2018 Annual Report

COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

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Contents

From the Director

CIRES is now in its fifties, and judging by this year's accomplishments, we are aging quite well. We had another outstanding year of scientific advances, support of the NOAA mission, service to the scientific community, and service to society.

I want to extend my deepest appreciation to every member of our team, from our scientists, engineers, and developers to our staff and students, who continue to make CIRES the great success that it is and an organization of which we can all be very proud. The last year continued CIRES' half-century run of great achievement and service, whether we measure by funding, publications, scientific impact, societal benefit, media attention, or other means.

The core of our effort is in support of NOAA—and our very successful review and recent five-year renewal indicate that we continue to serve that function well. Moreover, we have continued to leverage NOAA's investments in CIRES into a very robust environmental research enterprise. With more than 700 peer-reviewed journal articles published in 2017, and the fact that CIRES is home to 5 of CU Boulder's 10 highly cited researchers (Clarivate Analytics), CIRES continues to be instrumental in the ranking of CU Boulder as the #1 public university in the world in Geosciences (*U.S. News*).

The 2017 addition of Earth Lab, an initiative led by Assistant Professor of Geography Dr. Jennifer Balch to capitalize on the data deluge from space and other platforms, helped strengthen CIRES' capabilities in understanding and predicting Earth system change. I am pleased to say that Earth Lab is emerging as a powerful force in harnessing the power of big data to understand our changing world, reduce environmental risk, and train next generation Earth scientists. As part of the university's "Grand Challenge" investment, Earth Lab has hit the ground running, submitting 17 proposals in FY18, and successfully competed to serve as the U.S. Geological Survey's North Central Climate Science Center. This major achievement, which brings in $4.5 million in support from the USGS through 2023, provides another connection to a federal agency, nicely complementing our relationship with NOAA and furthering our ability not just to conduct world-class research, but to provide usable information to sponsors, stakeholders, and decision makers.

Many of our faculty and other scientists have established themselves as national and international leaders in their fields, which is a major reason we help make CU Boulder such a strong force in the geosciences. And with nearly 200 students in CIRES and dozens of postdocs and early career scientists, our leadership role in the geosciences will continue well into the future. Our newest faculty hire, Assistant Professor of Environmental Studies and CIRES Fellow Dr. Matt Burgess, brings new capabilities to CIRES: expertise in environmental economics, promising to make our environmental research portfolio even more robust with critical understanding of economic underpinnings and consequences of environmental decisions.

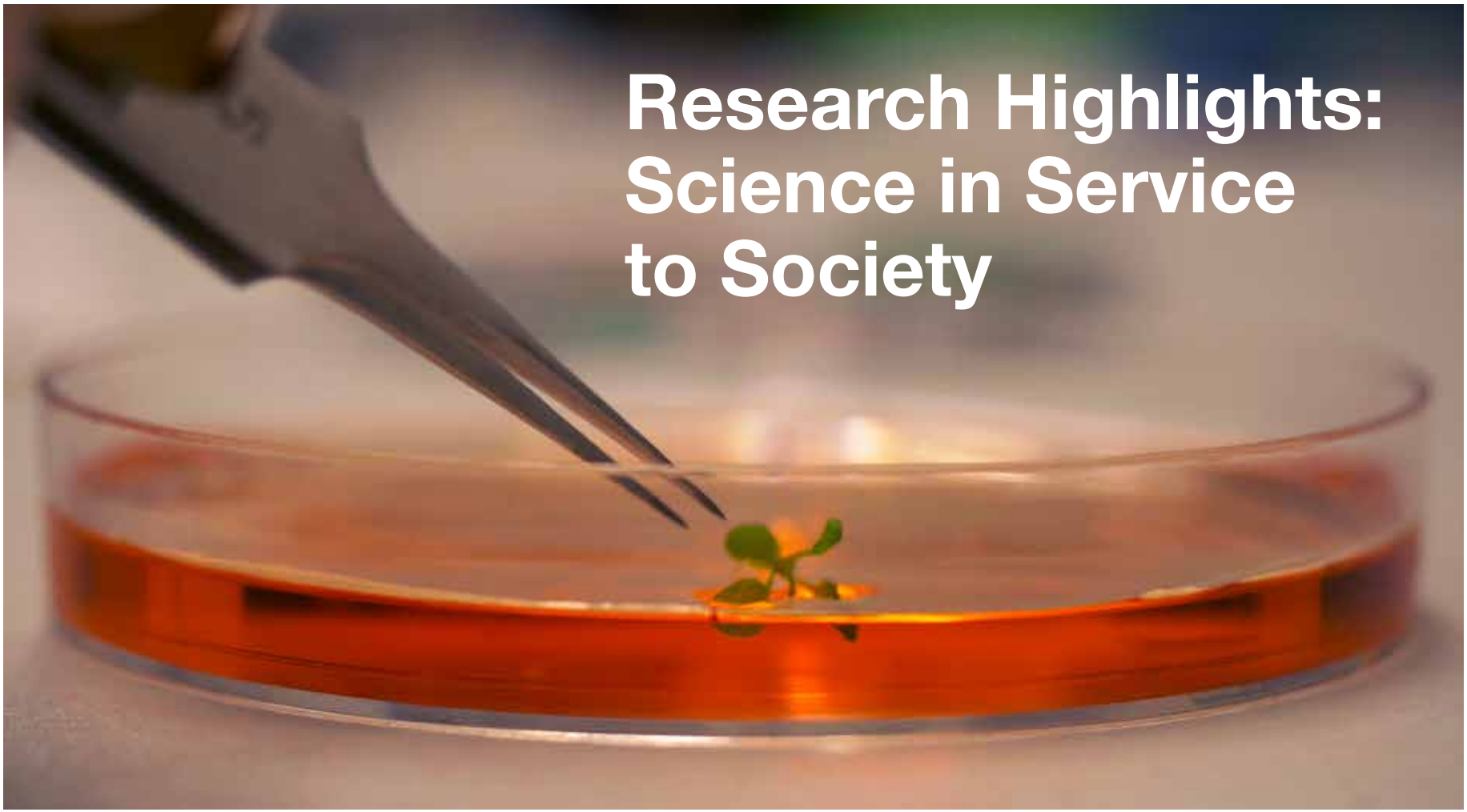
This past year, we have also increased our investment in diversity and inclusion. Dr. Susan Sullivan is working to increase our exposure to underrepresented groups and provide awareness and sensitivity workshops for our personnel. As Director of Diversity and Inclusion, she supports search efforts to attract diverse pools of candidates, and serves as a critical liaison to broader university and campus efforts. Dr. Sullivan's efforts are helping turn CIRES' strong commitment to diversity into meaningful outcomes.

By numbers, CIRES is very strong. In addition to our numbers of publications and highly cited researchers, we had nearly $93 million in expenditures last year. Our funding came from diverse sources and supported an 875-person research enterprise. In FY18, CIRES scientists brought in about one-sixth of the university's research funding.

But ultimately, CIRES is about much more than the numbers. CIRES is about understanding the world in which we live in ways that improve our lives and livelihoods at the individual level; at local, state, and regional levels; at the national level; and at the global level. We make the world a better place, as we seek to better understand and improve our relationship with our environment.

Waleed Abdalati
CIRES Director

Photo: Glenn Asakawa/CU Boulder



Research Highlights: Science in Service to Society

***Arabidopsis thaliana* floats in a petri dish.** Photo: Luiza Parvu/CIRES

The Cooperative Institute for Research in Environmental Sciences 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 innovating new ways to better forecast severe weather events that threaten lives and property and conducting climate research useful to decision makers, from local to international levels. Since its inception as one of NOAA'S first cooperative institutes 50 years ago, CIRES has been helping NOAA achieve strategic goals by hiring and supporting some of the best and brightest Earth scientists and leveraging NOAA investments with partnerships and funding from other institutions around the world. Here we highlight a few of the past year's activities and successes as they align with NOAA's Next Generation Strategic Plan.

WEATHER-READY NATION GOAL

- CIRES researchers in NOAA's National Weather Service are working to **improve the agency's abilities to forecast extreme rainfall and other high-impact events** that threaten lives and property. For example, CIRES staff support critical weather forecasting experiments (e.g., Winter Weather Experiment and Flash Flood and Intense Rainfall Experiment) with objective verification, increasing efficiency, and standardization. And CIRES staff have designed new methods to visualize weather predictions, to help forecasters quickly identify when a rainfall event has the potential to become extreme. (NWS-01/NWS-02; page 102)
- CIRES and NOAA scientists led a groundbreaking study that revealed that **VOCs from household and industrial products now rival motor vehicle-related emissions as the top source of urban air pollution.** Their continued efforts are helping form a big picture of the evolution of air quality, informing decision makers about the likely effectiveness of emissions control efforts in a changing world. (CSD-04; page 67)
- CIRES researchers work to **better understand and predict extreme climate and weather events,** which can profoundly affect society and the environment. This year, the team investigated the drivers of record Arctic warmth in 2016 (human-induced climate change could explain about 60 percent of the warmth), anthropogenic contributions to U.S. drought (significant, through a long-term increase in evapotranspiration over precipitation), and has begun to work on extreme rainfall in Colorado's Front Range and decadal droughts resulting in low Colorado River flow. (PSD-24; page 77)
- **A whole atmosphere model (WAM),** which extends the top boundary of the National Weather Service's Global Forecast System model from 60 km to 600 km, has been semi-operational since October 2017, capturing real-time changes in tropospheric weather, tropical convection, sudden stratospheric warming, and other tropospheric weather features. CIRES researchers continue to improve the model, supporting the prediction of space weather conditions that impact life, property, national security, and economic vitality. (SWPC-03; page 102)
- CIRES staff are part of a NOAA team that **verifies and evaluates forecast systems related to aviation safety,** such as icing, turbulence, and convection forecasts. CIRES scientists have completed assessments of an icing product for the Federal Aviation Administration in Alaska; have begun evaluation of the Ceiling and Visibility analysis products for helicopter emergency medical services; and evaluated the performance of various turbulence and convection forecasts, identifying the best models for specific areas and situations. (GSD-06; page 114)

Sea ice at the fall freeze up near the North Pole, August 2008. Photo: Matthew Shupe/CIRES

CLIMATE ADAPTATION AND MITIGATION GOAL

- As part of the Fire Influence on Regional to Global Environments Experiment and Air Quality (FIREX-AQ) campaign, CIRES scientists led **extensive measurements of wildfire fuel emissions** during experiments at the Fire Science Laboratory in Missoula, Montana. Those measurements have improved our understanding of smoke composition and the processes governing the variability of the emission; results will help guide upcoming field work to study biomass burning emissions and their impact on climate, air quality, and ultimately, human health. (CSD-04; page 67)
- A CIRES scientist in NOAA's Chemical Sciences Division chairs the internationally recognized **Tropospheric Ozone Assessment Report,** a global effort involving 230 scientists from more than 30 nations. The TOAR Surface Ozone Database was made public in August 2017, providing researchers around the world with comprehensive ozone data and metrics to conduct research. Scientists have drawn on the database to publish seminal assessments of ozone's global distribution and trends using metrics relevant to ozone's impact on human health, crops, forests, and climate. (CSD-03; page 66)
- The Montreal Protocol committed the global community to phase out use of ozone-depleting chlorofluorocarbons (CFCs). CIRES researchers were part of a NOAA-led team that **found the second-most abundant CFC, CFC-11, increasing—most likely from new, unreported production from an unidentified source in East Asia.** The research earned publication in *Nature* and widespread international attention. Followup investigations uncovered evidence that Chinese companies were using the chemical for building insulation; the United Nations Ozone Secretary said the discovery demands "decisive action." (GMD-05; page 108)
- The World Data Service for Paleoclimatology archives a wide variety of **paleoclimate data** that enable

NOAA's Ann Reiser operates Science On a Sphere® during the 2017 Girls and Science event in Denver, an effort to teach young girls and their families about earth sciences and being a scientist. Photo: Christina Bonfanti/ CIRES

understanding of climate change over decades, centuries, and millennia. CIRES staff completed a **multi-year project to enhance search capabilities on these data,** resulting in a comprehensive thesaurus of more than 2,800 terms and definitions. This improved search capacity significantly increases accessibility of NOAA data, and team members working on this project received the NESDIS Outstanding Information Technology and Engineering Employee Awards of 2018. (NCEI-11; page 88)

- CIRES researchers continue to produce **calibrated measurements of long-lived, anthropogenically influenced greenhouse gases.** These observations are the basis for various NOAA products, model and satellite data evaluation, and estimates of regional and global emissions and sinks, including impacts from El Niño events. This year, they released a complete upgrade of the World Meteorological Organization Central Calibration Laboratory analytical instrumentation for carbon dioxide and methane standard gas calibrations. (GMD-04; page 73)

ENGAGEMENT ENTERPRISE

- Around 3,000 users (from researchers to rig and ship operators) download the **National Snow and Ice Data Center's Sea Ice Index data** each month, making it the world's trusted source of Arctic sea ice information. This year, CIRES staff released an improved Version 3.0. and updated Sea Ice Index animations in NSIDC's Google Earth-compatible collection. (NSIDC-01; page 99)
- CIRES staff helped complete **updates to the Meteorological Assimilation Data Ingest System (MADIS),** which uses up-to-date observations to improve high-impact weather forecasts. This year, the MADIS team has continued to leverage partnerships with international agencies, federal, state, and local agencies, universities, volunteer networks, and the private sector (e.g., airlines and railroads), providing NOAA with an additional 66 million quality-controlled observations a day. (GSD-01; page 111)
- **Forecasting a Continuum of Environmental Threats (FACETS) high-resolution software** promises to help weather forecasters improve understanding of environmental threats like tornadoes, hail, and extreme rainfall—saving lives and property. CIRES staff have been developing FACETS for several years and will continue refining and improving the process in upcoming years. Transition plans for moving the new capabilities to operations are being developed. (GSD-09; page 116)
- CIRES staff support the **NOAA Science On a Sphere® (SOS) and SOS Explorer™ (SOSx) programs,** which allow users to view dynamic, animated images of the atmosphere, oceans, and solar system. This year, the team installed 12 new SOS systems in the United States, India, Australia, Denmark, and China; and improved SOSx to enhance virtual reality functionality, 360-degree picture and video support, a Tour Builder application, and more. (GSD-02; page 99)

SCIENCE AND TECHNOLOGY ENTERPRISE

- CIRES geomagnetism team members developed the **High Definition Geomagnetic Model and its real-time add-on,** which relies on real-time Deep Space Climate Observatory and magnetic observatory data to provide critical information to oil and gas industry partners, increasing the safety and efficiency of directional drilling and other applications. The team continued expanding its citizen science program CrowdMag, which uses a smartphone app to collect data about Earth's magnetic field—there are now more than 25,000 users. (NCEI-03; page 82)
- CIRES researchers provided experimental, daily, 10-day **sea ice forecasts of Arctic weather and sea-ice evolution** to stakeholders for the 2017 freeze-up season and began providing daily forecasts in April 2018. The team extended the forecasting domain of the Coupled Arctic Forecast System to include the Bering Strait, to provide additional guidance to the National Weather Service, and to include the Fram Strait, which lies in the domain of the planned Multidisciplinary Drifting Observatory for the Study of Arctic Climate campaign (MOSAiC). (PSD-21; page 95)
- CIRES scientists released to the public **the first space weather data from NOAA's GOES-16 satellite,** including a set of spectacular solar images from a period of intense flaring in September 2017. The CIRES team also developed an algorithm that intelligently finds and flags data from relatively infrequent solar events, to better meet the intense, sometimes real-time demand for such data. (NCEI-05; page 84)
- CIRES staff are working closely with the National Weather Service to provide the research and development necessary to advance the **next generation global predication system (NGGPS)** and to have the model ready for operation in 2019. NGGPS should enhance the accuracy of Earth system models, providing more reliable forecast products that address growing service demands, and increasing the accuracy of weather forecasts out to 30 days. (PSD-26; page 79)

This is CIRES

Pilots get a lift in a golf cart after a successful research flight in Guam, October 2016. As part of the POSIDON mission, CIRES scientists and colleagues were studying ozone distribution, sulfur chemistry, cloud microphysics, and more high above the western Pacific Ocean. Photo: Emrys Hall/CIRES

MISSION: 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.

