparison and data integrity investigation of the HEPAD observations archived by NCEI. Initial results identified some areas of good agreement among different flight models as well as some significant discrepancies that warrant further investigation. These initial results were presented at the European Space Weather Week in November 2015 and at the Space Weather Workshop in April 2016 (Rodriguez, 2016).



Comparison of GOES-8 and GOES-10 HEPAD proton fluxes from the Bastille Day 2000 solar energetic particle (SEP) event. This event is known as 'ground level enhancement (GLE) 59' based on neutron monitor observations. From Rodriguez (2016).

References:

- Redmon, R. J., J. V. Rodriguez, C. Gliniak, and W. F. Denig (2016), Internal charge estimates for satellites in low earth orbit and space environment attribution, 14th Spacecraft Charging Technology Conference, Noordwijk, Netherlands, 4-8 April 2016.
- Rodriguez, J. V. (2016), Cross-comparisons of GOES HEPAD solar proton fluxes, Fourth Working Meeting on the Harmonization of Solar Energetic Particle (SEP) Data Calibrations, Space Weather Week, Broomfield, Colorado, 25 April 2016, <http://www.swpc.noaa.gov/sites/default/files/images/u33/HSDC-WM4-Rodriguez-HEPAD-crosscal.pdf>

Sedares, L. M., J. R. Winsley, R. J. Redmon, J. V. Rodriguez, C. Buttles, B. Nowak, and A. D. Galvan (2016), Determining if the root cause of an anomaly is a single event upset, SpaceOps 2016, AIAA-2016-2564, Daejeon, Korea, 16-20 May 2016.

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

Successfully delivered many Space Weather Prediction Center (SWPC) website improvements and new products. One of the largest was deploying the Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics Model (CTIPE) Total Electron Content Forecast as an experimental website product. This plot illustrates the electron density through a vertical integration of the CTIPE output, across a Mercator map of the Earth (see attached example from 6/14/2016 at 14:50 UT).

Planned and executed a three-month migration of all Linux system applications, processors and models from Red Hat Enterprise Linux (RHEL) 5 to RHEL6. This highly

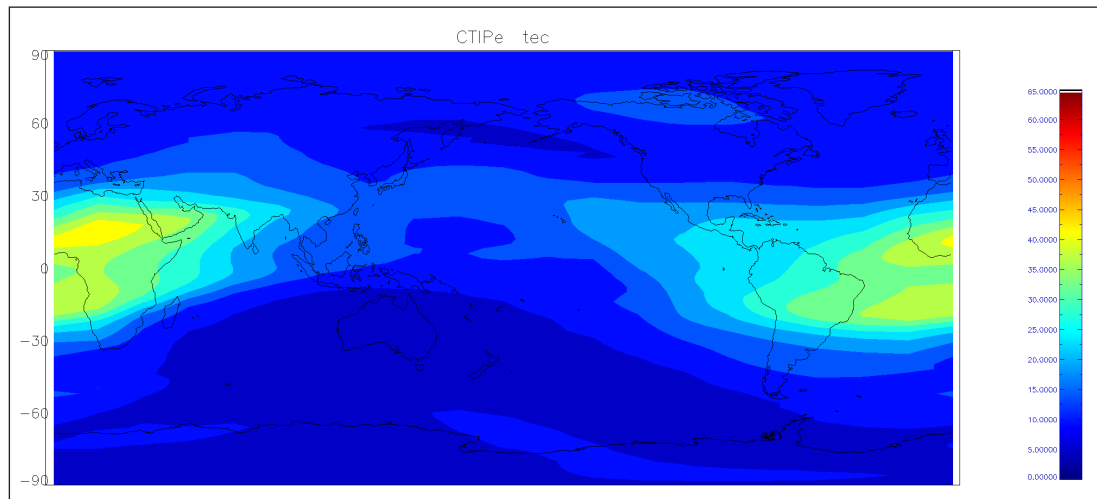
complex migration allowed SWPC to continue to operate under the tightening security requirements of the National Weather Service (NWS).

Implemented several ground data systems that provide SWPC data to our partners. The most important was the SWPC2AWIPS system, which delivers SWPC data to the NWS's All-Weather Information Processing System. This effort also included prototype delivery systems to the Whole Atmosphere Model (WAM) and Geospace Model projects - which will both be important new product implementations for next year.

Improved many of our development team's processes and tools by integrating Atlassian Stash, Jira, and Greenhopper. These software development tools allow our team to integrate seamlessly with version control, schedule and coordinate our work efforts, and collect metrics on our operating efficiency.

Provided timely operational support for the following critical systems and maintained a high customer satisfaction:

- Advanced Composition Explorer (ACE) processor
- Geostationary Environmental Satellite (GOES) processor and preprocessor
- WSA-Enlil (Wang-Sheeley-Arge Model)
- D Region Absorption Predictions (D-RAP)
- Air Force and Institute for Science and Engineering Simulation (ISES) Message Decoder (AIMED) processor
- Polar Orbiting Environmental Satellite (POES) processor
- SWPC's Microsoft SQL Server Space Weather Data Store (SWDS)



CTIPE Total Electron Content from 6/14/2016 at 14:50 UT. Image: CIRES and NOAA

Project Report: Space Weather Understanding and Prediction

SWPC-02: Enhancement of Prediction Capacity for Solar Disturbances in the Geospace Environment

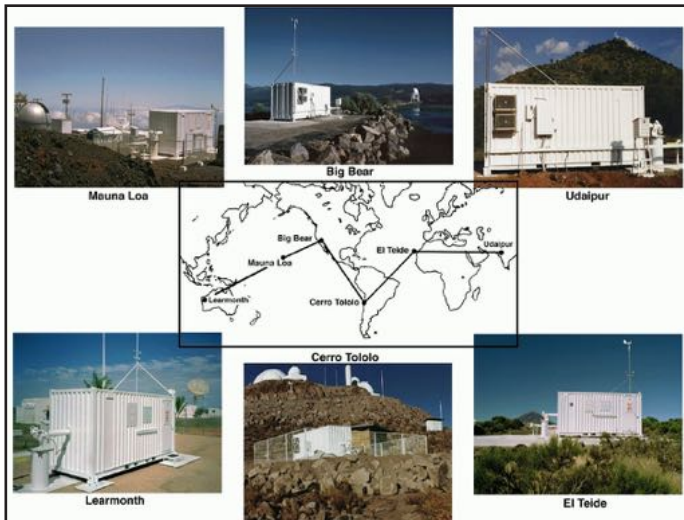
■ CIRES Lead: Alysha Reinard ■ NOAA Lead: Vic Pizzo
NOAA Theme: Weather-Ready Nation

Goals & Objective

This project will advance preparedness for solar storms affecting communication, transportation, and other U.S. infrastructure.

Accomplishments

We have made good progress on establishing a data processing pipeline for the GONG (Global Oscillation Network Group) data. The GONG instruments are located at six different sites around the Earth, allowing continuous observations of the Sun. The solar images collected by GONG are used by SWPC (the Space Weather Prediction Center) for situational awareness and as inputs to models of the solar wind. CIRES researchers and their colleagues determined that using the NOAA (National Oceanic and Atmospheric Administration)'s IDP (Integrated Dissemination Program) was the best option for a robust data processing pipeline, though in the short term it requires more preparation. At this point we have transferred the NSO code for processing H-alpha images over to the IDP and it is working nominally. We are in the process of transferring the magnetogram processing software. We are also working on issues related to bringing data into the IDP from the six GONG sites and sending the processed data out to the customers at SWPC and other interested parties.



The image shows the locations of each of the GONG data sites. These locations provide excellent seeing (i.e. very low chances of clouds or haze) and ability to continuously observe the Sun. Photos: NSO, <http://gong.nso.edu/gallery/disk2k10/data/resource/sites/sites.html>

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

The first effort this past year has been to test the whole atmosphere model with data assimilation in an operational environment, in preparation for transition in 2017. We have been running the whole atmosphere model (WAM) with data assimilation up to 60 km altitude in a real-time, test operational environment. The research parallel mode has been running stably since September 2015. This version of the model is using fixed solar (F10.7 index) and geomagnetic drivers (Kp geomagnetic index), and uses an older version of WAM and the Gridpoint Statistical Interpolation (GSI) NCEP data assimilation scheme.