The Cooperative Institute for Research in Environmental Sciences (CIRES) has been facilitating collaboration between the University of Colorado Boulder and the National Oceanic and Atmospheric Administration (NOAA) since its establishment in 1967. Our purpose is to support NOAA's mission by furthering research that crosscuts traditional scientific fields. By bringing scientists from CU Boulder departments and NOAA groups together into a network of divisions, centers, and programs, CIRES researchers can explore all aspects of the Earth system. These partnerships encourage innovation, rapid-response capabilities, and an interdisciplinary approach to complex environmental challenges. The work of CIRES helps strengthen the scientific foundation upon which NOAA's environmental intelligence services depend, and allows coordinated studies on a scale that could not be undertaken 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
- Economics
- Environmental Studies Program
- Geography
- Geological Sciences
- Molecular, Cellular, and Developmental Biology

NOAA EARTH SYSTEM RESEARCH LABORATORY (ESRL)

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

NOAA CENTERS

- NESDIS / National Centers for Environmental Information
- NWS / Space Weather Prediction Center
- NWS / Weather Prediction Center

CIRES Structure

CIRES research is organized into six divisions, each guided by Fellows; every CIRES scientist falls into one division. Our centers and core programs foster cross-fertilization of ideas and enable rapid response to emerging challenges. Institutional programs serve all of CIRES.

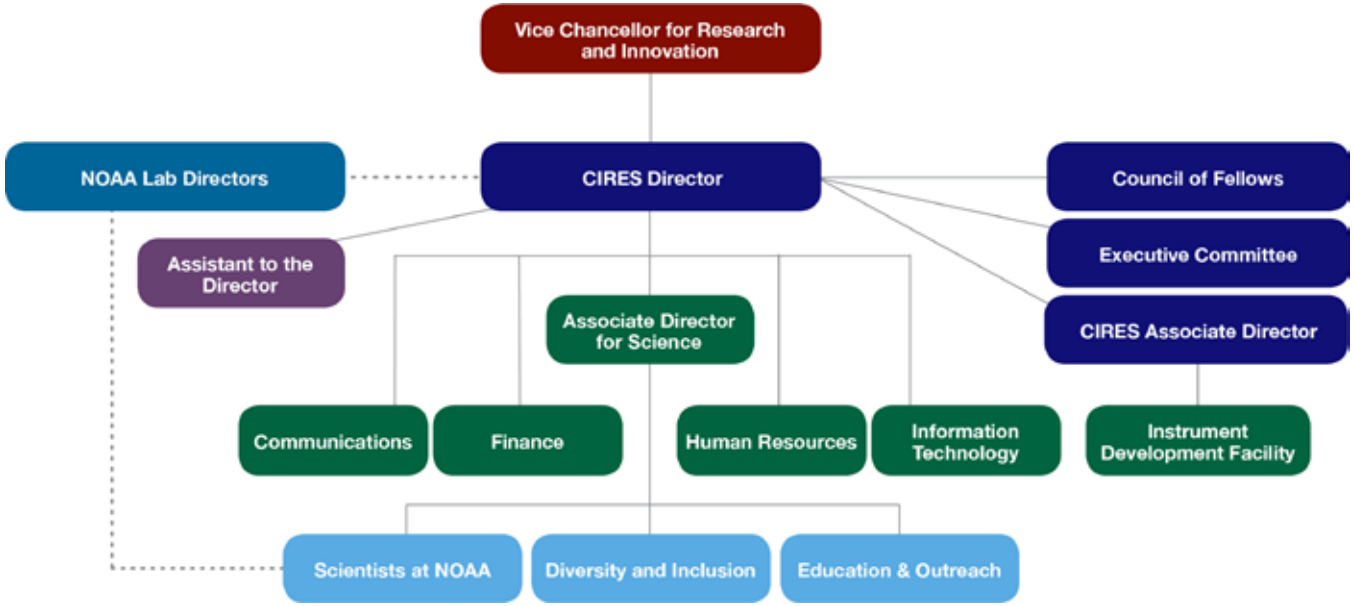
CIRES DIVISIONS

CIRES CENTERS

CIRES CORE PROGRAMS

OTHER INSTITUTIONAL PROGRAMS AND TEAMS

The Council of Fellows and the Executive Committee, with input from a senior leadership team, help the Director govern and manage CIRES. The CIRES centers, programs, and individual scientists connect NOAA to 10 university departments. Coordination among all these entities is facilitated through the CIRES administration. During the University of Colorado Boulder's FY18, the CIRES Director was Waleed Abdalati.



THE CIRES TEAM, FY2018

FACULTY	21
RESEARCH SCIENTISTS	257
ASSOCIATE SCIENTISTS	313
VISITING SCIENTISTS	10
POSTDOCTORAL RESEARCHERS	27
ADMINISTRATIVE STAFF	34
GRADUATE STUDENTS	122
UNDERGRADUATE STUDENTS	93
TOTAL	877

Governance

COUNCIL OF FELLOWS

The Council of Fellows constitutes the "Board of Directors" and chief governing body of CIRES. Fellows are selected because of their outstanding achievements and abilities in diverse areas of environmental sciences. These university faculty, senior research scientists, and government scientists and Fellows form the core of our institute. Members of the Council of Fellows:

- provide leadership at all levels in environmental science,
- maintain an active scientific research and education program,
- support the CIRES infrastructure through indirect cost recovery and in-kind contributions,
- participate in CIRES management, and
- contribute interdisciplinary expertise and participate in collaborative work.

Fellows personify the spirit of collaboration that is the founding principle of the NOAA Cooperative Institutes program. Ex-officio individuals include representatives of the Members' Council and CIRES administration. Fellows meetings are held monthly during the academic year. During this reporting period, the Council of Fellows met: September 21, October 19, November 16, and December 7 in 2017; January 18, February 22, March 22, and April 19 in 2018.

More details about the 40 members of the Council of Fellows begin on page 12.

EXECUTIVE COMMITTEE

The Executive Committee assists and advises the director in matters regarding day-to-day management of the institute. Members of the Executive Committee include the associate directors for each of CIRES' six divisions, four Fellows elected at large for two-year terms (renewable for one term), and two Members' Council representatives. The associate director for administration, associate director for science, and the director's executive assistant are ex-officio members.

CAREER TRACK COMMITTEE

This committee is charged with consideration of all nominations for promotion within the three CIRES career tracks: Research Scientist, Associate Scientist, and Administrative Associate. Nominations are made once yearly, and the committee's recommendations are forwarded to the Director for consideration and action.

FELLOWS APPOINTMENT COMMITTEE

Fellows of CIRES are selected by two-thirds vote of the Council of Fellows and are appointed or reappointed by the director of CIRES with the concurrence of the Vice Chancellor for Research and Innovation. The initial appointment of any new CIRES Fellow is for two years, and continuing-term reappointments are for five years. Qualifications for reappointment are the same as for the initial appointment, except that the established record of the appointee must show evidence of commitment to the affairs of CIRES.

DIVERSITY COMMITTEE

CIRES is committed to enhancing diversity by extending its community and knowledge across the full spectrum of cultures and backgrounds. The Diversity Committee and Diversity and Inclusion Director work with CIRES administration, scientists, and other staff to identify programs, mentorships, and other opportunities for CIRES to foster diversity and inclusion to enrich our professional community (page 45 highlights some diversity projects).

MEMBERS' COUNCIL

CIRES 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. 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, 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 Rendezvous science symposium, convening a committee to select CIRES Outstanding Performance Award recipients, and running the CIRES Bike Share program.

SPECIAL COMMITTEES

Additional special committees are appointed as needed by the Director. These may include faculty search committees, award committees, faculty promotion committees, and others created and disbanded to respond to needs. For example, CIRES committees select finalists for the following programs:

CIRES researcher Carolina Siso and NOAA scientist Steve Montzka at work in a NOAA Global Monitoring Division measurement laboratory.
Photo: David Oonk/CIRES

Finance

During the university fiscal year of July 1, 2017, to June 30, 2018, CIRES had total expenditures of nearly $93 million, including the university portion (graph 1).

CIRES researchers enjoy enviable success in obtaining external research awards, which comprise about 36 percent of total expenditures. Graph 2 breaks down our contracts and grant funding by main sources.

Graph 3 provides an overall look at our Cooperative Agreement funding, by task. Task I funds (further described in graph 4) support the 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.

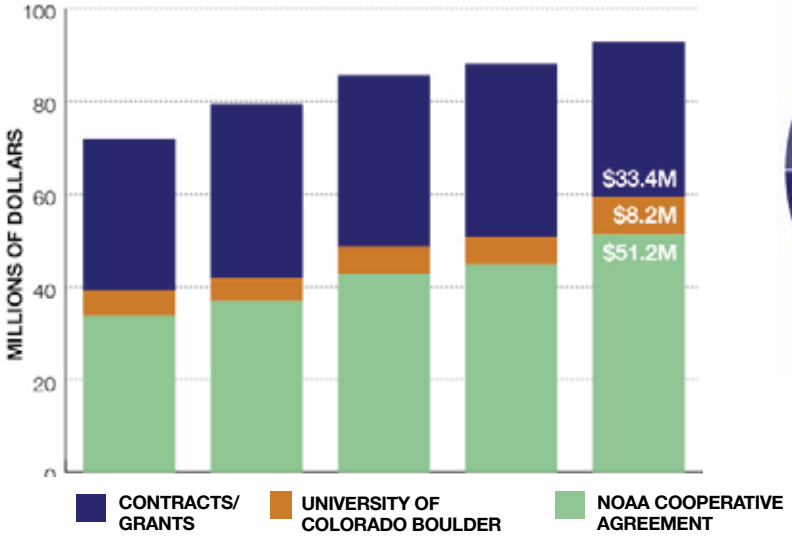
NOAA COOPERATIVE AGREEMENTS

	start date	end date
NA12OAR4320137 CIRES Five-Year Cooperative Agreement	**9/1/2012**	**8/31/2017***
NA15OAR4320137 CIRES Five-Year Cooperative Agreement	**9/1/2015**	**8/31/2017***
NA17OAR4320101 CIRES Five-Year Cooperative Agreement (new award number)	**9/1/2017**	**8/31/2022**

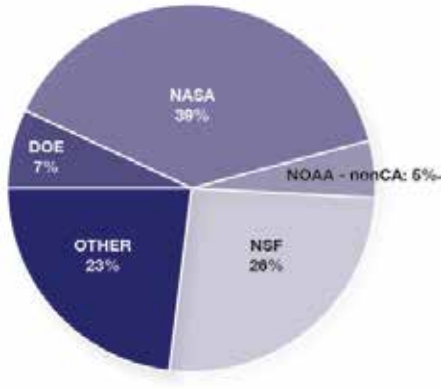
***No-cost extension requests under review**

***Please see page 151 for other active NOAA awards. Other agency awards are represented in graph 2 above; they are too numerous to list in full here.**

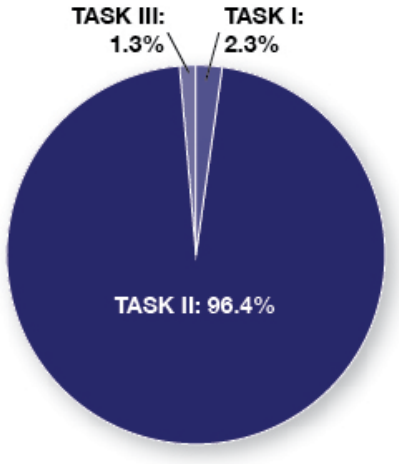
1. CIRES EXPENDITURES BY FUNDING SOURCE FY14-FY18



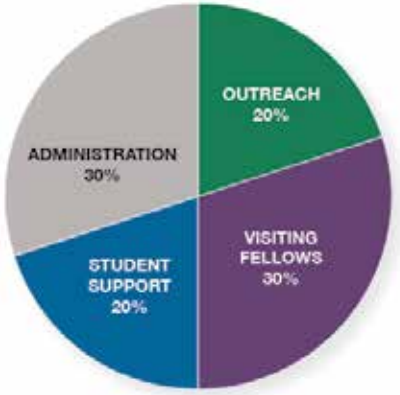
2. CONTRACT/GRANTS BY SOURCE, FY18



3. COOPERATIVE AGREEMENT EXPENDITURES BY TASK, FY18



4. BREAKDOWN OF TASK I EXPENDITURES, FY18



People & Programs

CIRES and NOAA scientists join the country in looking upwards during the August 2017 solar eclipse. Photo: Christina Bonfanti/CIRES

CIRES starts with people.

Cleaning frost from meteorological instruments on a 10-meter tower in Greenland. Photo: Sonja Wolter/CIRES

In this section, we highlight the diverse environmental science work being done at CIRES, beginning with **CIRES Fellows**. Reports on **CIRES' four centers and several programs** follow (page 22).

We also report on our prestigious **Visiting Fellowships** (page 51); pioneering research funded by CIRES' **Innovative Research Program** (page 49); and graduate and undergraduate programs including fellowship and diversity programs (page 46-49).

A more exhaustive description of CIRES projects for NOAA, involving hundreds of scientists and staff, can be found in **Project Reports** (page 62).