The second effort this past year has been to continue to develop and validate the ionosphere-plasmasphere-electrodynamics (IPE) code that will be coupled to WAM. This past year the electrodynamic has been implemented in the code and validated for quiet geomagnetic conditions. In addition, IPE has been tested for storm-time conditions during the St. Patrick's Day geomagnetic storms of 2013 and 2015. The model was driven by an empirical magnetospheric electric field and auroral precipitation model. The model successfully produced the storm-enhanced densities that were observed during these storms (see figure). The model tended to slightly overestimate the magnitude, most likely because of the empirical model for

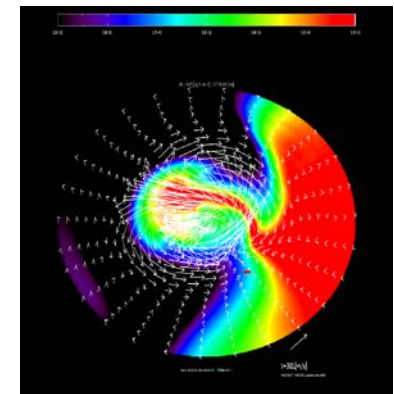
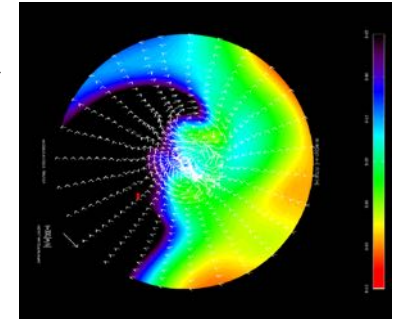


Illustration of the storm enhanced density during the St. Patrick's Day geomagnetic storm on March 17 2015. The upper panel shows the total electron content in color before the storm, with the vectors showing the plasma convection. In the lower panel, the plasma convection is stronger, the plasma density has increased in magnitude at mid latitude in response to the storm, and a tongue of ionization stretches over the polar cap. Image: CIRES and NOAA

neutral composition. More realistic neutral composition increases plasma loss rates, and will be provided by WAM in a coupled system.

For the third effort, WAM and IPE are being coupled using the Earth System Modeling Framework (ESMF). The two codes are both massively parallel, so they run on multiple processors. In addition, the model grids are very different. WAM is on a geographic grid in the usual vertical pressure coordinate used by weather models; the IPE uses a geomagnetic field line grid. ESMF is required to handle the exchange of parameters and interpolation between the two codes. This requires extracting out parameters from WAM, such as the neutral wind, composition, and temperature. The one-way connection transferring data from WAM to IPE was completed; the re-gridding accuracy was high and all fields were visually inspected.

SWPC-04: Geospace Modeling Effort

This is a new project.

■ CIRES Lead: Howard Singer ■ NOAA Lead: George Millward
NOAA Theme: Weather Ready Nation

Goals & Objective

This project will use first-principles physics-based models to predict variations of space weather conditions in Earth's near-space environment that affect critical infrastructure in space and on the ground.

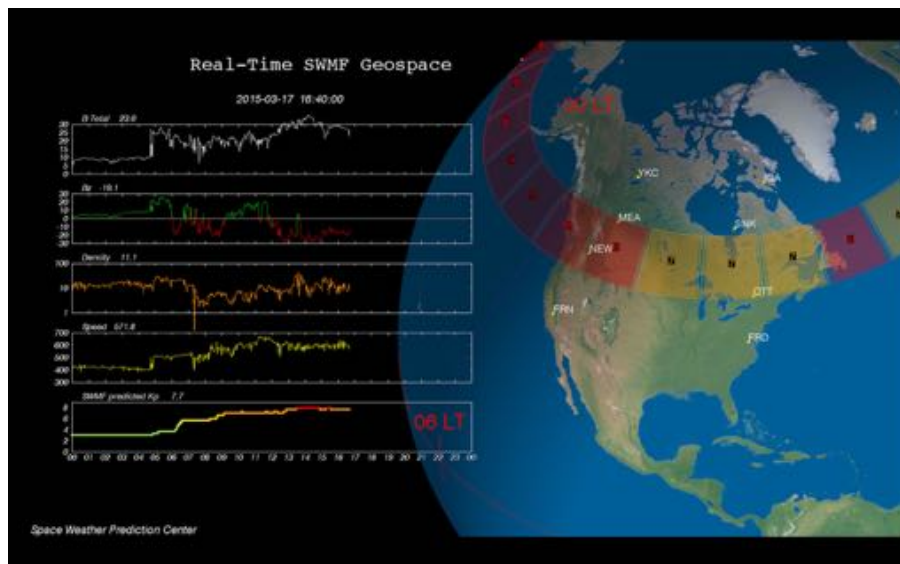
Accomplishments

The aim of this project has been to take the Space Weather Modeling Framework (SWMF) Geospace model, developed at the University of Michigan (UMICH), and transition it into full operations at the National Weather Service (NWS). The project has involved working closely with the model developers at UMICH to implement code and script changes needed for real-time, weather forecasting model usage. It has also involved working with technical staff at the National Center for Environmental Prediction Central Operation's Production Management Branch (NCEP/NCO/PMB) on all aspects of the real-time system, including the ingestion of real-time satellite data which is used as model input, and the dissemination of output products to the Space Weather Prediction Center (SWPC), and, for public consumption, to the web.

The 2015 NWS milestone for the project was to hand over the code to NCEP staff for operational implementation by the end of December 2015. This was achieved. The operational code has been running on the Weather and Climate Operational Supercomputing System (WCOSS) (in pre-operational 'parallel' mode) since early March, finished a period of formal testing (the 30 day test), and at the start of June 2016 was approved for full operational implementation by the director of NCEP.

Real-time test products are currently being produced and are available for the SWPC forecasters to view and start to make forecasts. The 2016 NWS milestone is that the model should be fully operational, with output products available to the public, by October 1.

A Geospace test product currently under development. The left hand lines trace show solar wind parameters measured by the ACE satellite and propagated to the position of Earth. The globe on the right shows the resulting prediction of a regional, local-time K value, as predicted by the SWMF Geospace model. Such a product will allow forecasters to assess regional Magnetic activity which has the potential, during disturbed times, to threaten the integrity of large scale electric power grid system. Image: Space Weather Prediction Center



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

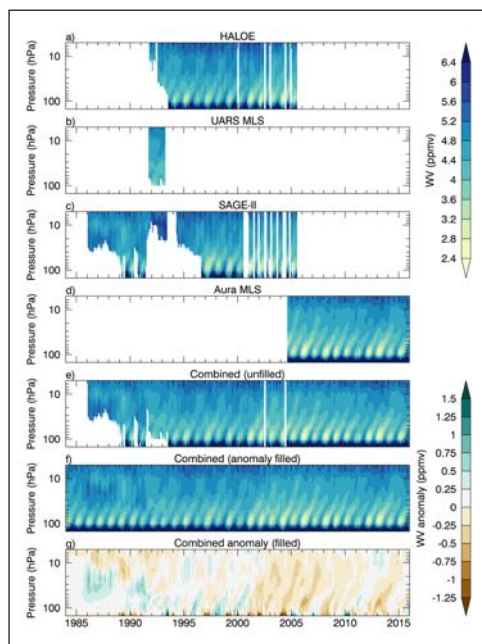
Goals & Objective

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 the stratospheric ozone layer, in that region of the atmosphere.

Accomplishments

A major component of this project is improving past estimates of variability in stratospheric water vapor and ozone. In 2015-2016, we made major progress in the development of the Stratospheric Water and OzOne Satellite Homogenized (SWOOSH) data set, a CIRES/CSD-led data record of ozone and water vapor. In 2015 and early 2016, the official public release of the SWOOSH data set was made. In addition to being hosted at NOAA ESRL, SWOOSH data were formally archived at the National Centers for Environmental Information (NCEI), and a paper describing the data set was submitted (Davis et al., submitted).

We used the SWOOSH data in several studies of atmospheric composition. In collaboration with NOAA Global Monitoring Division researchers, we used the Boulder Frostpoint Hygrometer (FPH) balloon measurements to identify a drift in the Aura Microwave Limb Sounder (MLS) satellite measurements (Hurst et al., submitted), which are widely



The tropical average (30°S – 30°N) water vapor concentration as a function of height and time, which is commonly referred to as the “tropical tape recorder”, for each satellite data set in the Stratospheric Water and Ozone Satellite Homogenized (SWOOSH) data set (a-d). The lower panes show the two merged and combined combined products (e-f) and the combined and filled anomaly product (g). Image: CIRES and NOAA

used in studies of stratospheric water vapor variability. We also analyzed the SWOOSH data to quantify past variability in the width of the so-called tropical belt edge (Davis et al., 2015), and to study the impact of circulation and climate variability such as El Niño on stratospheric water vapor (Davis et al., submitted). In related work, we were involved in a modeling study showing that direct injection of water vapor into the stratosphere via overshooting convection could be an important source of water vapor in the future (Dessler et al., 2016).

Our group also led work on potential future changes in the ozone layer due to changes in carbon dioxide, methane, and nitrous oxide levels (Butler et al., submitted). Under some scenarios, extratropical ozone will increase well above historical levels due to changes in these gases, decreasing surface ultraviolet (UV) radiation well below historical levels. Thus, future policy decisions may need to weigh the impacts of these three greenhouse gases on climate change against their effects on the ozone layer, in order to maintain the ozone and surface UV near historical levels.

We also made a significant improvement to radiative forcing estimates. The commonly used method of estimating radiative forcing assumes a linearity between global mean surface temperature change and top-of-atmosphere radiative imbalance that is not accurate over long timescales. We devised a new method that takes into account the nonlinearity and more accurately estimates radiative forcing (Larson and Portmann, 2016).