CIRES Fellows

The CIRES 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 form the core of our institute.

NOAA SCIENTISTS

Stan Benjamin
Christopher Fairall
Graham Feingold
Stephen Montzka

CIRES RESEARCH SCIENTISTS

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

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 FELLOWS

Waleed Abdalati

CIRES Director,
Professor of Geography

My research interests are in the use of satellite and airborne remote sensing techniques, integrated with in situ observations and modeling, to understand how and why the Earth's ice cover is changing, and what those changes mean for life on Earth. In particular, my research focuses on the contributions of ice sheets and high-latitude glaciers to sea level rise and their relationship to the changing climate. Toward that end, I have been heavily involved in the development of NASA's Ice Cloud and land Elevation Satellite (ICESat) and its successor, ICESat-II, and I have worked on cryospheric applications of various other satellites and aircraft instruments. Most of my research is supported by NASA, where I worked as a scientist for 12 years, before joining CIRES. From 2015-2018, I co-chaired the National Academies' Decadal Survey for Earth Science and Applications from Space. Our final report, *Thriving on Our Changing Planet*, sets priorities for NASA, NOAA, and USGS research in the next decade.

A glacial erratic. Photo: Michael Rhodes/CIRES

Richard Armstrong

Adjunct Associate
Professor of Geography

In general my interests cover a wide range of snow and glacier topics, from snow metamorphism to avalanches—and glacier mass balance, glacier area, and mass change in response to a warming climate. Methodologies include both in-situ and satellite data. My current focus is on determining how much river discharge originates as melting seasonal snow and how much as melting glacier ice across High Asia: the CHARIS project. 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.

Roger Bilham

Professor Emeritus of
Geological Sciences

I am a research scientist in CIRES with interests in earthquake, landslide, and volcano processes and their impact on society. I use various terrestrial and remote sensing geodetic methods to capture the deformation of the Earth's crust, and engineering and historical investigative methods to quantify the damage they produce now, and have produced in the past several thousands of years. My current research includes four areas: quantifying limits to the storage of strain energy in the Himalaya; investigation of fault creep in Anatolia and California; global seismic hazards and the influence of corruption in the building industry; and tectonics of Colombia and the Caribbean.

Stanley G. Benjamin

Senior Scientist for Advanced
Modeling Systems,
NOAA Global Systems Division

I am a senior scientist for advanced modeling systems at NOAA's Global Systems Division in Boulder, Colorado. My interests lie in data assimilation, including for clouds, radar and boundary layer, and global subseasonal coupled (atmospheric-ocean-aerosol) modeling and forecasting. Our group in GSD works closely with the National Weather Service on improving NOAA's operational models. We focus on improved frequently updated convection-allowing modeling for severe weather, aviation/transportation, hydrology, and energy applications. We also work on improving model representations of the boundary layer, land surface, and stable and convective clouds including aerosol interaction.

Maxwell Boykoff

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

I am a CIRES Fellow, an Associate Professor in Environmental Studies with a courtesy appointment in Geography, and Director of the Center for Science and Technology Policy Research (CSTPR). I am also a Deputy Editor at the journal *Climatic Change* and a Senior Fellow at the University of Oxford Environmental Change Institute. My research and creative work focus on cultural politics and environmental governance, creative climate communications, science-policy interactions, and climate adaptation. Through connected projects and collaborations, I examine how climate science and policy find meaning in people's everyday lives, and how this, in turn, feeds back into science and policy decision-making.

CIRES FELLOWS

Eleanor C. Browne

Assistant Professor of Chemistry and Biochemistry

My group is primarily interested in developing instrumentation for measuring gases and aerosols in the atmosphere and in using this instrumentation to investigate how atmospheric processing affects the chemical composition of gases and aerosols. The group is specifically interested in organonitrogen and organosilicon compounds and investigates the fate of these compounds using laboratory and field measurements. My current work focuses on understanding the role of organonitrogen in new particle formation and growth, and in nitrogen deposition. The organosilicon work focuses on constraining the fate of organosilicon compounds that are found in personal care products and preferentially partition to the atmosphere.

Ceratocephala testiculata. Photo: Adam Mahood/CIRES

John Cassano

Associate Professor of Atmospheric and Oceanic Sciences

My research group studies the weather and climate of the polar regions to better understand the processes that link the atmosphere to the underlying ocean, sea ice, ice sheet, and land surfaces. We use in-situ autonomous observations from automatic weather stations and unmanned aerial vehicles, satellite and reanalysis data, and numerical weather prediction and climate models in our research. We are synthesizing our understanding of polar climate processes through the development of a Regional Arctic System Model, which provides a framework for exploring linkages between the components of the polar climate system.

Shelley Copley

Professor of Molecular, Cellular and Developmental Biology

My lab studies evolution of bacteria in novel environments, and in particular the evolutionary potential lurking in the proteome due to inefficient side activities of enzymes that normally serve other functions. Current work focuses on determining how such "promiscuous" activities have been patched together into a pathway for degradation of pentachlorophenol, a toxic anthropogenic pollutant, and how the bacterium manages to survive the toxicity caused by pentachlorophenol and its degradation products. Other projects address how bacteria can adapt to deletion of an essential gene and the process by which new enzymes arise from promiscuous enzymes by a process of gene duplication and divergence.

Xinzhao Chu

Professor of Aerospace Engineering Sciences

My research goal is to explore unknowns in the atmosphere, space, and beyond. My group works to explore advanced spectroscopy principles and develop new lidar technologies to push detection limits and make new discoveries. By making measurements with unprecedented accuracy, resolution, and coverage, we study the fundamental physical and chemical processes that govern the structures and dynamics of the whole atmosphere, and advance the understanding of the universal processes in the Earth's space-atmosphere interaction region and how they shape the atmospheres of Earth-like planets. 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.

Joost de Gouw

CIRES Senior Research Scientist, Adjoint Professor of Chemistry and Biochemistry

I am a senior research scientist with the Cooperative Institute for Research in Environmental Sciences. My main interests are the sources and chemical transformations of organic compounds in the atmosphere; the formation of ozone and secondary organic aerosol; and the impact that these processes have on air quality, climate change, and human health. To study these issues, I use measurements of organic compounds by mass spectrometry and gas chromatography. I am also interested in the environmental effects of energy production and use at present and in the future.

CIRES FELLOWS

Lisa Dilling

Director, Western Water Assessment,
Associate Professor of Environmental Studies

My research focuses on understanding how society chooses to respond to environmental risks such as climate change. I use interdisciplinary, empirical methods to study questions such as how different views about the nature of risk affect the outcomes of decision processes. I am also interested in the tradeoffs involved in implementing new policies at the local scale and understanding how science can best support robust decision making in deeply uncertain contexts. My work has recently focused on drought and urban water management, climate change and public lands, geoengineering, and municipal policies regarding natural hazards.

Chris Fairall

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

I am a physicist at NOAA's Earth System Research Laboratory in Boulder, Colorado, where I head the Boundary-Layer Observations and Processes team. I have spent decades developing and deploying air-sea interaction observing systems for NOAA ships and aircraft and have participated in nearly 50 research field programs and cruises from the Tropics to the Arctic Ice Cap. My 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.

G. Lang Farmer

Professor of Geological Sciences, Divisional Dean for Natural Sciences

My research centers on applications of trace element abundances and radiogenic isotopic data from natural materials to study the origin and evolution of Earth's lithosphere. Currently, my research group has used hafnium and neodymium isotope data from silicic sediments to investigate the paleogeography of ancient continents; used sediment isotopic data to study past instabilities in the East Antarctic Ice Sheet; investigated the origin of Mo-bearing granitic rocks in North America; and used space-time-compositions patterns in volcanic activity in western North America to assess the evolution of the deep continental lithosphere beneath this region over the past 70 million years.

Graham Feingold

Research Scientist, NOAA Chemical Sciences Division

I am a research scientist at NOAA's Chemical Sciences Division, in Boulder, Colorado. My interests lie in aerosol-cloud-precipitation interactions and implications for climate change. My group's focus is on process-level studies using high resolution models and observations (aircraft and surface remote sensing) at the cloud scale (10s of meters to 100 km). We primarily study shallow clouds and how they are modified by particulate matter (aerosol) and how they might change in a warmer climate (the cloud feedback problem).

Noah Fierer

Professor of Ecology and Evolutionary Biology*

My group works at the interface of the fields of ecology and microbiology. We study 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. Previous work has focused on those microorganisms living inside our homes, in soil, on the human body, and in the atmosphere. We explore the diversity of microbial communities, identify the fundamental controls on microbial processes, and examine the mechanisms by which microorganisms influence human health and the health of ecosystems.

***promotion effective August 2018**

Jökulsárlón, Iceland. Photo: Thomas Falkowski/CIRES

Timothy J. Fuller-Rowell

CIRES Senior Research Scientist, NOAA Space Weather Prediction Center

My group studies space weather, including the dynamics, energetics, chemistry, and electrodynamics of the thermosphere and ionosphere. When the sun is active, the impact of solar variability, such as flares or coronal mass ejections, dominates space weather. Recently we have become increasingly aware of the impact of lower-atmospheric processes on space weather: A whole spectrum of waves is continually bombarding the upper atmosphere, and they originate from tropospheric convection, absorption of radiation by ozone and water vapor, sudden stratospheric warmings, jet stream adjustment, and ocean waves. To quantify the impact of this lower-atmosphere spectrum of waves, we have been working with our NOAA partners to build a whole atmosphere model (WAM). WAM can now simulate a large part of this neutral atmosphere wave spectrum.

On its trip back from Hawaii, this flamingo became disoriented and ended up mummified at the South Pole. Photo: Michael Rhodes/CIRES

R. Michael Hardesty

CIRES Senior Research Scientist

My research interests center around development, evaluation, and application of optical remote sensing techniques to investigate atmospheric processes. We use different lidar techniques to study a broad range of phenomena, including boundary layer dynamics, space-based measurement of winds, air pollution, and greenhouse gas emissions. Results of this research improve understanding and modeling of weather and climate processes, sources of particulate and gaseous air pollution, and renewable energy production.

Craig H. Jones

Professor of Geological Sciences

My research focus is on the deformation of continents with a special interest in the western United States. The West is one of the broadest elevated areas on Earth. If you took intro geology, you might think this was because everything in the West was shortened (and so the crust thickened) from about 200 to 50 million years ago, and then this was modified as the thick crust thinned out under its own weight in places like the Basin and Range. Were this the case, there would be little to do. But it is more complex. I've spent much of my career trying to understand the Sierra Nevada, and I've written a book, *The Mountains that Remade America,* published by UC Press in 2017.

José-Luis Jiménez

Professor of Chemistry and Biochemistry

My group studies aerosols, which are small particles suspended in air with lifetimes of 1-2 weeks in the atmosphere. They have major effects on climate, human health, visibility, crops, and ecosystems. A large portion is composed of organic compounds. Important sources of these organic aerosols (OA) include anthropogenic pollution (cars, trucks), biogenic compounds (plants, soils), and biomass burning (agricultural, wildfires). Gas-phase chemistry followed by gas-to-particle conversion produces secondary OA (SOA) and inorganic species. The amount, properties, and evolution of aerosols from these sources are poorly characterized, and our group combines field, laboratory, and modeling research to better understand them. We also investigate aerosol and gaseous pollutants in indoor air (where humans spend most of their time) using similar techniques as for outdoor air. Finally, we perform instrument development when we are interested in measuring species or properties that no current instrument can measure.

Helen Lake, Sierras, California. Photo: Anne Perring/CIRES

CIRES FELLOWS

Kris Karnauskas

Associate Professor of Atmospheric and Oceanic Sciences*

My lab explores the dynamics of the coupled Earth system toward useful predictions of impacts ranging from marine ecosystems to human health. Specifically, we aim to understand the circuitry of the tropical ocean and atmosphere, its interaction with ecosystems and with higher latitude regions, how and why the climate system has changed in the past, and how climate will continue to change in the future–both naturally and as driven by human activities. Through teaching, I aim to equip students with the tools to investigate, communicate, and act intelligently on matters of global change.

Ben Livneh

Assistant Professor of Civil, Environmental, and Architectural Engineering

My research group explores the impacts of changing land-cover and climate on water resources. Specifically, we seek to quantify how the mean-state and variability of the hydrologic system are changing, to identify key processes and explore predictability. A component particularly sensitive to change in the western U.S. is snowpack, serving as a natural reservoir to store winter precipitation and release it during the warm-season when it is needed most. Active areas of research include sediment transport, land-cover disturbance, hydrologic connectivity, forecasting, and estimating components of the surface water balance from space.

Jennifer Kay

Assistant Professor of Atmospheric and Oceanic Sciences

I am an assistant professor in the Department of Atmospheric and Oceanic Sciences and a Fellow of CIRES at the University of Colorado Boulder. I remain a visiting scientist at the National Center for Atmospheric Research, where I worked prior to joining CU Boulder. My research group investigates polar climate change, feedbacks, and variability, with a specific focus on connecting global coupled climate modeling with observed cloud, precipitation, and sea ice processes. I work at the nexus of observations and modeling to understand the processes controlling climate change and variability.

Peter Molnar

Professor of Geological Sciences

I teach a little and carry out research in the Department of Geological Sciences at the University of Colorado Boulder. I was trained as a seismologist, but most of my current work addresses either geodynamics or climate. I study how mountain ranges are built and how the dynamics of flow within the mantle affects the earth's surface. I also study how manifestations of geodynamic processes, like high mountain ranges and plateaus or ocean gateways, have affected climate on geologic time scales.

William M. Lewis Jr.

CIRES Associate Director, Professor of Ecology and Evolutionary Biology

My research at the CIRES Center for Limnology focuses on three themes: biogeochemistry, food web structure, and biological productivity of inland waters. I work with students and other collaborators to conduct biogeochemical studies in aquatic environments by use of quantitative measures of conversion rates for multiple forms of nitrogen, phosphorus, and carbon that reveal the rates of metabolic processes in aquatic ecosystems. Related food web studies include quantification of interactions across trophic levels within the food web, often by use of naturally occurring isotopes of nitrogen and carbon. Analyses of this type have been applied by myself and collaborators to Colorado lakes and streams as well as tropical waters of South America. Food webs are often manipulated by humans through harvesting, stocking, pollution, or physical interventions in aquatic ecosystems. Thus, understanding of food web functions offers the possibility for reconstruction of altered food webs. Studies of biomass production parallel studies of food webs, but focus on overall energy flow across the main levels of the food web rather than the many specific pathways of nourishment as reflected by the food web. Biotic productivity varies greatly in natural environments, but also reflects human influences such as the release of nutrients to aquatic environments or suppression of productivity by physical or chemical alteration of aquatic ecosystems. Through the related fields of biogeochemistry, food web analysis, and quantification of biological production, studies of inland waters within CIRES demonstrate functions of both natural and impaired aquatic ecosystems.