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

Major progress was made on the homogenization of historical ozone profiles as the records from the five main long-term stations (Samoa, Hilo, Boulder, Summit, and South Pole) were painstakingly reverted back to their raw, unedited versions and then uniformly converted into a data set that is ready for standardized, non-destructive processing using the new criteria developed over the past year. In order to develop this criteria, several working sessions were conducted with our worldwide partners such as Southern Hemisphere ADditional OZonesondes (SHADOZ) and various experts in the field of ozonesondes in order to finalize criteria and historical instrument performance. The vast majority of work has been completed but some minor issues delayed completion of homogenization as there was some remaining disagreement upon acceptable sensor cell background currents, naming

conventions, and finalization of solution corrections. Validation of changes to the homogenized ozone vertical profiles was accomplished through comparisons between old and new dual-sonde profiles, as well as comparisons between integrated ozonesonde profiles and Dobson column measurements at several NOAA stations where both types of measurements were routinely performed since the 1980s (Figure 1). Data is archived at the NOAA/ESRL/GMD ftp site (<ftp://ftp.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.

Ozone data record at 6 NOAA NEUBrew (NOAA-EPA Brewer UV-ozone Monitoring

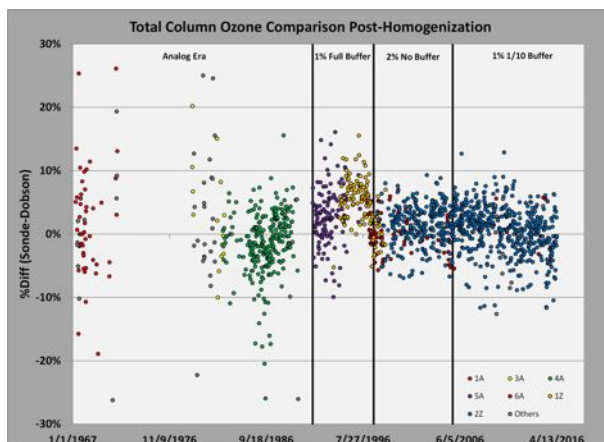


Figure 1. Ozonesonde vs. Dobson Total Column Ozone Comparison for Boulder, Colorado post homogenization. Image: CIRES and NOAA



Figure 2. Brewer instrument at the CU Boulder Mountain Research station north of Boulder. Photo: CIRES and NOAA

Network) sites was continued in 2015-2016 (Figure 2). Comparisons with co-located Dobson Umkehr and ozonesondes profiles are ongoing in Boulder, Colorado to verify the consistency of the 10 years of measurements. Work also is underway to assess the record for possible shifts in the data processing after applying new constants to account for replacement of the old filters with the new thermally stable crystal. Ozone calibrations traceable to the World Meteorological Organization (WMO) triad of NEUBrew instruments were performed in the fall of 2014. Results are under evaluation. NEUBrew data were used regularly in 2015-2016 by the NPP Ozone Mapping and Profiler Suite (OMPS) satellite ozone team for validation of the satellite total column ozone product.

Dobson Total Column Ozone (TCO) measurements continued at fourteen WMO supported sites in 2015-2016. In addition balloon-borne ozonesonde profile launches were continued at 10 stations nationally and globally through the first half of 2016 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 man-made chemicals and natural processes. The data are also used to provide continuous ground-based verification of performance of satellite-based ozone datasets (i.e. JPSS/OMPS). In order to produce data in near real time, a new automation system was installed at five NOAA Dobson stations; Fairbanks, Alaska; Boulder, Colorado; Mauna Loa Observatory, Hawaii; Lauder, New Zealand; and Observatoire de Haute-Provence, France stations.

Total Column Ozone data from all fourteen Dobson stations (including stations operated by NOAA Weather Service personnel) was processed by GMD personnel at the end of physical year (2015 and 2016) and archived locally at NOAA, at the NDACC (NOAA/NASA) archive, and at the WMO ozone and UV archive center in Canada (WOUDC).

In May 2016, the world standard Dobson D083 was sent to the Pulsed Laser Setup for Advanced Characterization of Spectroradiometers (PLACOS) at the Physikalisch-Technische Braunschweig, Germany for characterization as part of the ATMOS campaign. Information learned from this study will be used to understand the limits of Dobson spectrometers.

The analysis of measurements from all seventeen stations in NOAA surface ozone network was completed to understand the seasonal and daily expected ozone levels and variation. This work serves as the foundation for analysis of long-term changes in background ozone levels and high ozone event frequency. High levels of ozone in the Colorado Front Range have been analyzed for the impact of fires on these episodes and the frequency of high ozone that has been affected by compounds released from wildfires. NOAA Colorado surface ozone stations data have been used for understanding large-scale stratospheric intrusions and the impact on high ozone conditions. Surface ozone data at Trinidad Head, California was analyzed to study the attribution of ozone variability to the meteorological conditions and synoptic scale events.

In order to advance the program, all stations data processing was merged with the Global Monitoring Division aerosol CPD software. This allows for near real-time data access for use by program scientists as well as the external community model verification. This data

Project Reports: Stratospheric Processes and Trends

processing advancement assists with maintaining instrument functioning and ensures complete data capture for each location. The collaboration with the Aerosol network allows for co-located data to be plotted together for understanding of aerosol and meteorological influence on surface ozone conditions.

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

Accomplishments

Our work and accomplishments are tied to our long-term global observations derived by the two surface networks 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" quadrennial report and also are essential components to the IPCC reports on climate change. 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 routine sample measurements have begun. The increased throughput, higher precision and accuracy, and the additional measurements of new and more volatile



NASA's Global Hawk taken in Guam during the last ATTREX deployment. Photo: David Fratello/NASA

compounds will enhance our flask program.

Regular low-altitude airborne flask measurements and periodic higher-altitude, mission-oriented measurements complement these surface observations. This Airborne program helps 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 are referenced 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. A major focus of our Airborne programs this year was the Atmospheric Tomography Mission (ATom) Project. Substantial upgrades and associated paperwork were completed to prepare for the 2016 integration and deployment of PANTHER (PAN and other Trace Hydrohalocarbons Experiment), UCATS (UAS Chromatograph for Atmospheric Trace Species), NOAA PFP (Programmable Flask Package), and a last minute add-on PICARRO (cavity ring-down spectrometer). ATom will use the NASA DC-8 to generate a chemistry-oriented extension of the global-scale tropospheric HIPPO observations from 2009 to 2011, with a focus on OH. With this extensive payload, we will be tracking the interplay between transport and chemistry in the free troposphere and will ultimately have full seasonal coverage.

We continued our analysis of ozone and other data from the NASA Airborne Tropical Tropopause Experiment (ATTREX) campaigns, which focused on tropical convective processes near the western Pacific 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 (TTL) and the stratosphere. Our results showed that ozone in the tropospheric part of the TTL averaged about 20 ppb in March 2014 over the western tropical Pacific, which is higher than some recent ozonesonde measurements in this region. Even higher (~40 ppb) ozone values earlier in the year were associated with long-range transport from areas far to the west (Africa and South Asia). TTL ozone values generally increased from the western to the eastern Pacific. The data are consistent with frequent deep convection bringing low ozone air from the marine boundary layer to the upper troposphere of the western tropical Pacific, and generating profiles with nearly constant mixing ratios of short-lived organic halogen compounds from the free troposphere to the base of the TTL. A paper describing these results has been written and is in the internal review stage by the coauthors.

Work on stratospheric transport continued, resulting in the submission of a publication this fiscal year that compares our work using the free-running tropical leaky pipe (TLP) approach to output of a 3-D chemical model. The goal of this study was to demonstrate that by adding photolytic tracers to the age tracers in our TLP work, we can uniquely detangle mean Brewer-Dobson circulation from tropical entrainment. By combining this with previous TLP work we have now demonstrated the ability to use the proposed StratCore data set to detangle the distributed Brewer-Dobson circulation from tropical entrainment,

the seasonal cycle of stratospheric transport, the quasi-biennial oscillation in tropical zonal winds, and major volcanic eruptions. This would then allow a more accurate description of climate-driven stratospheric circulation trends, which most likely vary significantly with altitude, modify O₃ distributions, and represent a major feedback on climate forcing.

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

The goal is to improve our understanding of what drives water vapor changes in the Upper Troposphere/Lower Stratosphere and how these changes influence climate.

Accomplishments

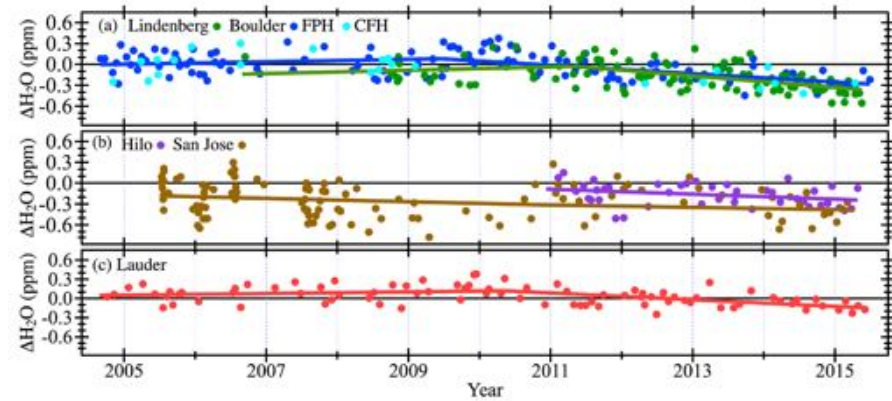
Monthly water vapor soundings with the balloon-borne NOAA Frost Point Hygrometer (FPH) continued at our three monitoring sites (Boulder, Colorado; Hilo, Hawaii; Lauder, New Zealand). Each measured vertical profile extends from the surface to the middle stratosphere (~28 km), spanning a range of water 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 36 years in length (1980-present). The record lengths at Lauder and Hilo now extend nearly 12 and 6 years, respectively.

A paper was recently submitted that quantifies the emerging divergences in stratospheric water vapor measurements by frost point hygrometers (FPs) and the Microwave Limb Sounder (MLS) over five different sites. The Figure shows the downward trends in FP-MLS differences, starting between mid-2009 and early 2011 and continuing through mid-2015, at the five sites. In many cases, these trends have caused FP-MLS differences to now exceed the combined measurements accuracies of the two instruments. We attribute these recent divergences to MLS measurements drifting high (wet) in recent years, primarily because it is very unlikely that two different types of FPs, independently manufactured and calibrated,

would be drifting at the same rates at several sites.

A second paper was recently submitted that documents the history of the NOAA frost point hygrometer, including significant instrumental changes and upgrades. This paper also describes the current design of the FPH and quantitatively assesses its measurement uncertainties from laboratory-based tests and performance metrics during actual soundings.

We continued to prepare for the upcoming validation of water vapor and ozone profiles that will be measured by the space-borne Stratospheric Aerosol and Gases Experiment (SAGE-III) spectrometer. This instrument awaits installation on the International Space Station in late 2016. Once SAGE III is deployed and making measurements, we will perform nighttime balloon soundings in coordination with its overpasses over Boulder and Lauder for validation purposes.



Differences in coincident stratospheric water vapor measurements by frost point hygrometers (FPs) and the MLS at 68 hPa over five FP sites. Trends were determined using piecewise continuous linear regression because statistically significant change points were detected. Image: CIRES and NOAA

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

This project provides long term data for a network of sites on the amount of solar irradiation that reaches the Earth's surface, including potentially harmful ultraviolet radiation. These measurements are important for climate monitoring, as well as providing ground truth data for numerous satellite programs.

Accomplishments

We have embarked on an ambitious effort to replace all our Multi-Filter Rotating Shadowband Radiometers (MFRSRs) with the newest model from Yankee Environment Systems, Inc., and that, by special request from us, each of the new units includes a 1625 nm channel in place of 615 nm. Adding the 1625 nm channel improves retrievals of aerosol and cloud properties. The longer wavelength, sensitive to larger particles, will help constrain

the size distribution of coarse mode aerosol particles, allowing for more accurate retrievals of aerosol optical properties. We also expect to improve cloud optical depth and mean effective cloud particle size retrievals using a combination of this near IR wavelength and a mid-visible one.

In concert with the installation of these new MFRSRs, we are also adding a paired MFRSR sensor to our tower instruments to measure reflected spectral shortwave data. This measurement is particularly unique, with only

The solar tracker located at Bondville, Illinois SURFRAD station. The tracker was relocated to this position due to an obstruction obscuring the sun in early morning hours a few weeks each year. The Kipp & Zonen CHP1 pyrheliometer is mounted on the side of the tracker with yellow cable signal cable attached. Photo: NOAA



an estimated twenty or so stations globally making this measurement. The SURFRAD network, both fixed and mobile sites, account for about half of these stations. With the tower-mounted MFRSR sensors, known as a Multi-Filter Radiometer (MFR) when installed in this fashion, we will be able to provide the scientific community with surface spectral albedo at all our stations. The 1625 nm wavelength will better constrain the spectral surface albedo estimates, especially for vegetation, which has a strong spectral dependence across the visible and near-IR.

New direct sun-pointing broadband pyrheliometers are also being installed. These instruments are the model CHP1 manufactured by Kipp & Zonen, and are replacing the Normal Incidence Pyrheliometer (NIP) by The Eppley Laboratory, Inc. We expect to improve the uncertainty of the direct-normal broadband measurement by 50% with this change. To better understand what impact the CHP1s will have, we will operate the NIPs along with the CHP1s for one year.

To date we have installed these instruments at four of our seven fixed SURFRAD stations, and the other three will receive them later this calendar year. The addition of the new instruments is very exciting and has also motivated substantial infrastructure improvements and upgrades at all the sites. These updates have included adding power outlets at all our towers and new signal cables with greatly improved UV protected jackets, as well as a host of smaller improvements. While not as broadly interesting as new instrumentation, upgrading and improving the infrastructure is foundational to the long-term success of the SURFRAD network. It is this careful attention to our infrastructure that has resulted in truly remarkable up-times consistently well-exceeding 99% across the network, and is a major reason why the SURFRAD network is regarded by the scientific community as the "Gold Standard" of surface radiation monitoring networks.

The Global Monitoring Division Radiation Group, along with the seven fixed stations that make up the SURFRAD network, also operate two Mobile SURFRAD (M-SURFRAD) stations. These stations have in the past been deployed in support of large field campaigns studying air quality and others studying short-term cloud forecasting to help improve the integration of photovoltaic generated energy into regional power grids. In February of this year a M-SURFRAD station was installed for a one-year campaign in eastern Oregon with the purpose of improving wind forecasting in complex terrain. The M-SURFRAD stations benefit from our vast experience operating the fixed network, and have quickly come to be regarded, by researchers outside of our traditional extended colleagues, as high quality stations that provide accurate and desirable information in support of these diverse scientific studies.

GSD-01: Innovative Weather Data Delivery 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

- Meteorological Assimilation Data Ingest System (MADIS) transitioned from a Research-to-Operations project into a conduct to transfer other projects and data into operations. MADIS transitioned the following projects into NWS Operations during this period. The restored products were moved from a research side door feed to an NWS front door feed.
- Added the Automated Flood Warning System (AFWS) product
 - Added the Weather Information Exchange Model (WXXM) format to the restricted products for the Aircraft-Based Observations.
 - Added a real-time public data product for the Aircraft-Based Observations. It currently only contains the water vapor scaling (WVS) model.
 - Added Aircraft weather data displays using ESRI software.
 - Restored Tropospheric Airborne Meteorological Data Reporting (TAMDAR) aircraft data.
 - Restored Federal Aviation Administration (FAA) binary one minute Automated Surface Observing System (ASOS) data. The first stage is only the data on the five minute marks; next year every minute.
 - Restored Indiana Department of Transportation road weather data.
 - Restored Kansas Department of Transportation road weather data.
 - Added Massachusetts Department of Transportation weather data.
 - Restored Maine Department of Transportation weather data.
 - Added Michigan Department of Transportation weather data.
 - Added Minnesota Department of Transportation weather data.
 - Added North Dakota Department of Transportation weather data.
 - Restored New Hampshire Department of Transportation weather data.
 - Restored Ohio Department of Transportation road weather data.
 - Upgraded the West Texas Mesonet (from Texas Tech University) weather data feed.
 - Added Georgia Department of Transportation weather data.
 - Restored the Wyoming Department of Transportation weather data.
 - Restored DigiWx weather data.
 - MADIS is working on transitioning the Clarus and NWS Hydrometeorological Automated Data System (HADS) system into MADIS.
- MADIS added a RAM processing disk for temporary surface processing to reduce IO resources needs and to reduce through-put times.
MADIS added automated build and verification scripts to reduce build, deploy, and test times.

GSD-03: Improving Numerical Weather Prediction

■ CIRES Lead: Curtis Alexander ■ NOAA Lead: Georg Grell
NOAA Theme: Science and Technology Enterprise

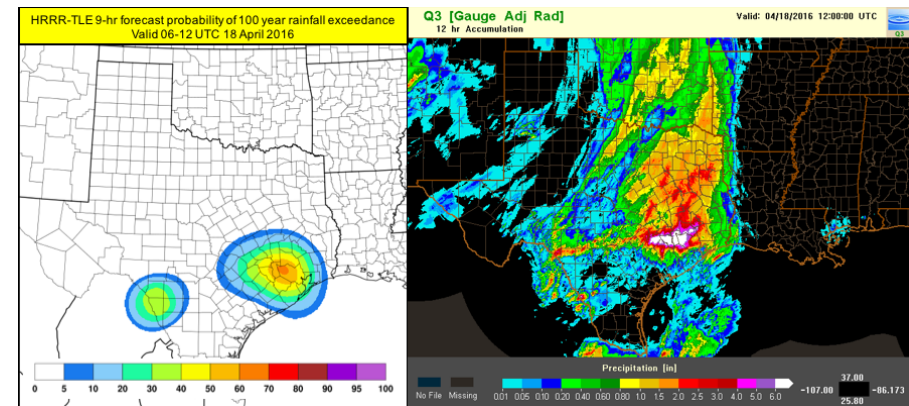
Goals & Objective

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 third version of the Rapid Refresh (RAP) and second version of the High-Resolution Rapid Refresh (HRRR) were transitioned from GSD to the National Centers for Environmental Prediction (NCEP) Environmental Modeling Center (EMC) on 17 December 2015 and then to NCEP Central Operations (NCO) in February 2016. Contained in these model versions are an expanded RAP domain to match the North American Mesoscale (NAM) model and hourly forecast length extensions of the RAP and HRRR to 21 hours and 18 hours respectively.