***promotion effective August 2018**

Stephen A. Montzka

Research Chemist, NOAA Global Monitoring Division

My research focuses on measuring and understanding changes in the chemical composition of the global atmosphere, particularly related to ozone-depleting substances, greenhouse gases, and hazardous air pollutants; identifying the role of natural and human-related influences on hemispheric to global-scale atmospheric composition; diagnosing variability in the atmosphere's oxidizing capacity, in terrestrial photosynthesis, and in stratosphere-troposhere exchange; quantifying fluxes of trace gases from the United States; and effectively communicating scientific results via national and international assessment reports.

Evening sun penetrates clouds after a hailstorm in Switzerland. Photo: Mylène Jacquemart/CIRES

William Neff

CIRES Senior Research Scientist

My research focuses on the stable atmospheric boundary layer (ABL) where the Earth's atmosphere interacts with its surface. The stable ABL occurs when the atmosphere is coldest near the surface. Improving our understanding of the stable ABL in high latitudes and its response to changing atmospheric dynamics and surface characteristics is important as the science community seeks to better forecast variability and changes in high-latitude climate.

Balaji Rajagopalan

Professor of Civil, Environmental, and Architectural Engineering

My main research program is a diverse and interdisciplinary effort to enable sustainable water quantity and quality for the growing populations under increasing climate variability and change. This entails three interconnected themes: (1) Understanding the large-scale climate drivers of year-to-year and multidecadal variability and predictability of regional hydroclimatology and their extremes; (2) Developing ensemble hydroclimate projection tools with large-scale climate information; and (3) Coupling the projections with resources management and decision support system. In addition, I have keen interests in paleo and contemporary variability of Indian monsoon, big-data analysis and modeling techniques, water and wastewater quality, construction safety, and building energy efficiency.

R. Steven Nerem

Professor of Aerospace Engineering Sciences

My research involves using satellite-based geodetic techniques to monitor changes in the Earth's shape and gravity field. The former deals mainly with global and regional changes in sea level and vertical crustal motion. The latter deals with changes in the distribution of water and ice on the Earth's surface. My research group tries to decipher what is causing changes in these variables, including the impact of climate change. I am also interested in astrodynamics and work on developing satellite missions to measure these phenomena. I've been closely involved in the TOPEX, Jason-1, 2, 3, GRACE, and GRACE follow-on missions.

Prashant Sardeshmukh

CIRES Senior Research Scientist, NOAA Physical Sciences Division

I am a climate dynamicist with broad interests in the diagnosis, modeling, and predictability of large-scale weather and climate variations around the globe on time scales of days to centuries. Our team is engaged in documenting and understanding the regional aspects of ongoing climate changes, especially changes in extreme weather statistics, and determining to what extent they are anthropogenic or consistent with natural climate variability. We are also interested in documenting and understanding the actual as well as potential skill of weather and climate predictions, which are inherently limited due to the chaotic nature of the system, and how the current prediction systems need to be improved to achieve the potential skill.

CIRES FELLOWS

Mark Serreze

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

I am an Arctic climate scientist and Director of the CIRES National Snow and Ice Data Center. Over the past two decades, my research has focused on making sense of the profound changes unfolding in the North: shrinking sea ice, rapidly rising temperatures, and thawing permafrost, and what they mean not just for the Arctic's future but for the rest of the planet. I am also very active in science outreach and education. Today, more than ever, it is important that scientists reach out and make science more accessible and relevant to society. In 2018, my book *Brave New Arctic* came out to positive reviews, including in the *New York Times*.

Kristy Tiampo

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

My research focuses on understanding the processes that govern natural and anthropogenic hazards. These studies incorporate large quantities of remote sensing data such as space-based differential interferometric synthetic aperture radar (DInSAR), GPS data, seismicity, and gravity, in order to provide insights into the nature and scale of these hazards. Specific projects focus on improvements in the quality of those data, development of innovative analysis techniques, and assimilation into geophysical models of the underlying processes. As part of that effort we investigate the implications and consequences of hazards such as earthquakes, volcanoes, landslides, groundwater extraction, and induced seismicity on infrastructure and society.

Anne F. Sheehan

Professor of Geological Sciences

My research involves the use of geophysical methods, primarily seismology, but also including geodesy and electromagnetic methods, to understand mountain belts, subduction zones, and earthquakes. I am interested in the properties of the Earth's crust and mantle, the nature of lithospheric deformation, and the causes and consequences of induced seismicity. My group's field-based projects include broadband and short-period seismometer deployments, ocean bottom seismic and seafloor pressure gauge measurements, magnetotellurics, and geodesy.

Margaret Tolbert

Distinguished Professor of Chemistry and Biochemistry

I am a professor of Chemistry at the University of Colorado Boulder. My research group focuses on clouds and aerosols in atmospheric chemistry. Research topics include stratospheric ozone depletion, cirrus cloud chemistry, tropospheric clouds and particles, the interaction between clouds and climate, and the chemistry of planetary atmospheres including Titan and Mars. Our work is laboratory-based: we use simulation chambers to identify key atmospheric aerosol processes important in different environments. Novel laboratory techniques include aerosol optical levitation, aerosol mass spectrometry, and aerosol optical techniques such as photoacoustic and Raman spectroscopies.

Robert E. Sievers

Professor of Chemistry and Biochemistry

I study analytical chemistry, pharmaceutical science, aerosols, microparticles and nanoparticles, inhalable vaccines and antibiotics, and supercritical fluids.

For more than 40 years, my research group has conducted fundamental and applied studies of the formation of nanoparticle and microparticle aerosols and innovative methods for synthesis, purification, and characterization of useful materials. Carbon dioxide-assisted nebulization provides superior aerosols. I am collaborating with medical professionals and engineers to develop new methods for delivery of aerosol particles useful in direct and painless administration of therapeutic drugs and vaccines against measles, influenza, infections, stress, COPD, and asthma. Two of the 14 "Grand Challenges" identified by the Bill and Melinda Gates Foundation and the NIH Foundation as critical to world health have been addressed by my group.

In technology transfer, Sievers Instruments, Inc. and successor companies, Ionics-Sievers and GE Analytical, have manufactured 30,000 detectors and analyzers for 10,000 users for applications in trace analysis for environmental, water treatment, energy, pharmaceutical, and other applications from 1984 until the present.

CIRES FELLOWS

Angel Peak Scenic Area, New Mexico. Photo: Becky Poore/CIRES

Greg Tucker

Professor of
Geological Sciences

My interests lie in geomorphology and landscape evolution. My group seeks to understand the physics of diverse geomorphic processes and how these processes interact to shape terrain and move sediment. Some of our efforts are geared toward understanding the evolution of the Earth's surface over geologic time; others focus on contemporary issues such as gully development and erosional threats to toxic waste repositories. We also develop and share open-source software technology to support computational modeling of diverse earth-surface processes. Through teaching, I strive to equip students with the skills in writing and quantitative analysis that they need to understand, investigate, and make informed decisions about our fascinating and dynamic planet.

Veronica Vaida

Professor of Chemistry
and Biochemistry

Our group is interested in building chemical complexity with sunlight: spectroscopic studies of atmospheric molecules, radicals, and their complexes. My research interest focuses on issues of photoreactivity in planetary atmospheres, including the contemporary and ancient Earth. The approach employed to obtain the structure and dynamics of molecules, radicals, and their complexes involves a combination of spectroscopic, photofragment, and theoretical techniques. Aqueous environments, especially water-air interfaces as available at the sea surface and on atmospheric aerosols, are special reaction environments investigated by surface reflection spectroscopy.

Rainer Volkamer

Associate Professor of
Chemistry and Biochemistry

I am an Associate Professor in the University of Colorado Boulder Chemistry Department. My teaching in Instrumental Analysis with Environmental Emphasis (undergraduate level), and Analytical Spectroscopy (graduate level) is often enhanced by my research in atmospheric chemistry to inform chemistry-climate interactions, energy and the environment. My research group develops instrumentation (in-situ optical spectroscopy and sub-orbital remote sensing) to solve analytical and physical chemistry problems in the real world, to better quantify sources (air-sea exchange, urban, agriculture, biomass burning, etc), characterize aerosols (optical closure), and to probe mechanisms by which gases modify aerosols, oxidative capacity, atmospheric mercury, tropospheric ozone, and methane.

CIRES FELLOWS

Carol A. Wessman

Professor of Ecology and Ecology and Evolutionary Biology, Director of the Environmental Studies Program

My lab group seeks to gain insights into the dynamics between landscape structure and ecosystem functioning, with a strong focus on understanding ecosystem resilience and response to multiple disturbances. Our approach involves the use of field studies; remote sensing methodologies investigating temporal and spatial heterogeneity in ecosystem properties; and landscape and ecosystem theory. Current Research projects include: Subalpine forest response to multiple disturbances; integration of field, UAV, and satellite datasets for scaling canopy structure and species composition; vegetation state transitions and forest recovery from large disturbances in the Southern Rockies; and social-ecological systems in urban environments.

Michael Willis

Assistant Professor of Geological Sciences

My research revolves around questions about the changing cryosphere and time-varying topography, with a particular interest in the contribution of glaciers and ice sheets to sea level rise. I also have a developing research track deciphering the processes involved with cascading hazards such as tsunamis, landslides, and coastal inundation. My lab combines fieldwork with geodetic and remote sensing tools and high performance computing resources to examine changing topography at a variety of scales. These changes are driven by a variety of mechanisms such as melting or accelerating glacier ice, eroding permafrost, and seismic events—processes that have a direct impact on society.

Paul Ziemann

Professor of Chemistry and Biochemistry

The primary focus of our group's research is to determine the fate of volatile organic compounds emitted to air from biogenic and anthropogenic sources in both outdoor and indoor environments. In air, these compounds react by a variety of complex mechanisms that lead to the formation of oxidized products that can condense onto surfaces and also form microscopic organic aerosol particles. The resulting gases and particles can affect global climate, visibility, and human health. In the laboratory we conduct experiments under simulated atmospheric conditions and then identify and quantify organic gas and aerosol reaction products using a variety of analytical instruments and methods. This information is then used to develop detailed, quantitative chemical reaction mechanisms for predicting organic aerosol formation, which can be used to improve regional and global atmospheric models. We also conduct field studies in indoor environments to better understand the processes that influence indoor air quality.

CIRES Fellow Carol Wessman logs data during field research. Photo: CIRES

CIRES is home to four centers, which represent historic and current research foci. They also provide an identity and organizational structure for some of CIRES' major research areas.

Limnology

CENTER FOR SCIENCE & TECHNOLOGY POLICY RESEARCH

Earth Science & Observation Center
THE UNIVERSITY OF COLORADO AT BOULDER

NSIDC

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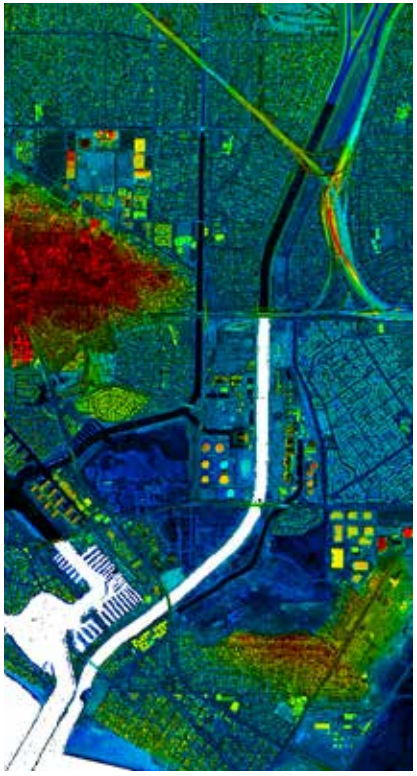

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Center for Limnology

The Center for Limnology conducts field and laboratory studies of aquatic ecosystems in Colorado. The following describes some research conducted in the last year.

MASS SUICIDE OF PHYTOPLANKTON IN A COLORADO LAKE

A 35-year data record of environmental characteristics for Lake Dillon, a water supply reservoir at 2,750 m above mean sea level in Summit County, Colorado (Figure 1), allows the study of problems that require long data records. The CIRES Center for Limnology is currently focusing on phytoplankton dynamics in Lake Dillon.

Phytoplankton are small, unicellular algae (~1 to 100 μm) that live suspended in the water column of lakes or oceans, where they are the sole agents of photosynthesis (Figure 2). Phytoplankton species of lakes total approximately 10,000, including six or more taxonomic divisions; a given lake in a given year often will have 50-70 species that appear in routine cell counts (Figure 2). Species composition changes by season and across years. Because species differ from each other ecologically, characteristics of a phytoplankton community are byproducts of the species mix in a given season or year.

In principle, a phytoplankton cell could be immortal, in contrast to a mammal, in that a given cell, if living in a favorable environment, will replicate itself by a division process that produces two daughter cells from the mother cell. The daughter cells typically are genetically identical to each other and to the mother cell, which means that the mother cell lives on in the form of two identical daughter cells. This process can be disrupted, however, by a number of factors. Phytoplankton are harvested by planktonic grazers, including primarily crustaceans and rotifers (Figure 2). A second cause of death is sinking; cells that pass through the lower boundary of the upper water column (epilimnion) may die from deficiency of or inorganic nutrients. Another cause of death is parasitism, principally by viruses. Also, phytoplankton can be swept away by water leaving a lake.

Figure 1: Lake Dillon, Colorado, offers a 35-year data record, making it an excellent location for study. Photo: Laura Compton

Center for Limnology

The Center for Limnology has quantified losses of phytoplankton associated with specific causes in Lake Dillon. As shown in Figure 3, the known causes, which typically are assumed to account for mortality (textbook model), account for only a small portion of mortality in Lake Dillon. In Lake Dillon, a large, undefined source of mortality is present every year, i.e., it is not irregular, as would be the case for viral infection or consumption by grazers.

Phytoplankton in marine environments can die without external cause, i.e., spontaneously. Spontaneous death that is genetically programmed has been given the name "apoptosis;" it appears to be accompanied by the release within the cell of a chemical agent, probably an enzyme, that causes the cell to disintegrate. Apoptosis is well known in mammals, including humans, but does not cause death of the organism. Specific cells kill themselves in response to a metabolic cue inside the body. Apoptosis is known to occur, but still is not understood, in ocean phytoplankton; it has not yet been documented for lakes.

Some known causes of mortality could be mistaken for apoptosis. For example, a cell that sufferers metabolic problems because of prolonged lack of nutrients or some other metabolic hardship could lose control of its metabolism and disintegrate. In addition, cells could be attacked by agents invisible to examination with a light microscope (viruses), but it is known that viruses cause mortality that is irregular, as bacterial infections are in humans.