These versions of the RAP and HRRR assimilation enhancements include: Extension of surface data assimilation to include mesonet observations; and improved use of all surface observations. The RAP hybrid ensemble/3D-variational data assimilation increases the



HRRR Time-Lagged Ensemble (HRRR-TLE) forecasted probability of 6 hour rainfall exceeding the 100 year return interval based upon the NOAA Atlas 14 precipitation frequency dataset (left). The 9 hour forecast was issued at 03 UTC 18 April 2016 and valid between 06-12 UTC 18 April 2016. At right, the 12 hour observed rainfall as estimated by the Multi-Radar Multi-Sensor (MRMS) system across Texas between 00-12 UTC 18 April 2016, which resulted in severe flooding in and near Houston, Texas. Image: CIRES and NOAA

Project Reports: Systems and Prediction Models Development

weighting of Global Forecasting System ensemble-based background error covariance estimation and introduces this hybrid data assimilation configuration in the HRRR.

RAP and HRRR model physics in these versions include improved boundary layer prediction using the updated Mellor-Yamada-Nakanishi-Niino (MYNN) parameterization scheme with short-wave radiation attenuation from sub-grid scale clouds, Grell-Freitas-Olson (GFO) shallow and deep convective parameterization, aerosol-aware Thompson microphysics and an upgraded Rapid Update Cycle (RUC) land-surface model to reduce a warm and dry daytime during the warm season, along with improved convective forecasts in more weakly-forced diurnally-driven events.

Development of the fourth version of the experimental RAP and third version of the experimental HRRR took place in late 2015 and early 2016 through retrospective testing of improved RAP terrain specification, higher resolution land use data, updates to the GSI data assimilation and adoption of WRF-ARW model version 3.7.1. Emphasis includes improvements to the eddy diffusivity mass flux parameterization in the MYNN scheme and tighter coupling to the convective, radiation, and microphysics parameterizations. Preliminary results from these changes show improved forecasts of upper-level winds and further reduction in the lower-level warm/dry bias. The hydrometeor analysis included preliminary testing of variational data assimilation capabilities.

In addition to the development of the experimental RAP and HRRR, a real-time high-resolution nest in the Pacific Northwest within the HRRR domain was executed for use in renewable energy applications such as the second Wind Forecast Improvement Project (WFIP2) with a grid spacing of 750 m.

In April 2016, a peer-reviewed manuscript on the RAP including a description of model physics and data assimilation components was published in *Monthly Weather Review*.

In May 2016, the real-time experimental RAP and HRRR were extended to forecast lengths of 39 hours and 36 hours respectively for every third cycle. A real-time experimental HRRR was established over Alaska with 36 hour forecasts every three hours.

HRRR ensemble development took place through several efforts including probabilistic hazard prediction guidance of heavy precipitation, intense snowfall, and severe thunderstorms leveraging real-time, bias-corrected, time-lagged ensemble HRRR (HRRR-TLE) forecasts. Additionally, a formal real-time HRRR ensemble (HRRRE) was established over a moveable sub-CONUS domain in March 2016 that provided hourly-cycled 3-km ensemble data assimilation of conventional observations and 3 to 18 member ensemble forecasts of severe thunderstorm potential on a daily basis in April and May 2016.

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

We cannot report progress in this project this year due to staff changes and human relations challenges at the University of Colorado system level, which have significantly delayed filling a critical position.

GSD-06: Verification Techniques for Evaluation of Aviation Weather Forecasts

■ CIRES Lead: Matthew Wandishin ■ NOAA Lead: Mike Kraus

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.

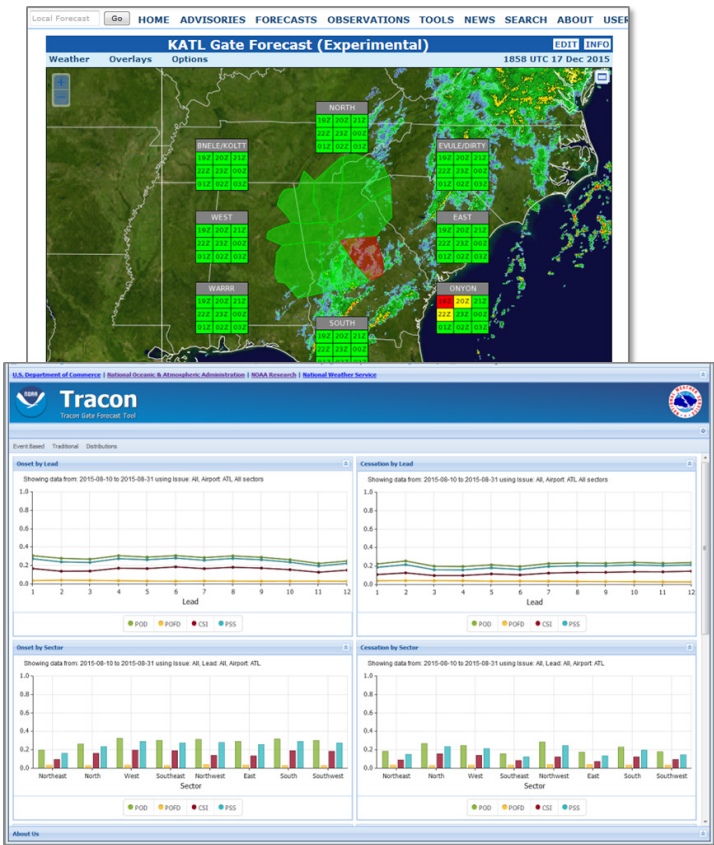
Accomplishments

The Forecast Impact and Quality Assessment Section (FIQAS) performed a quality assessment of the nowcast version of the Graphical Turbulence Guidance (GTG) product, finding that the nowcast product outperformed the short-term guidance currently available to pilots and traffic managers.

The scope of the follow-on assessment of the automated Collaborative Convective Forecast Product was broadened to include the 2016 convective season and so this project is still ongoing.

FIQAS completed an evaluation of the Offshore Precipitation Capability (OPC) developed by Massachusetts Institute of Technology Lincoln Laboratory, a product using satellite and lightning to create a radar-like analysis of convective activity outside of radar coverage for oceanic flights near the southeast United States. The evaluation identified the strengths and weaknesses of the product, in particular, finding that while OPC was very similar in characteristics to radar over land, it had notably different characteristics over water that could impact how the product should be used operationally.

FIQAS continued to work together with National Weather Service (NWS) aviation forecasters to develop a tool (Central Weather Service Unit Briefing and Verification Tool CBVT) to capture the information from weather briefings to FAA traffic managers, and provide a report on the performance of these forecasts to managers. The first phase of this project—related to



Example of the Terminal Radar Approach Control Facilities Gate forecast (top) and the related verification tool (TFVT; bottom).

forecasts of wind shifts affecting airport operations—is nearing completion.

A prototype for the Terminal Radar Approach Control Facilities Gate Forecast Verification Tool (TFVT) was completed this year, along with expanding the tool to additional airports.

The GTG-Alaska project has been pushed back in favor of the GTG-global project. Activities for this year have focused on attempts to define the scope of the project in coordination with the World Area Forecast Centers in the United States and the United Kingdom.

An assessment of National Weather Service forecasts of wind shifts at airports relative to the performance of available numerical guidance products found all forecasts to perform

poorly. In addition, the functional requirements were determined to be poorly conceived with little relevance to actual airport operations.

The Verification Requirements and Monitoring Capability (VRMC) tool was expanded this year to include general techniques in support of grid-to-grid verification.

Core research projects investigating Pilot Report (PIREP) location uncertainty, object-oriented techniques for verifying forecasts of convective initiation, the identification of weather-related pilot deviations using aircraft track data, and the ability to express forecast uncertainty through the use of weather scenarios (as opposed to simple probability fields) was all completed during this past year and reported to the sponsors, which included the FAA and the Global Services Division Office of the Director.

GSD-07: Numerical Prediction Developmental Testbed Center

■ CIRES Lead: Ligia Bernardet ■ NOAA Lead: Stan Benjamin

NOAA Theme: Weather-Ready Nation

Goals & Objective

This project aims broadly to improve numerical weather prediction for research and operations by building, sharing and maintaining code and techniques for data assimilation, forecast, verification, and more.