The 35-year data record shows that most of the mortality of phytoplankton in Lake Dillon has occurred by either apoptosis or obscure environmental factors that cause mortality. Apoptosis seems most likely, because of high regularity in the mortality.

Apoptosis is a puzzle for biologists because it seems inconsistent with the principles of natural selection, which guides adaptation in organisms. What benefit, in other words, could apoptosis offer a phytoplankton cell? There is yet no obvious answer to this question. The Lake Dillon studies are exciting because regular occurrence of apoptosis in large amounts is, for the first time in a lake, shown to be the probable main cause of phytoplankton mortality over an extended interval.

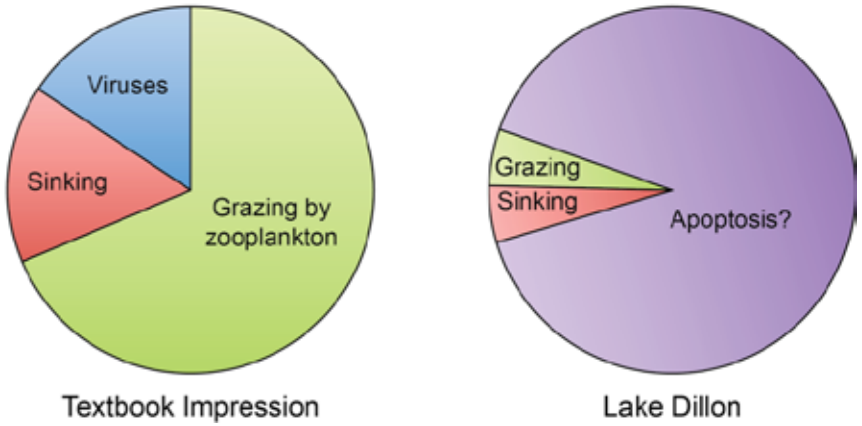


Figure 2, above: Common species found in Lake Dillon. Clockwise from upper right: rotifer (phytoplankton consumer), copepod (phytoplankton consumer), *Dinobryon* (phytoplankton), *Aphanothece* (phytoplankton), *Chrysochromulina* (phytoplankton). Copepod photo: Tommy Detmer/CIRES; all others: NOAA GLERL.

Figure 3, at left: Sources of loss for phytoplankton biomass. The textbook impression of phytoplankton biomass loss does not include apoptosis, which is seen in large amounts in Lake Dillon.

Center for Science and Technology Policy Research

The Center for Science and Technology Policy Research (CSTPR) was initiated within CIRES at the University of Colorado Boulder in 2001. We were recognized as an official University center in 2002 as a contribution both to the CIRES goal of "promoting science in service to society" and to the University's vision of establishing research and outreach across traditional academic boundaries. The mission of CSTPR is to improve how science and technology policies address societal needs through research, education, and service. CSTPR common themes are:

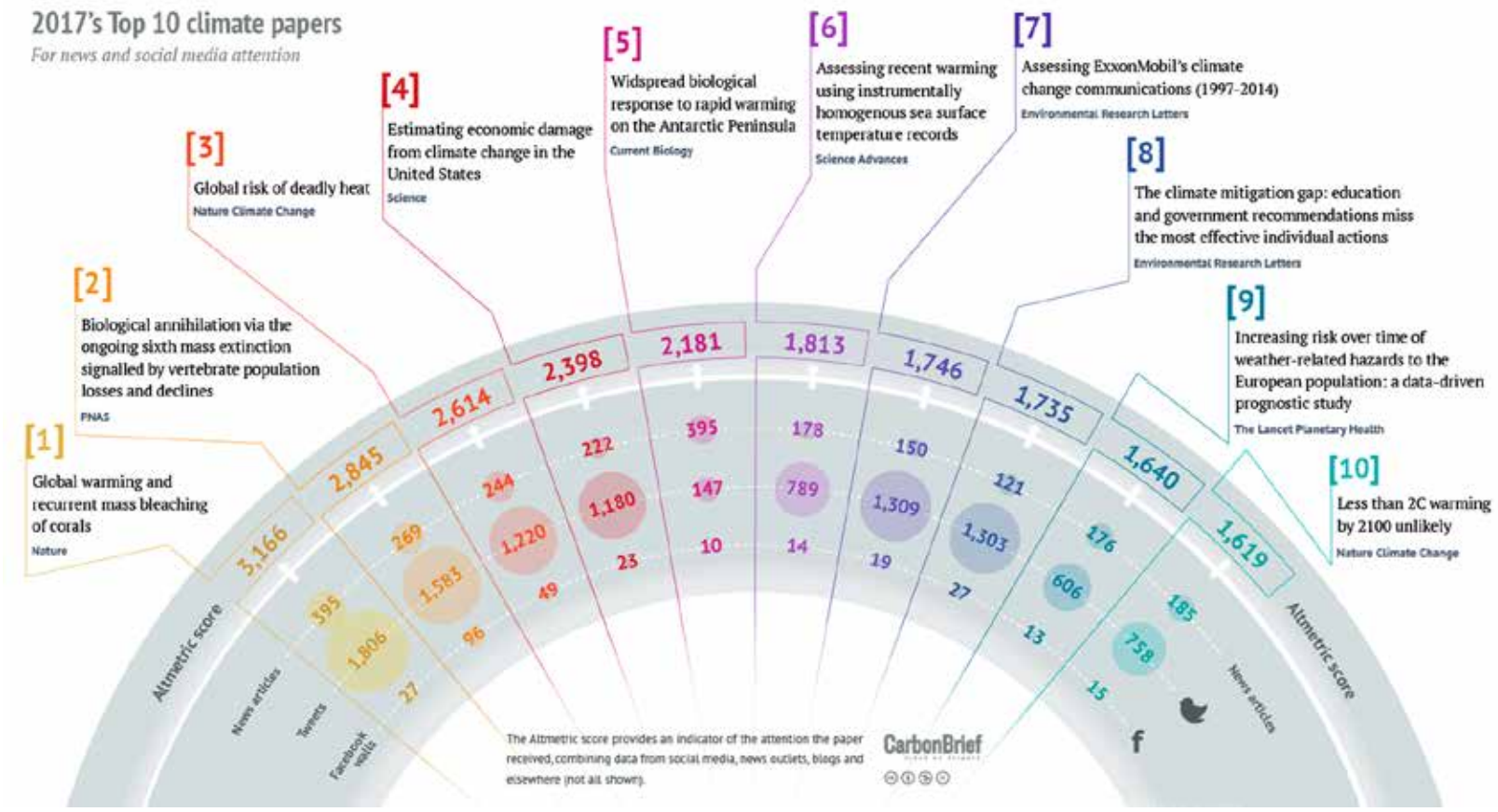
- **Science and Technology Policy:** We analyze decisions at the science-policy interface, including making public and private investments in science and technology; governing the usability of scientific information; and critically engaging the scientific and technical construction of emerging issues.
- **Innovations in Governance and Sustainability:** We study innovations in governance and the complexity of sustainability challenges, including the development of new institutions that transcend conventional political boundaries or bring actors together in new ways; new tools and experimental interventions for inducing behavioral change or enabling participation in decision making; and new forms of association in the creation and protection of collective goods.
- **Drivers of Risk Management Decisions:** We interrogate how individuals and institutions—at local, regional, national, and international scales—make decisions to respond and adapt to perceived risks, and what factors promote or inhibit effective decision making.
- **Communication and Societal Change:** We experiment and conduct critical analysis as we study communication strategies and engagement in varying cultural, political, and societal contexts.

2017 Red Cross/Red Crescent Climate Centre Fieldwork team enjoying fresh sugar cane after completing a set of interviews. Photo: Katie Chambers/CSTPR and CU Boulder

Center for Science and Technology Policy Research

HIGHLIGHTS

- In 2017, CSTPR celebrated its fifteenth anniversary. To celebrate, CSTPR hosted a keynote address by Brian Deese, Former Climate and Energy Advisor to U.S. President Obama.
- CSTPR created the Radford Byerly, Jr., Award in Science and Technology Policy in recognition of Rad's contributions to and impact on the CSTPR community. The 2018 award winner, Angela Boag, a Ph.D. candidate in Environmental Studies at CU Boulder, studies how changing climate and wildfire regimes impact forest resilience, as well as how private forest owners adapt to changing conditions.
- Several CSTPR graduate students received degrees in Environmental Studies in December 2017 or May 2018: Kevin Adams (M.S.); Jackie Albert (M.S.); Sofia Corley (Senior Honors Thesis); Lauren Gifford (Ph.D.); Elizabeth Koebele (Ph.D.); Lucy McAllister (Ph.D.); Marisa McNatt (Ph.D.); Rebecca Page (M.S.); and Claire Stumpf (M.S.).
- CSTPR hosted two visitors: Bienvenido León (University of Navarra, Spain) under the Faculty in Residence Summer Teaching program (FIRST) in the CU Office of Continuing



The *Lancet* "Countdown on health and climate change: from 25 years of inaction to a global transformation for public health" was the 11th most featured climate paper in the media in 2017 according to CarbonBrief. By early 2018, the report had earned an Altmetric (online attention) score of 1552, one of the top scores for papers with University of Colorado Boulder co-authors. Image: CarbonBrief

Center for Science and Technology Policy Research

CIRES Director Waleed Abdalati, making a toast at CSTPR's 15th Anniversary reception alongside CSTPR Director Max Boykoff, speaker Brian Deese, CU Vice Chancellor David Kang, CSTPR Associate Director Lisa Dilling and other guests on September 28, 2017. Photo: Katie Weeman/CIRES

Education; and Anna Kukkonen (University of Helsinki), under the Fulbright Doctoral Program.

- CSTPR core faculty published in *Journal of Extreme Events, Energy Research & Social Science, Environmental Planning A, Environmental Modelling & Software, Science and Engineering Ethics, Climatic Change,* and *Environmental Research Letters,* and *Systems Research and Behavioral Science.*
- Lisa Dilling released a new science guide for researchers, "Making Research More Usable at CU Boulder." The handbook, which was widely distributed to the Boulder scientific community, provides tested, tangible methods for researchers to produce useful science for those who write legislation, implement policy, manage natural resources or public resources, or manage their own business—bridging the gap between critical scientific research and constructive societal impact.
- Max Boykoff contributed to the *Lancet* "Countdown on health and climate change." Nearly 300 media outlets including *The Guardian*, NBC News, *Forbes*, NPR, and *Time* magazine mentioned the report.
- CSTPR organized the fifth annual 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 2018 winners were Julia Bakker-Arkema, a Ph.D. candidate in Chemistry and Biochemistry, and Kaitlin McCreery, a Ph.D. candidate in Mechanical Engineering. They met with members of Congress after the two-day workshop to discuss the policy implications of their research. The competition is supported by CSTPR, the CU Boulder Graduate School, and the Center for STEM Learning.
- CSTPR faculty delivered public lectures around the world on various science, technology and policy research topics. These include "Re-Defining the Boundaries of Science and Journalism in the Debate on Climate Change," Universität Hamburg (Max Boykoff); "Urban Water Systems: Drought Response Lessons for Climate Change Adaptation," London School of Economics (Lisa Dilling); "Transformative Learning," University of Dundee, Scotland (Bruce Goldstein, Environmental Design, CU Boulder); and "Justice, Democracy, and Water Allocation: A Tale of Two Basins," Lund University, Sweden (Steve Vanderheiden, Political Science and Environmental Studies, CU Boulder).
- The Red Cross/Red Crescent Climate Centre Internship Program placed CU Boulder Civil Engineering Ph.D. student Katie Chambers in Ethiopia in the summer of 2017.
- CSTPR partnered with CU Boulder's College of Engineering, the CU Boulder Office of Government Relations, and Colorado state representatives Chris Hansen and Bob Rankin to create the first Colorado Science and Engineering Policy Fellowship. CU Engineering's Michelle Lin, Sage Sherman, and Abby Oglesby are the 2018 fellowship winners.

Earth Science and Observation Center

Mike MacFerrin and Baptiste Vandecrux at KAN-U station, next to ice cores showing meltwater ice lenses throughout. Photo: Tasha Snow/CIRES

CIRES' Earth Science and Observation Center (ESOC) provides a focus for the development and application of novel remote-sensing techniques for all aspects of Earth sciences at CU Boulder. Our aim is to study natural and anthropogenic processes at all scales, from technique development in small test sites to understanding problems and patterns on regional and global scales. ESOC's long-term goal is to advance our understanding of the Earth system and its interactions with human society and activities through remote sensing.

Earth Science & Observation Center
THE UNIVERSITY OF COLORADO AT BOULDER

ADVANCING EARTH SCIENCE FROM SPACE

Every 10 years, NASA, NOAA, and the USGS, through the National Academy of Sciences request a community-based prioritization of space-based Earth observations in which to invest. Waleed Abdalati, Director of CIRES and an ESOC scientist, co-chaired the latest National Academies study. Results were published in early 2018, *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space.*

ESOC scientists help guide their fields by serving on many other technical committees and science teams, including the NASA Soil-Moisture Active-Passive Mission, the NASA Surface Water and Ocean Topography Mission, the National Advisory Council on Water Information - Subcommittee on Sedimentation, the CloudSat and CALIPSO Science teams, the Western North America InSAR executive committee, and the Alaskan Satellite Facility User Working Group.