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.

Two highlights are worth mentioning. The multistorm HWRF capability, developed to both speed up and improve numerical forecasting of tropical cyclones by incorporating multiple storms in a single forecast realization, was incorporated onto the centralized HWRF code through the coordination and scripting work of CIRES and collaborators. This HWRF configuration underwent realtime testing during the 2015 Atlantic hurricane season and is a candidate for 2017 operational implementation. Another important contribution from CIRES toward the improvement of NOAA numerical weather prediction models was the development and testing of a hybrid, regional, four-dimensional ensemble variational initialization capability. Tests of the use of multi-time level observations for the initialization of the Rapid Refresh (RAP) model led to promising results and identification of avenues for further development.

In July 2015 the DTC established a new project, the Global Model Test Bed (GMTB), aimed at enhancing the transition of new research and developments to NOAA's opera-

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tional global forecast system. A sea ice modeling workshop was hosted to review existing efforts in the community and make a recommendation to NOAA's Next-Generation Global Prediction System on which model to adopt. Since a large focus of GMTB is the support for the development of atmospheric physical parameterizations, activities also focused on the creation of requirements and standards documents for a physics library and an interoperable physics driver that could facilitate the use of this library in multiple model dynamical cores. Additionally, work started toward the development of a hierarchical test bed, with capabilities to evaluate the parameterizations in an idealized setting (using a single column model) and in an end-to-end forecast workflow.

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GSD-08: Observing System Simulation Experiments and Observing System Experiments (OSSEs/OSEs)

This is a new project.

■ CIRES Lead: Jason English ■ NOAA Lead: Lidia Cucurull
NOAA Theme: Science and Technology Enterprise

Goals & Objective

This project will conduct observational and simulation experiments to improve numerical weather prediction skills.

Accomplishments

As part of project SHOUT (Sensing Hazards with Operational Unmanned Technology), we completed Observing System Simulation Experiments (OSSEs) for three winter storms, contributed to two Global Hawk field campaigns, and completed Observing System Experiments (OSEs) using data from one of the field campaigns.

We completed a series of OSSE experiments where we studied the impact of targeted observations of temperature, winds, and humidity on the GFS forecast performance for three

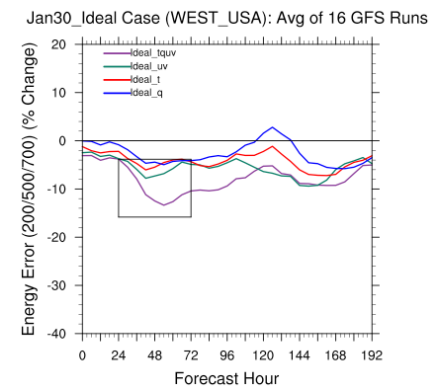


Figure 1: Percent change in Energy Error (temperature and wind error at 200, 500, and 700 mb levels) relative to the control run for the January 30 storm averaged across the western half of the U.S. as a function of forecast hour for all observations (tquv), wind-only (uv), temperature-only (t), or specific humidity-only (q). Image: CIRES and NOAA

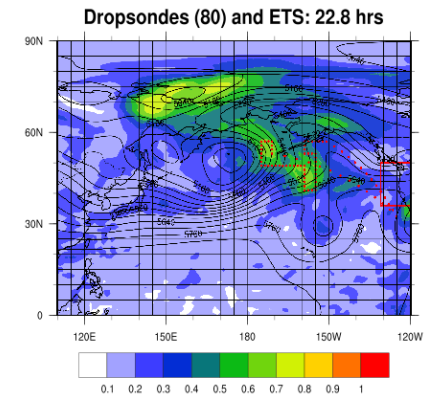


Figure 2: Sensitivity regions determined by Ensemble Transform Sensitivity (ETS) technique for the January 30 Storm, Oregon verification region (red box). "Sensitivity Domain" includes all grid-points with Sensitivity >0.5. "Flight Path Domain" shown in red dots. Image: CIRES and NOAA

winter storms present in the Nature Run (January 29, January 30, and February 25). First, we looked at the impact of adding temperature, wind, and humidity observations over an idealized domain (sampling over a large domain of the Pacific Ocean). Adding all three types of data provided a significant reduction in forecast energy error for all three storms (January 30 storm in Figure 1). Temperature- and wind-only data provided more benefit than humidity-only. Next we generated sensitivity maps for targeted observations using the Ensemble Transform Sensitivity (ETS) technique for one verification region in each storm (Oregon region for January 30 storm in Figure 2). Forecasts based on assimilating data in the "Sensitivity Domain" (regions where sensitivity exceeded a 0.5 threshold) and in the "Flight Path Domain" (simulated flight paths around the sensitivity domains), generally reduced forecast energy error, although to a smaller extent than the Idealized Domain, as expected. These results suggest the potential value of targeting observations.

We supported two Global Hawk flight campaigns this year: An Alaska field campaign in September 2015 and the NOAA El Niño Rapid Response (ENRR) campaign in February/March 2016. We provided daily weather briefings and guidance on possible weather features to study including ETS sensitivity maps, created a real-time SHOUT webpage with targeting and forecast tools, and one team member (Andrew Kren) supported the ENRR campaign in person.

We started OSEs for one of the storms sampled in the ENRR flight campaign (February

21), testing the impact of adding High Altitude MMIC Sounding Radiometer (HAMSR) microwave retrievals and dropsondes, and are currently in the process of analyzing the results. Preliminary results suggest that targeting observations with the ETS technique are able to positively impact forecasts downstream in the pre-determined verification regions. Forecast track, intensity, and precipitation errors are often reduced compared to the run without the observations.

GSD-09: Improve the AWIPS Weather Information System

This is a new project.

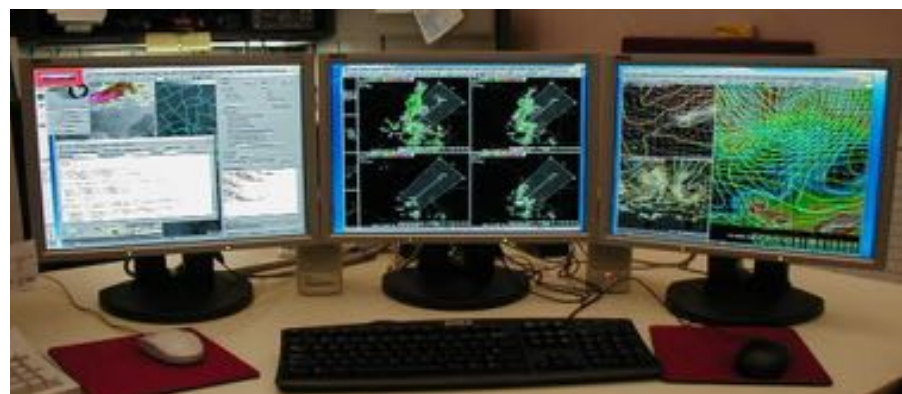
■ CIRES Lead: Paul Schultz ■ NOAA Lead: Mike Kraus
NOAA Theme: NOAA Engagement Enterprise

Goals & Objective

This project focuses on developing forecast tools for NWS forecasters using the AWIPS-2 system. It is directed at the computer user interface issues presented by advancements in (primarily weather) data technology, and by evolving practices in weather forecasting operations.

Accomplishments

The Ensemble Tool in the Advanced Weather Information Processing System (AWIPS) was expanded from basic situational awareness capabilities to practical decision support tools that forecasters can use interactively with emergency managers, for example. The initial features for situational awareness were spaghetti and plume displays, and simple calculations such as mean and spread. The two new features, delivered in March 2016, are a Distribution Viewer and the Matrix Navigator. The Distribution Viewer allows the forecaster to pick a point and see a plotted cumulative distribution with interactive options to read



AWIPS weather display system. Photo: NOAA

probability of exceedence vs. threshold. The Matrix Navigator allows the forecaster to do one-click A-B comparisons between two alternative forecast scenarios, which is particularly useful in situations where the outcome appears to have bi-modal character. These are methods of expressing forecast uncertainty in live decision support situations.

GSD-10: National Energy and Weather System (NEWS)

This is a new project.