CRYOSPHERIC RESEARCH

Our research continued to focus on processes driving changes in the cryosphere. This broad research includes:

- **Glaciers and ice sheets.** During 2017, we continued exploring changes on and around the Greenland ice sheet in a warming climate. The research included monitoring the world's largest array of firn compaction measurements across the Greenland ice sheet, to support and validate current and future satellite altimetry products from NASA and the European Space Agency. Michael MacFerrin has examined how meltwater-induced lenses in the Greenland ice sheet enhance runoff as the surface continues to warm. Waleed Abdalati and his students have characterized the nature and extent of crevasses around Greenland, meltwater plumes, and more, to characterize warm-water-induced basal melting of outlet glaciers, which in turn affects Greenland's contributions to sea level rise. Mike MacFerrin and colleagues examined assumptions about radar penetration into the upper layers of snow and firn on glaciers in Alaska, finding unabated mass loss in the region. MacFerrin and colleagues also used direct measurements of meltwater systems to demonstrate that water can be stored within the Greenland ice sheet and delayed before being released to the ocean.
- **Arctic DEM.** 2017 saw the release of the complete Arctic DEM (ArcticDEM.org) a public/private re-mapping of the entire Arctic region at a resolution of 2 meters. Data from this ongoing effort—sponsored by NSF, Bluewaters Petascale and the National Geospatial Intelligence Agency—are being made publicly available. Processing of new DEM strip files is ongoing, allowing users to compare topography

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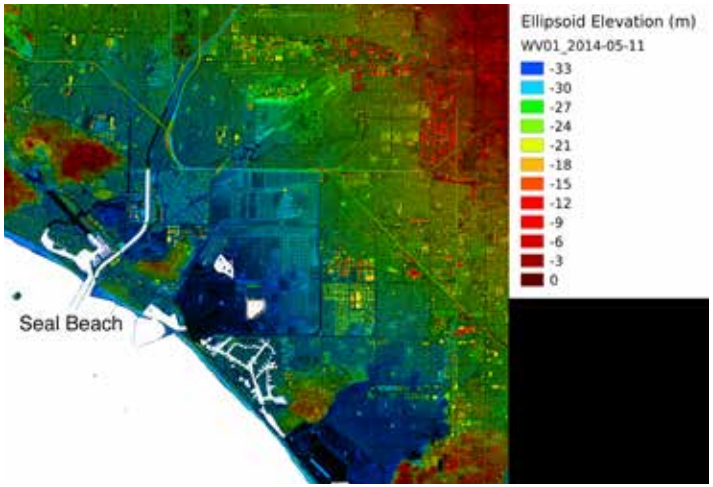
observations acquired at different times. This work resulted in the first known observation, by CIRES Fellow Mike Willis and colleagues, of climate-driven river piracy due to the retreat of the Kaskawalsh Glacier in the Yukon.

- **Assessing the influence of Arctic cloud feedbacks on Arctic sea ice loss.** Jen Kay's group uses spaceborne lidar primarily to measure the observed cloud response to Arctic sea ice loss. Recently, her team's work has expanded globally, evaluating the impact of shortwave radiation on the mean-state climate.



High-resolution, 2 m DSM of Seal Beach, just south of Los Angeles, CA. Ellipsoidal heights; mean sea level is at approximately -33.1 m. Background image: Worldview-1 image, DigitalGlobe Inc., 2014 (c).

LIDAR REMOTE SENSING AND LASER SPECTROSCOPY

Remote sensing technology development, combined with atmospheric and space observations, data analysis, and theoretical modeling, allows us to better understand the structure and dynamics of the whole atmosphere. Xinzhao Chu's research group completed a 12th trip to Antarctica this year, and achieved the first simultaneous Na density, temperature, and vertical wind measurements by the STAR Na Doppler lidar at Arrival Heights in January 2018. The infrastructure at McMurdo enables first-rate science at the bottom of the world. Recent discoveries from these lidar observations in Antarctica (such as the discovery of stratospheric gravity waves) are challenging the understanding of electrodynamics, chemistry, composition, and energetics in Earth's geospace environment.

HYDROLOGICAL RESEARCH

Remotely sensed hydrological research is a primary focus for the upcoming NASA Surface Water and Ocean Topography (SWOT) Mission, NASA's first ever hydrologically-dedicated satellite mission. In addition to ocean research, SWOT will focus on global inland surface water, including lake and wetland elevations, extents and volumes, and large river water discharge. In most of the world outside of the United States, inland surface water is one of the least known global processes. In the summer of 2017, ESOC scientist Toby Minear, as part of the SWOT project, participated in the NASA Arctic and Boreal Vulnerability Experiment (ABoVE) project, one of the largest-ever NASA field campaigns. Researchers flew 10 aircraft with various radar, lidar, optical and EM instruments over sites from the Midwest through Canada and into northern Alaska to remotely capture accurate, cutting-edge detail about the world's rivers, wetlands, and oceans—far beyond what had been recorded by previous technology. Results are already improving NASA mission algorithms for remote sensing techniques.

In early 2018, ESOC hosted the Reservoir Sedimentation Management Webinar series, attended by approximately 2,000 participants from all types of agencies, and held two NASA-sponsored meetings, one on defining possible surface water inundation extent data products and the other on inland water biogeochemical cycling.

Minear and Ben Livneh are collaborating to better understand the links between sedimentation processes and climate information. A paper published in the *Journal of Advances in Modeling the Earth System* describes a new framework for estimating sediment loading within a state-of-the-art land surface model, and ongoing research is focused on how climate variability impacts sedimentation.

HAZARDS STUDIES

Efforts to provide a comprehensive understanding of the processes that govern natural and anthropogenic hazards include studies focusing on the integration of remote sensing data such as space-based GPS data, differential interferometric synthetic aperture radar (DInSAR), seismicity, and gravity, to provide critical information on the nature and scale of these hazards. We are investigating the consequences of hazards such as groundwater extraction, volcanic unrest, and induced seismicity on infrastructure and society.

In the fall of 2017, ESOC fellows Livneh, Minear, Tiampo, and Willis, and associates Andrew Badger and Christopher Williams, kicked off a new, NASA-funded interdisciplinary project to study cascading hazards using modeling, field studies, and remote sensing data. The goal is to illuminate the processes linking landslides and large fluvial events, and potential links to wildfire damage and earthquake ground motions.

Willis, Magali Barba (Ph.D. student) and Tiampo studied enormous landslides and tsunamis that occurred in Alaska and Greenland, helping the Greenland government assess the risk of additional landslides. Willis produced before and after DEMs of the damage caused by the 2015 Kaikoura Earthquake in New Zealand.

In addition, Willis is collaborator on a NASA-funded project on sea-level rise, led by CIRES Fellow R. Steven Nerem, investigating the impact of sea-level rise on large, urban coastal cities using high-resolution digital surface models (DSMs), such as that shown for a region south of Los Angeles. Willis and Tiampo are extending that work to examine how vertical land motion can be estimated for regions with no freely available geodetic infrastructure using InSAR techniques. Willis and colleagues' findings were presented at several conferences and were published in *Science* in June 2018.

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, 2017, to May 31, 2018, follow.

LONG-PERIOD OCEAN WAVE ACTION TRIGGERS ANTARCTIC ICE SHELF DISINTEGRATIONS

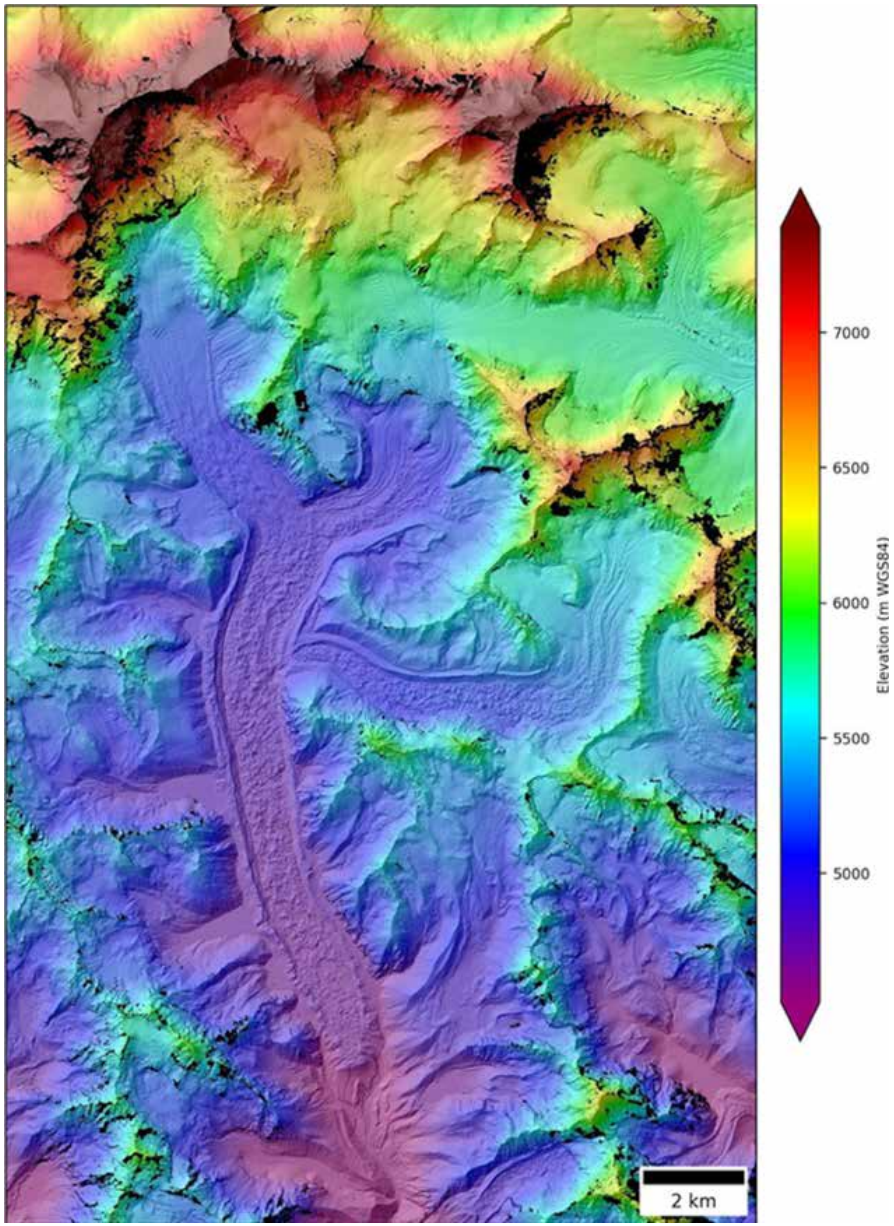
NSIDC scientist Ted Scambos was a coauthor on a recent paper in *Nature*, "Antarctic ice shelf disintegration triggered by sea ice loss and ocean swell." It discussed how ocean waves trigger Antarctic ice shelf disintegrations, such as the Larsen B 2002, Larsen A 1995, and Wilkins 2008 and 2009 events, when sea ice retreat has exposed the ice shelf fronts to the global ocean swell.

SUMMER ARCTIC SEA ICE EXTENT END UP 8TH LOWEST, WINTER ARCTIC HEAT WAVES

At the end of the 2017 melt season, Arctic sea ice extent stood at the eighth lowest in daily average and seventh lowest in monthly average over the satellite record (1979 to present). The overall rate of ice loss during the summer of 2017 was slowed by persistent low sea level pressure over the central Arctic Ocean. During the winter of 2017-2018, ex-

Large iceberg floating among sea ice floes during an operation IceBridge survey flight on April 21, 2018. Photo: Linette Boisvert/NASA

National Snow and Ice Data Center



tent tracked at record or near record low levels. As has been the case of the last several years, the winter of 2017-2018 was punctuated by extreme heat waves over the Arctic Ocean. Extent at the March sea ice maximum was the second lowest on record. We posted these analyses on nsidc.org/arcticseaicenews.

NASA OPERATION ICEBRIDGE

Operation Icebridge (OIB) is an airborne mission that has been flying yearly Arctic and Antarctic campaigns for over 10 years to gather data on changing conditions. This past year, OIB flew far more than their typical two campaigns—they flew seven! And they deployed new Lidar instruments that dramatically increased the amount of data gathered. As the NASA archive for all OIB instruments, NSIDC has been very busy making data available to the public. Users from all over the world have downloaded over 250 Terabytes of data from over 70 products, from Snow Radar and Lidars to digital images of the regions.

HIGH MOUNTAIN ASIA

The high mountain regions of Asia impact a large swath of the world's population, and changes in snow, ice, and water in the region have large repercussions. NASA and the Chinese Academy of Sciences have been holding joint workshops on glacier changes and associated hazards. NSIDC is both the data archive for this effort, and an active science participant. The latest meeting in Dujiangyan, Chengdu, China in May 2018, has already led to the publication of new Freeze/Thaw/Melt datasets.

FUTURE OF THE SUMMER ARCTIC FRONTAL ZONE

NSIDC director Mark Serreze and former graduate student, Alex Crawford, coauthored a paper in the *Journal of Climate* titled "Projected Changes in the Arctic frontal zone and summer Arctic cyclone activity in the CESM Large Ensemble." The Arctic frontal zone (AFZ) is a narrow band of strong horizontal temperature gradients that develops along the Arctic coastline each summer in response to differential heating of the atmosphere over adjacent land and ocean surfaces. Past research by NSIDC scientists has linked the AFZ to summer Arctic cyclone development. The paper discusses the future of the summer AFZ based on simulations with the Community Earth System Model Large Ensemble in conjunction with an advanced cyclone detection/tracking algorithm, including how the AFZ remains a significant cyclone intensifier through the 21st Century.

THE EXCHANGE FOR LOCAL OBSERVATIONS AND KNOWLEDGE OF THE ARCTIC (ELOKA)

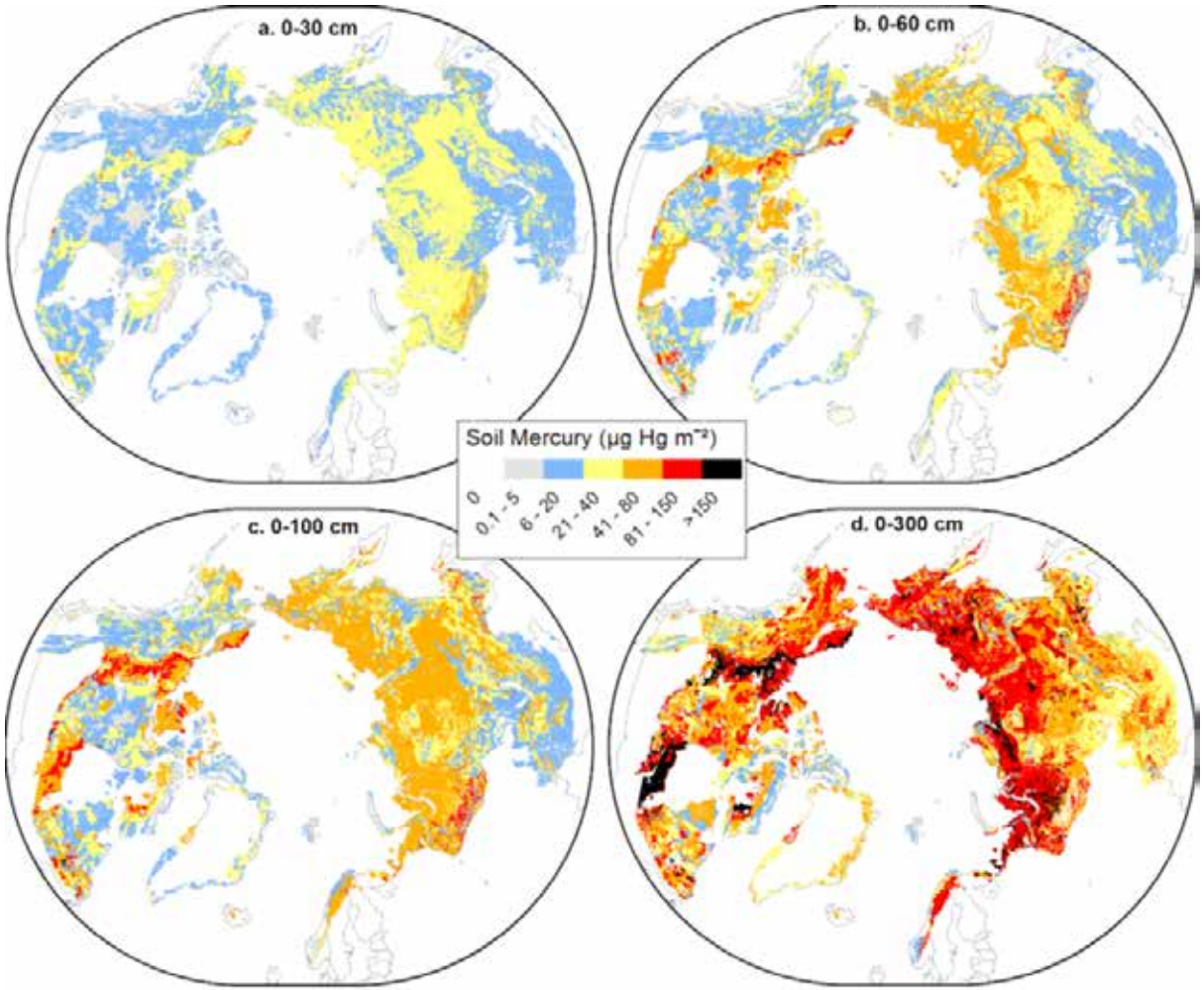
This year, the ELOKA project team (http://eloka-arctic.org/) has:

- Partnered with Calista Education and Culture to develop and expand the Yup'ik Environmental Knowledge Project and a related online Atlas.