■ CIRES Lead: Chris Clack ■ NOAA Lead: Melinda Marquis
NOAA Theme: Science and Technology Enterprise

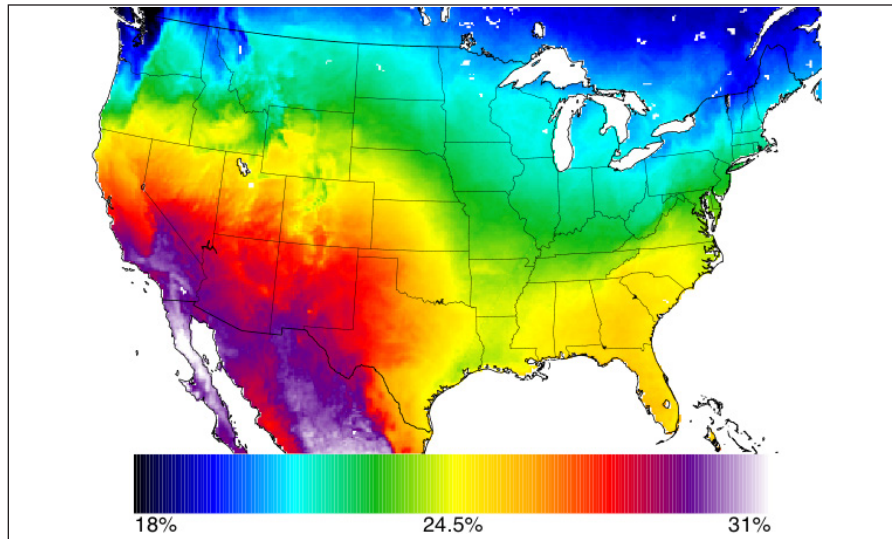
Goals & Objective

This project is directed toward simulating the electric and energy sector and designing optimal energy systems, particularly ones that use large amounts of weather-driven (wind and solar) power.

Accomplishments

Between June 2015 and May 2016 the National Energy and Weather System (NEWS) project made considerable progress. The biggest, or most notable, highlight was the publication of a paper in *Nature Climate Change* in January 2016. The paper was titled “Future cost-competitive electricity systems and their impact on U.S. CO₂ emissions”. That paper received enormous press coverage and elevated the position of the NEWS project on a national scale. There were various other accomplishments that should be noted:

- Peer-reviewed publication in *Wind Energy* on the effects of Rotor Equivalent Wind Speeds (REWS) in numerical models.
- Peer-reviewed publication in *Wind Energy* on the effects of REWS theoretically and observationally.
- Three presentations at AGU and four presentations at AMS on the NEWS project, in particular on work carried out by student researchers.
- Panel participation at the AMS Washington Forum on the use of atmospheric science in energy planning; using the NEWS simulator as a center piece.
- The NEWS simulator has had its datasets for wind and solar expanded to a decadal period (2006-2015) at 13km, hourly resolution and three years (2013-2015) at 3km, hourly resolution.
- The NEWS simulator has been expanded to have the capabilities to represent more generators, finer resolution transmission, increased complexity and reality for generator and market operation, and different optimization questions.
- The NEWS lead, Christopher T. Clack, has cultivated many collaborations in the past year:
 - Providing a data stream of real-time and operation weather model variables for Wind Forecast Improvement Project 2 (WFIP2) partners within ESRL, notably CSD and GMD.



An image of the average solar photovoltaic potential in capacity factor. The data included in the image is the entire 2006 through 2009 hourly output from the Rapid Update Cycle (RUC, 13km) assimilation model processed to determine the electric energy potential. Image: *Nature Climate Change*/Christopher T. Clack

- Archiving five numerical weather prediction models for GSD, GMD, CSD, and PSD. There is currently 270 TB of data archived, with a total of 350 TB by the end of 2016.
- Collaboration with National Renewable Energy Laboratory (NREL) has been strengthened, as Clack spends 1 day per month (on average) at the NREL site in Golden, Colorado. He is on the external advisory board for a number of projects and is working with NREL staff to produce a joint study using NEWS and NREL models.
- Stanford University and Harvard University have been working with Clack on various ideas and possible collaborations.

The NEWS project has been presenting at numerous academic institutions, agencies, national laboratories, and interested organizations. The aim was to spread the word on the usefulness of the model and how it can be used to relentlessly test hypotheses.

GSD-11: Improve RAP/HRRR for Wind and Solar Forecasts

This is a new project.

■ CIRES Lead: Joe Olson ■ NOAA Lead: Melinda Marquis
NOAA Theme: Science and Technology Enterprise

Goals & Objective

This project focuses on improving the skill of Rapid Refresh and High-Resolution Rapid Refresh forecasts of low-level winds and downward shortwave radiation, which are both useful for the electric power system.

Accomplishments

Four developmental tasks were planned: 1. Revise the mixing length in the Mellor-Yamada-Nakanishi-Niino (MYNN) planetary boundary layer (PBL) scheme to improve the representation of local mixing; 2. Improve the representation of the subgrid-scale clouds; 3. Couple a mass-flux scheme to the MYNN PBL scheme to improve the representation of non-local mixing; and 4. Develop a database, query-loading scripts, and web interface for comparing the second Wind Forecast Improvement Project (WFIP2) observations with the experimental models.

An improved mixing length formulation has been implemented into an experimental version of the High-Resolution Rapid Refresh (HRRR). Modifications to the length scales include: a) removal of buoyancy enhancement factor (for convective conditions) in the buoyancy length scale; b) addition of Cheinet and Teixeira (2004) length scale for clouds; and c) revised magnitudes for the surface and buoyancy length scales. Preliminary results show that the experimental HRRR generally outperforms the original HRRR. A further reduction in the cloud-specific mixing lengths has been shown to improve the precipitation verification in the RAP. Results are discussed further below.

A new subgrid-scale cloud parameterization (after Chaboureaud and Bechtold 2002, 2005, hereafter “CB”) has been implemented and tested within the MYNN PBL scheme. The CB parameterization produces robust stratus and shallow-cumulus clouds, which the MYNN’s original parameterization (taken from Sommeria and Deardorff, 1977) was known to be deficient in. The CB parameterization has also been implemented into the mass-flux scheme (discussed below) for consistency within the set of subgrid-scale cloud types (stratus, shallow-cumulus, deep-cumulus). Test runs comparing model output to satellite imagery suggest that the default length scale parameter, central to the CB scheme, of 900 m produces too much cloudiness, while a value of 300 m best matches the observed areal coverage of marine stratocumulus. Results from tests within the HRRR are discussed further below.

Two different mass-flux schemes have been implemented into the MYNN PBL scheme: the Stochastic Eddy diffusion-Mass-Flux (StEM) scheme and the Total Energy Mass-Flux (TEMF) scheme. Each scheme has been developed to include multi-plumes (dry & condensing), turbulence kinetic energy (TKE) transport, momentum transport, scale-aware properties, and numerical stability. Preliminary SCM testing shows positive results for shal-

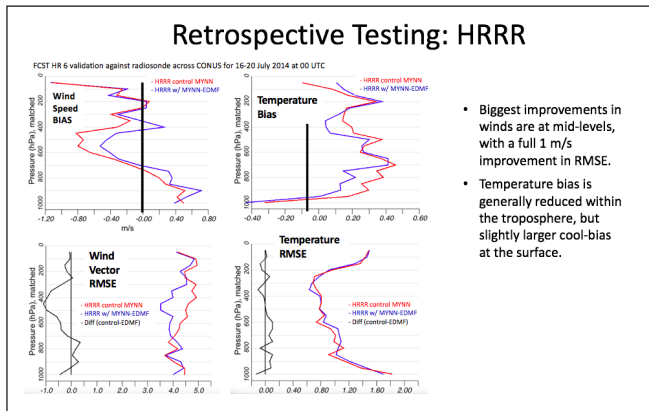


Figure 1. On the left, time-height profiles of cloud mixing ratio from (top) StEM, (middle) TEMF, and (bottom) LES. On the right, profile comparisons selected at hour 2.5 and 9 showing a comparison of potential temperature (top) and water vapor (bottom). Image: CIRES and NOAA

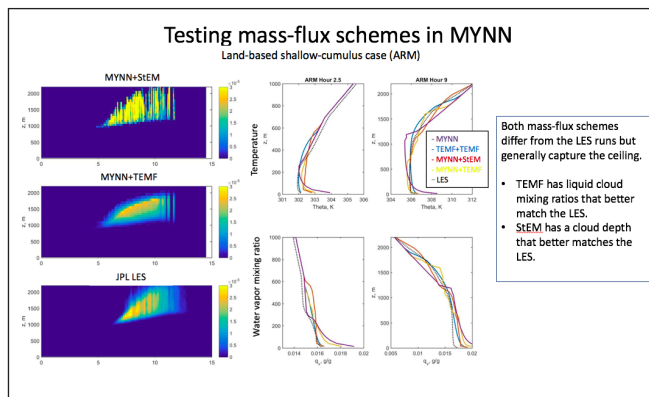


Figure 2. HRRR forecast hour 6 validation against all radisondes across the CONUS. The left shows the wind speed bias (top) and wind vector RMSE (bottom). The right shows the temperature bias (top) and RMSE (bottom). Image: CIRES and NOAA

low-cumulus cases and improved results for the stratocumulus case. Figure 1 shows time-height plots of the cloud-water mixing ratio for the ARM case, which is an excellent test for the shallow-cumulus regime. The cloud decks formed by either mass-flux scheme appear about an hour earlier than the large-eddy simulation (LES; bottom row), which is the considered the truth. The cloud top and depth are best simulated by the StEM scheme, but the TEMF scheme exhibits a more continuous cloud deck. Both also reasonably reproduce the profiles at hour 2.5 and 9 of the simulation. Much of the improvements in the cloud evolution can be attributed to adjustments in the entrainment rate, updraft area fraction, and plume initialization characteristics. The full set of modifications from tasks 1-3 were tested in an experimental version of the HRRR (Figure 2). The biggest improvements in winds are at mid-levels, with a full 1 m/s improvement in RMSE. The temperature bias is generally reduced within the troposphere, but slightly larger cool-bias at the surface.