Left: Detail in a High Mountain Asia Digital Elevation Model (DEM) of the Mt. Everest region. Mottled texture in the branching valley shows the debris-covered Ngozumpa Glacier, Nepal. Image: NSIDC

National Snow and Ice Data Center

- Developed three new atlases under the Atlas of Alaska Place Names Project: the the Deg Xinag Atlas, and the Gwich'in Nąįį Gogindì' K'ìt / Gwich'in Place Names Atlas.
- In partnership with the EU-funded INTAROS project, ELOKA co-hosted a major workshop on the technological aspects of community-based monitoring, held in conjunction with the major Arctic Change conference in Quebec City in December 2017. A major report on related articles will be published in 2018.
- NSIDC researchers Peter Pulsifer and Colleen Strawhacker led the recent Polar Data Planning Summit, bringing together almost 40 experts to plan national/international coordination of polar data initiatives in the coming years.



PERMAFROST STORES A SIGNIFICANT AMOUNT OF MERCURY

Permafrost regions represent the largest pool of mercury on the planet, with twice as much mercury as the rest of the soils, the ocean, and the atmosphere combined. Naturally occurring mercury bonds to organic matter by mimicking nutrients like iron. Over time, mercury has accumulated in Arctic soils and become frozen into permafrost. NSIDC scientist Kevin Schaefer, in collaboration with USGS colleagues, drilled soil cores in Alaska, analyzed them, and estimated the total amount of mercury in permafrost regions. As long as the organic matter remains frozen, the mercury will stay in the permafrost. However, permafrost has begun to thaw as a result of climate change, and large amounts of mercury could release into the environment. This new, previously unknown pool of mercury represents a risk to global food supplies, the team reported in *Geophysical Research Letters* (https://doi.org/10.1002/2017GL075571).

MELTWATER ON GLACIER

Using a new method that combined observations and simulations, NSIDC scientist Twila Moon and colleagues were, for the first time, able to separate the distinct sources of ice sheet freshwater production on the Greenland Ice Sheet and determine how each source's contribution changed over a year. They applied their new method to Sermilik Fjord, finding that iceberg melt plays a unique role in the system: icebergs produce more melt in fall than other sources, add water throughout the fjord, and over a year produce more melt than any other source. *Nature Geoscience* published the research in December, 2017, highlighting it with a cover photo in their January, 2018 print edition.

Left: A map of the distribution of mercury in the top 300 cm of soil for permafrost regions based on in situ measurements of mercury content in soil samples in Alaska. Image: Schuster et al. (2018). Permafrost stores a globally significant amount of mercury. *Geophys Res Lett*, **doi.org/10.1002/2017GL075571.**

National Snow and Ice Data Center

Illuminated by the midnight sun, large icebergs and smaller bergy bits slowly melt in calm waters in the Ilulissat Icefjord, Greenland. Photo: Twila Moon/NSIDC

ICE GROWTH

NSIDC scientist Julienne Stroeve studied the winter of 2016-2017 and its record warmth to provide some insight into recent extreme winter heat waves over the Arctic Ocean, and their impact on sea ice cover. According to three different sea ice thickness products derived from CryoSat-2 and a series of model simulations, the very warm conditions led to less thermodynamic ice growth—by April 2017 the ice cover was likely 12-13 cm thinner than average as a whole. But when areas of ice are pushed together, the ice can thicken, leading to thicker spring ice in the Barents and Kara seas. The ice cover was particularly slow to retreat in these regions the following summer.

CONTINENT-WIDE ESTIMATES OF ANTARCTIC STRAIN RATES FROM LANDSAT 8-DERIVED VELOCITY GRIDS

Strain rates are fundamental measures of ice flow which are used in a wide variety of glaciological applications, but are calculated using a variety of methods and length scales with details often not specified. NSIDC scientist Allen Pope compared the different strain-rate calculations based on a satellite-derived velocity field of the Antarctic Ice Sheet generated from Landsat 8 satellite data. Pope also demonstrated the importance of specifying a length scale over which strain-rate calculations are made, which can strongly influence other derived quantities such as basal mass balance on ice shelves and presented strain-rate data products calculated using an approximate viscous length-scale with satellite observations of ice velocity for the Antarctic continent.

NSIDC SCIENTIST WINS INAUGURAL INTERNATIONAL MOHN PRIZE (SHARI FOX, NSIDC)

Shari Fox, an NSIDC scientist and team lead behind *The Meaning of Ice* project, won the inaugural International Mohn Prize for outstanding Arctic-related research in January, 2018. The International Mohn Prize review committee selected Fox's project in part because it, "made groundbreaking contributions to our understanding of Arctic ice-dominated systems via a highly innovative combination of natural science, social science, and indigenous knowledge … [it] exemplifies a major development in Arctic science that will stimulate others to make use of similar procedures to address a wide range of topics in the coming years."

Dr. Shari Fox (center) shakes hands with Mohn Prize Chair Dr. Anne Husebekk at the ceremonies in Tromsø, Norway. Also pictured are second recipient Eddy Carmack and *The Meaning of Ice* team members Lene Kielsen Holm and Toku Oshima. Photo: Enje Mortensen/ Arctic Frontiers

Programs at CIRES develop and evolve in response to scientific trends, societal need, and more. Our programs bridge scientific disciplines, institutions, and geographies, enabling rapid scientific response to emerging challenges and fostering collaboration.

Earth Lab
UNIVERSITY OF COLORADO BOULDER

CIRES
Education
& Outreach

IGAC
INTERNATIONAL GLOBAL ATMOSPHERIC CHEMISTRY

WESTERN WATER ASSESSMENT
A NOAA RISA TEAM

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Earth Lab

Earth Lab's mission is to harness the data revolution through research, analytics, and training to accelerate understanding of global environmental change and help society better manage and adapt. Earth Lab integrates the deluge of Earth systems data from space, airplanes, sensor networks, social media, and more, to address key environmental challenges. Earth Lab joined CIRES in July 2017, and CIRES administrative support has been central to its rapid growth. The long-term goal of Earth Lab is to build a national synthesis center for data-intensive global change research and applications.

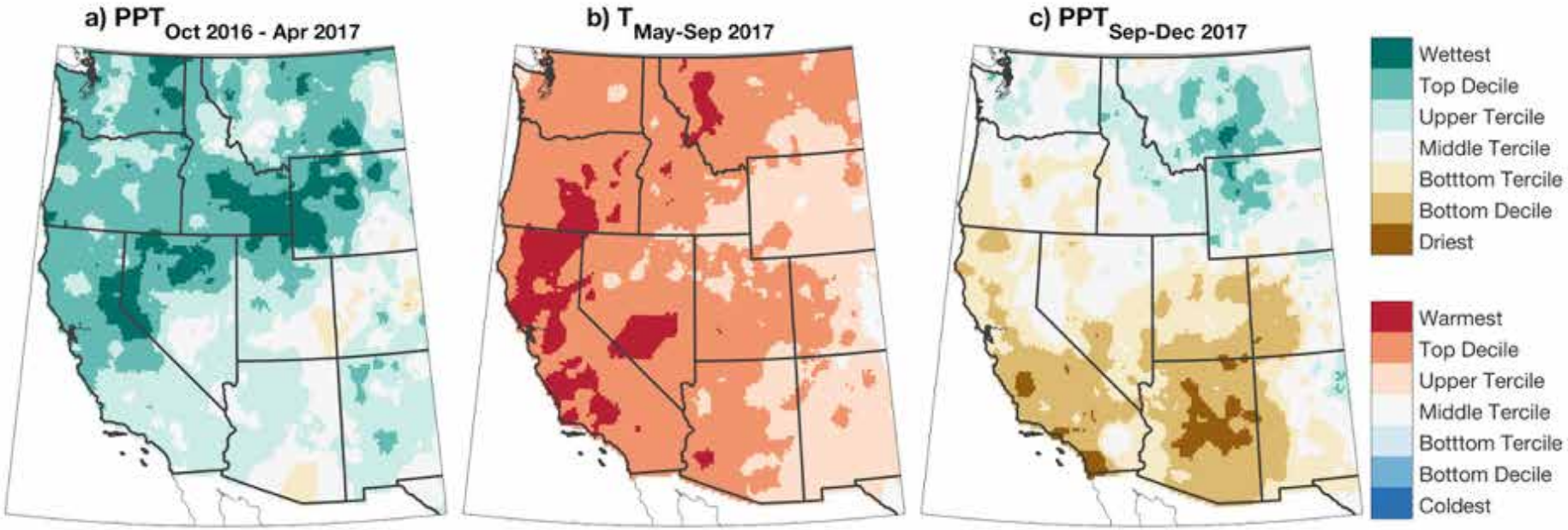
MEETING THE DATA CHALLENGE

Traditional computing methods are insufficient to handle the massive volume of complex, wide-ranging Earth data available today. Earth Lab meets the challenge of big data by building multidisciplinary teams, using cloud computing and new developments in open source software and tools, and building education materials to address knowledge and skill gaps. As a result, our collaborative, interdisciplinary science teams have produced substantial work in global change research across a range of fields, including wildfire, forest dynamics, Arctic change, disaster tracking via social media, human health, and much more.

Earth Lab's commitment to open, reproducible science is key to our progress. We have helped make open science more prominent on campus with over 150 publicly available training modules, tools, code recipes, and datasets. We share software tools, datasets, and code recipes on Earth Lab's Github repository—and we have engaged with more than 300 colleagues, through courses, data jams, workshops, science slams, and public seminars, including bringing four leading environmental journalists to discuss science communication. We are working to establish strong industry and federal partnerships to identify new research areas, co-develop tools, and accelerate research into real-world applications. Earth Lab completed its first joint

A drone collects multispectral imagery in the Earth Lab field site in Cold Springs near Nederland, Colorado as part of the Earth Lab-IRISS Project Forest partnership. Photo: Megan Cattau/CIRES

Earth Lab



In 2017, the United States experienced its costliest wildfire season ever, with damages exceeding $18 billion, and its third largest fire season (by area burned) in nearly 60 years. Large portions of the U.S. West experienced a pile-on of extreme events: the wettest winter, the hottest summer, and the driest fall, all helping to promote wildfires.This figure profiles categorical percentiles of (a) October 2016–April 2017 precipitation; (b) May–September 2017 temperature; and (c) September–December 2017 precipitation; based on NOAA Climgrid data, relative to the 1895–2017 period of record. Nine percent of the U.S. West had the wettest October–April on record (42% in the top decile); 9% of the U.S. West also had its warmest May–August on record (57% in the top decile). Thirty-three percent of the West had both a top-decile October–April precipitation total and a top-decile May–September temperature. Image: Balch et al. 2018

industry research project with Newmont Mining exploring use of machine learning and DigitalGlobe's imagery to detect recoverable gold from space.

In the spirit of open education, we published 94 new Earth Analytics courses and 6 teaching data subsets online (https://earthdatascience.org/courses/earth-analytics). Our newly published online course has grown in popularity, now drawing over 10,000 unique visitors a month. Since our inception, we have trained 19 undergraduate interns in data-intensive science, and early longitudinal surveys demonstrate that 80 percent of previous interns and students are using Earth Analytics skills learned in our programs in their current careers. Earth Lab's Education Initiative also developed a new professional certificate in Earth Data Analytics - Foundations, one of the first national programs, that will launch in August 2018.

Finally, Earth Lab is pathfinding how best to bring university researchers into the cloud. We now have a dozen projects using the cloud, and our computing totals over 30,000 hours to date. We assisted 32 researchers and developed 8 new software tools, including cloud compute workflows that have been adopted by the Earth Lab community.

FOREST RESILIENCE HIGHLIGHTS

- NASA Grant Awarded: NASA New Investigator Program. Ecological Stability and Disturbance - Recovery Dynamics in Southern Rockies forests: Upscaling from the tree- to the Landsat-level. Megan Cattau, Earth Lab Postdoc working with CIRES Fellow Carol Wessman.
- Cattau generated a map of the Thomas Fire in California that was retweeted to 80,000 people.
- Cattau was interviewed for her research on forest disturbances in the Rocky Mountains: Hennig, A., Hall, R., and Clark, M. The Future of Forests. Atavist. (Link: https://foresthealth.atavist.com/the-future-of-forests)

ENVIRONMENTAL RISKS AND DECISION MAKING HIGHLIGHTS

- We published a peer-reviewed journal article on "Managing climate risks on the ranch with limited drought infor-

Earth Lab

mation." (https://www.sciencedirect.com/science/article/pii/S2212096317301407?via%3Dihub)

- The Risk Team completed the first online experiment using its drought decision-making simulation model (DRIR-R), recruiting over 500 participants who made ranch management decisions (such as using drought insurance) over the course of 10 years with and without drought conditions. The original version of the simulation model is available at: www.ranching.io.
- Project Risk developed a widely available drought data analysis tool (the Drought Index Insurance Analysis Laboratory, available in beta version at http://165.227.28.112/), designed to compare measures of drought (e.g., PDSI) with NOAA's gridded precipitation data. The research goal is to test alternative drought indices as insurance triggers to determine if they might be more efficient than the gridded precipitation data at indicating drought impacts and the need for insurance payouts.