The final task was to develop an Enhanced Verification System (EVS), consisting of a database and scripts to navigate or mine the database. Model and observational data have been loaded into the database. Thus far, the sodar, 915 Wind Profiling Radar (WPR), and 449 WPR data has been loaded into the database. Various versions of the Rapid Refresh (RAP) and HRRR and 750 m are also being loaded. The capability to plot profiles and time-series has been developed, but time averaging is still being developed. Proto-type web interface has been developed on a private server. This will soon be accessible by all WFIP2 members from a GSD web server. The capability to make scatter plots and histograms is expected to be available by the end of summer 2016.

GSD-12: NOAA Environmental Software Infrastructure and Interoperability Project

This is a new project.

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

NOAA Theme: Science and Technology Enterprise

Goals & Objective

The project advances understanding and improves predictions of the Earth system by delivering infrastructure software that enables new scientific discoveries, fosters interagency collaborations, and promotes resource efficiency.

Accomplishments

This year, our NOAA Environmental Software Infrastructure and Interoperability (NESII) project advanced the goal of coordinating U.S. Earth System modeling across agencies. We worked with modelers at NASA, NOAA, U.S. Navy, the National Center for Atmospheric Research, other federal centers, and their university research partners to implement the software interface standards developed by our team in their coupled modeling systems. The resulting collection of compliant codes, called the Earth System Prediction Suite (ESPS), includes national modeling systems that are relied on for critical functions such as weather forecasting, military operations, and climate projections. Our software enables the groups that develop these modeling systems to share infrastructure code and exchange science components, such as ocean and ice models, with each other. This encourages the exchange of knowledge, reduces redundant software development, and makes new science options available to modelers. We documented this achievement in a paper in the *Bulletin of the American Meteorological Society* (BAMS), entitled "The Earth System Prediction Suite: Toward a Coordinated U.S. Modeling Capability" (Theurich et al.). It will be out in August 2016.

The BAMS paper also describes the NESII infrastructure on which the ESPS is based. A core capability is the Earth System Modeling Framework (ESMF), which includes tools for building and connecting models. U.S. operational centers created a separate interface to this ESMF software, called the National Unified Operational Prediction Capability Layer (NUOPC Layer). It provides additional tools such as compliance checking. The NESII

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Table 1. ESPS COUPLED MODELING SYSTEMS						
	NEMS	COAMPS	NavGEM	GEOS-5	ModelE	CESM
Model Driver	●	●	●	●	●	●
ATMOSPHERE MODELS						
GSM	●					
NMMB	●					
CAM						●
FIM	●					
GEOS-5 Atmosphere				●		
ModelE Atmosphere					●	
COAMPS Atmosphere		●				
NavGEM			●			
NEPTUNE			●			
OCEAN MODELS						
MOM5	●			●		
HYCOM	●		●		●	●
NCOM		●				
POP						●
POM	●					
SEA ICE MODELS						
CICE	●		●	●	●	●
KISS	●					
OCEAN WAVE MODELS						
WW3	●	●		●		●
SWAN		●				
LEGEND						
●	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)
 - POP:** Parallel Ocean Program model
 - SWAN:** Simulating Waves Nearshore
 - WW3:** WaveWatch III

team released updated versions of both packages this year, as ESMF/NUOPC v7.0.

One of the codes in the ESPS is the new NOAA Environmental Modeling System, or NEMS. NEMS is designed to be a unified modeling system that spans time scales from weather to seasonal prediction. It will replace the models in the current operational National Weather Service (NWS) suite. This year, the NESII team worked with the NWS Environmental Modeling Center and other collaborators to deliver milestones for a three-way (atmosphere, ocean, ice) coupled seasonal prediction system, an atmosphere-ionsphere space weather prediction system, and a five-way coupled system that includes separate components for land surface and water predictions (atmosphere, ocean, ice, land, hydrology). Similar projects to couple separate land and water components to atmosphere-ocean-ice models are underway as NESII collaborations with the Navy and NASA.

In addition to developing modeling infrastructure and the ESPS, the NESII team also delivered infrastructure in support of the Coupled Model Intercomparison Project 6 (CMIP6), an international effort that is the basis for climate assessments like the Intergovernmental Panel on Climate Change (IPCC). The CoG collaboration environment, developed by NESII, is becoming the user interface for downloading all of the climate data generated in this project (and the preceding CMIP5). It is part of a federated data distribution environment managed by the Earth System Grid Federation, an international consortium. The main CoG installation is at CU, but there are separate CoG installations in France, Sweden, the U.K, U.S. federal labs, and other countries. From a single CoG installation you can see projects and download data from all other federated CoG installations.

Major U.S. weather and climate codes currently included in the Earth System Prediction Suite (ESPS). ESPS high performance coupled models and components are compliant with Earth System Modeling Framework (ESMF) and National Unified Operational Prediction Capability (NUOPC) conventions. These conventions enable the science components—atmosphere, ocean, sea ice, and wave models—to run easily in multiple coupled systems. The columns in the table show the science components and options in each coupled prediction system, and the rows in the table shows the extent to which different agencies are able to share the same science components.

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Publications

CIRES scientists and faculty published at least 718 peer-reviewed papers during calendar year 2015. Below, we tabulate publications by first author affiliation, per NOAA request. CIRES scientists and faculty published additional non-refereed publications in 2015, 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 last year may be responsible for the jump between 2013 and 2014. 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

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
CIRES Lead Author	188	141	130	110	158	137	238	186	189	141	158
NOAA Lead Author	20	81	73	99	79	63	41	30	44	65	64
Other Lead Author	145	289	264	385	342	312	293	312	370	490	496
Total	353	511	467	594	579	512	572	528	603	696	718

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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
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

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Active NOAA Awards (June 1, 2015, to May 31, 2016)

Please note that data shown in the table below are preliminary; the University of Colorado switched to a new accounting system in 2015, which has delayed the usual close of the fiscal year. We will provide final data when available.

Record number	Description	Start date	End Date	Amount in \$
NA15OAR4590160	Validation and Improvement of Microphysical Parameterizations for Better Orographic Precipitation Forecasts	9/1/15	8/31/17	\$249,702
OCG6128B	Intergovernmental Personnel Act Agreement	6/1/14	5/31/15	\$178,668
NA15NWS4680009	Integrating Unified Gravity Wave Physics into the Next Generation Global Prediction System	5/1/15	4/30/17	\$235,596
NA15OAR4310144	Western Water Assessment: Building Climate Resilience by Design	9/1/15	8/31/16	\$698,426
NA15OAR4310103	Modeling and Data Infrastructure in Support of NOAA's Global Models	8/1/15	7/31/16	\$839,951
NA14OAR4310140	Basin-wide Top-down Estimates for CH ₄ Emissions from Oil and Gas Extraction using Aircraft Observations	8/1/14	7/31/17	\$73,462
NA14OAR4310142	Ground-based Measurements to Study Fossil Fuels Production Operations Emissions of Methane and Non-methane Hydrocarbons and their Atmospheric Impacts	8/1/14	7/31/17	\$186,876
NA15OAR4310103	Modeling and Data Infrastructure in Support of NOAA's Global Models	8/1/16	7/31/17	\$839,954
NA15OAR4310171	Snow-Atmosphere-Ice Interactions to Advance Sea Ice Predictability	8/1/15	7/31/18	\$287,254
NA15OAR4310171	Snow-Atmosphere-Ice Interactions to Advance Sea Ice Predictability	8/1/15	7/31/18	\$262,108

Personnel Demographics

CIRES Personnel Breakdown 2015–2016¹

	Total Count of CIRES employees	≥50% NOAA ²	Highest Degree Earned for those ≥50% NOAA ²			
			BS	MS	PhD	No Degree listed
Faculty	20	1	0	0	1	0
Research Scientist	257	152	0	0	152	0
Visiting Scientist	15	0				
Postdoctoral Researcher	29	9	0	0	9	0
Associate Scientist	264	179	84	75	20	0
Administrative	34	28	18	5	2	3
TOTAL	619	369	102	80	184	3
Hourly/Undergr	97	41	1	1	0	0
Grad Students	113	8				
GRAND TOTAL	829	418	103	81	184	

CIRES personnel in NOAA Boulder Laboratories receiving any funding from NOAA CA

ESRL DIR	10
CSD	79
GMD	59
GSD	53
PSD	91
TOTAL OAR	292
NCEI (NESDIS)	61
SWPC	25
NWS	2
GRAND TOTAL	380

During the period June 2015 to May 2016, six CIRES employees obtained federal employment with NOAA groups in Boulder.

¹Counted April 29, 2016

²CIRES personnel receiving 50% of more of their pay from our NOAA Cooperative Agreement (CA)