WILDFIRES HIGHLIGHTS

- NSF Grant Awarded: Quantifying the Invasive Grass-Fire Cycle and Implications for Carbon Storage in the Continental U.S.; PI and Co-PIs: Bethany Bradley, Jennifer Balch, Chelsea Nagy; Sponsors: NSF Geography and Spatial Sciences.
- Two publications in 2018 in a new open-source journal for fire research:

  Balch J.K., T. Schoennagel, J. Abatzoglou, P. Williams, M. Cattau, N. Mietkiewicz, L. St. Denis. 2018. Switching on the big burn of 2017. *Fire* 1(1): 17, https://doi.org/10.3390/fire1010017

  Nagy, R.C. C., E. Fusco, B. Bradley, J. T. Abatzoglou, and J. Balch. 2018. Human-Related Ignitions Increase the Number of Large Wildfires across U.S. Ecoregions. *Fire* 1(1): 4, https://doi.org/10.3390/fire1010004.

- Postdocs Nathan Mietkiewicz and Lise St. Denis are investigating over 1.5 million government reports and over 200 million housing records to reveal how wildfires threaten our lives and property.

The Thomas Fire burned more than 113,000 hectares from early December 2017 to late January 2018, making it the largest fire in California's modern history. Image: NASA Earth Observatory

COMMUNITY HIGHLIGHTS

- Extremes Collider: In May 2018, Earth Lab hosted its first collider two-day event on Extreme Environmental Events, bringing together experts from CU Boulder, other universities, federal agencies, and industry partners to share research ideas and identify common data and analytics challenges in this domain. This was the first stage in what will be a three-part series on extreme events.
- Building a Research and Education Sandbox in the Cloud: The education team has been working closely with Project Jupyter to build an Earth Analytics, Python cloud environment hosted by Google Cloud to conduct real-time data- and computation-intensive work—in the classroom or for rapid research collaborations. This environment will be supported by the Docker/Conda environment and will ensure that all Earth Analytics students have access to a working space.
- Earth Analytics in the Cloud Day: We worked with Amazon Web Services, the Sustainability Innovation Lab at Colorado, and Future Earth to jointly host a workshop with expert-led panels and technology and research discussions on CU Boulder's campus. About 130 participants from academia, industry, government, and nonprofit organizations shared ideas on leveraging big data analytics and Earth observation datasets to shape the future of sustainability.

CIRES Education & Outreach

The CIRES Education & Outreach (E&O) group provides programming and opportunities across the spectrum of geosciences and environmental education, including teacher professional development, digital learning resources, student programs, workforce development, program evaluation, as well as mentoring opportunities and support for early career scientists, and more. Some of this busy and vibrant team's projects are described below.

TEACHER EDUCATION

The CLEAN collection (cleanet.org) is a peer-reviewed digital repository of climate and energy learning resources, syndicated through NOAA's Climate.gov and the National Science Teachers Association. During the 2017 AGU meeting, this collection of 700 resources was recognized with the Friend of the Planet award by the National Center for Science Education. The project developed and disseminated new models of how to combine CLEAN educational resources within units that follow the new integrated teaching approach mandated in the Next Generation Science Standards. Our team completed and published a new curriculum around community resilience in partnership with the Denver Public Schools, Denver charter schools, and researchers focused on curriculum co-development between teachers and scientists. New materials focus on understanding local and global climate change and on addressing food waste in schools. We are also offering teacher trainings based on the Lens on Climate Change project to implement instructional units that guide students in capturing the impacts of local climate change in short films.

PRE-COLLEGE STUDENTS AND PUBLIC

Through the Lens on Climate Change program, middle and high school students produce films featuring climate change impacts on their local communities, implemented with the support of science researchers, CIRES graduate students, and film students. Students from Front Range and rural Colorado school districtshave participated, as have student groups from Trinidad State Junior College's Upward Bound Math Science program and the I Have A Dream foundation.

Going Global, an NSF CAREER grant awarded to CIRES Fellow Jennifer Kay, includes education research designed to test if emotional hooks, such as polar bears, will lead to more student engagement and learning. We measured student engagement by multiple methods, including skin conductance. We have completed three educational videos, in versions with and without polar bear imagery, and are implementing them in educational settings.

CIRES E&O hosted the 19th regional ocean science-themed trivia competition, the Trout Bowl, as part of the National Ocean Sciences Bowl in February, 2018. In April, 2018, CIRES E&O also hosted the first NOSB national competition held in a fully landlocked state: 125 top students from around the country battled for the title and participated in many local field trips. CIRES E&O is offering for the first time the Girls on Rock program in which underserved, diverse high school girls are exposed to science and science careers through outdoor and climbing education.

The Research Experience for Community College Student cohort 2018, ready to tackle their summer research projects. Photo: Katie Weeman/CIRES

Teammates confer on answers during the 2018 Trout Bowl at the University of Colorado, a Jeopardy-style knowledge competition among high school teams from around the United States. Photo: Katie Weeman/CIRES

CIRES Education & Outreach

A Lens on Climate Change team films an interview with a CIRES researcher about water in the West. From left to right: Jacoby Sanchez (Des Moines, New Mexico), Jeff Lukas (CIRES scientist), Erik Morales (Anthony, New Mexico), Catherine Sullivan (Colorado Film School), Elliasar Soto (Monte Vista, Colorado). Photo: Katie Weeman/ CIRES

UNDERGRADUATE AND GRADUATE EDUCATION

The Research Experiences for Community College Students (RECCS) project, which supports community college students to conduct research at CIRES and NOAA, was awarded a renewal for another three years of funding. To date, RECCS has served 49 community college students from across Colorado. RECCS students are diverse along many dimensions, including first-generation college attendees, people of color, and veterans.

CIRES E&O has partnered with CU Boulder's Geology Department on a study of undergraduate spatial thinking skills and ways in which their spatial skills can be trained and strengthened to increase student preparation for a career in STEM disciplines, include the geosciences. A study published in *Geosphere* showed insightful correlations between childhood play and the development of spatial reasoning skills.

As part of an NSF-CAREER award to Julie Lundquist, and in partnership with the PhET group, CIRES E&O is developing a blueprint for two educational simulations around wind energy and atmospheric conditions for the formation of wind. Two educational videos are being produced that provide background information for the simulations.

EVALUATION AND EDUCATIONAL RESEARCH

CIRES provides program and project evaluation services to a wide variety of STEM education partners. Of note this year is the evaluation of a NASA award to the Fiske Planetarium. Fiske is producing short videos highlighting NASA science missions for wide distribution to planetariums and museums. We are providing external evaluation, including audience surveys and script alignment with NASA priorities. CIRES E&O also supported CIRES Fellow Max Boykoff's Inside the Greenhouse course implementation by assessing the course's impact. CIRES E&O continues to provide external evaluation services for a summer research experience for undergraduates in solar and space science, and provides internal evaluation support for CIRES E&O projects.

CIRES E&O co-developed a new climate concept inventory and tested it in different educational settings; this concept inventory provides a critical community resource. We have submitted a paper to the journal *Climatic Change* describing this concept inventory, which is currently under review. CIRES E&O was also a critical partner in the NSF-funded Grand Challenges working group focused on in atmospheric and climate educational research priorities.

International Global Atmospheric Chemistry

The atmosphere is the integrator of the Earth system. Human emissions of pollutants and long-lived greenhouse gases into the atmosphere have dramatically transformed the planet, and altered air quality, climate, and nutrient flows in every ecosystem. Understanding the global atmosphere requires an international network of scientists providing intellectual leadership in areas of atmospheric chemistry that need to be addressed, promoted, and would benefit from research across disciplines and geographical boundaries. The International Global Atmospheric Chemistry (IGAC) Project formed in 1990 to address this need.

CIRES is reporting on IGAC's accomplishments for three reasons: The IGAC International Project office is hosted by CIRES; IGAC Executive Officer Megan L. Melamed is a CIRES Research Scientist III; and funding for IGAC—which comes from NSF, NASA, and NOAA—comes in through CIRES' Cooperative Agreement with NOAA.

IGAC's mission is to facilitate atmospheric chemistry research towards a sustainable world. We achieve this through three focal activities: fostering community, building capacity, and providing leadership. More information can be found at igacproject.org.

FOSTERING COMMUNITY

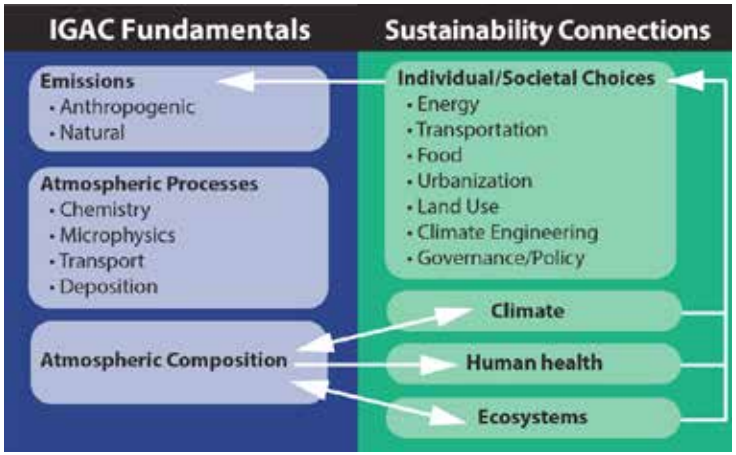
IGAC is an open international community of atmospheric scientists actively collaborating across geographical boundaries and disciplines in order to address the most pressing global change and sustainability issues through scientific research. The IGAC biennial science conference and the facilitation of numerous thematic workshops every year provide opportunities to build cooperation and disseminate scientific information across the IGAC international community.

BUILDING CAPACITY

IGAC builds scientific capacity through an early career program and national and regional working groups. The early career program allows scientists to join an international network early in their careers. National and regional working groups create a strong cohesive community of atmospheric scientists in emerging countries/regions.

PROVIDING LEADERSHIP

IGAC provides intellectual leadership by identifying and fostering activities on current and future areas within atmospheric chemistry research. This links fundamental research on emissions, atmospheric processes/composition to global change



Participants in the 4th Interdisciplinary Biomass Burning (IBBI) Workshop, July 2017. Photo: IGAC

International Global Atmospheric Chemistry

Participants in the Aerosols-cloud-precipitation-climate (ACPC) Workshop, April 2018. Photo: IGAC

and sustainability issues (e.g. human health, climate, ecosystem).

From June 2017 to May 2018, IGAC accomplished the following:

- Sponsored seven scientific activities;
- Endorsed three scientific activities;
- Fostered four national/regional working groups;
- Financially sponsored or endorsed 18 workshops across the world on a range of atmospheric chemistry topics. Two workshops took place at the University of Colorado Boulder, with administrative support provided by CIRES:

4th Interdisciplinary Biomass Burning (IBBI) Workshop, July 2017: The aim of the workshop was to capitalize on the U.S. research campaigns Fire Influence on Regional and Global Environments (FIREX) and Western Wildfire Experiment for Cloud Chemistry, Aerosol Absorption, and Nitrogen (WE-CAN) in the global and operational contexts. The workshop brought together 53 participants from 15 countries to discuss how to leverage efforts in the United States and Europe to improve scientific research and understanding of open biomass burning around the world and maximize benefits from new satellite instrumentation.

Aerosols-cloud-precipitation-climate (ACPC) Workshop, April 2018: The goal of the ACPC initiative is to improve the understanding of the mechanisms by which aerosol perturbations may modify clouds and precipitation, and to quantify the impact this may have on climate. The focus is at a regional scale. Observational studies are supported by simulations with cloud-resolving and cloud-system-resolving models. On the basis of progress discussed in a series of meetings, the ACPC group gathered at CU Boulder in April 2018, to coordinate scientific research on two cloud regimes: deep convection and marine stratocumulus.

Western Water Assessment

Western Water Assessment (WWA) is one of 11 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.

PILOTING A NEW SPATIAL SNOW WATER EQUIVALENT (SWE) PRODUCT

A key indicator of water availability and drought, and the primary input to streamflow models, is snow-water equivalent (SWE), which we monitor from a network of in-situ NRCS Snow Telemetry (SNOTEL) observing sites across the West. However, conditions at SNOTEL sites may not be representative of conditions in the large areas between these point measurements, and at elevations above and below the range of the SNOTEL sites. WWA has been looking to augment the use of in-situ data with spatial products in a manner that adds appreciable value at low cost to users. In the spring of 2018, in an effort to kickstart broader awareness and use of spatial snow data, WWA pilot-tested a MODIS-based spatial SWE product developed by Noah Molotch's research group for the WWA region. From late March to late May, we distributed a spatial SWE product and accompanying report to a small group (~15) of water managers, snow scientists, streamflow forecasters, and climate service providers, followed by phone interviews by Heather Yocum to systematically collect feedback on the pilot product. The pilot test has indicated the benefits and limitations of the MODIS-based SWE product. Current-

Snow measurement instruments in summer in Senator Beck Basin. Photo: Mark Raleigh/WWA

Western Water Assessment

ly, we are partway through the analysis of the interviews about the MODIS-based spatial SWE product. We expect that this feedback, along with interaction at the upcoming September workshop in western Colorado, will indicate priorities for ongoing work in this area.

DROUGHT PREPAREDNESS AND MANAGEMENT IN THE COLORADO AGRICULTURE SECTOR

In 2018, WWA worked with the Colorado Department of Agriculture and the Colorado Water Conservation Board to develop a survey of the agriculture sector in the state asking about drought impacts, planning, and response. The results of this survey will be included in the 2018 update of the Colorado Drought Plan.

Our goal was to better understand the water and drought challenges farmers and ranchers across the state face, including their past experiences and future concerns about water availability for their operations. A geographically broad sample of the agricultural community participated, giving us a snapshot of these producers and their previous and current experiences with drought. Fifty-five percent of respondents believe their operations are located in a geographical area that frequently experiences prolonged drought, and the majority (89 percent) reported that they had made changes to their operations to better prepare for the next drought. The types of changes they made to their operations are mostly technological, such as installing drip irrigation or using more center pivots, and managerial, such as changing crop types or using less intensive tillage practices.

INCORPORATING CLIMATE CHANGE IN PROBABLE MAXIMUM PRECIPITATION ESTIMATES FOR DAM SAFETY

The Colorado Division of Water Resources and the New Mexico Office of the State Engineer have identified and set as a priority the need to update the decades-old extreme precipitation estimates used in the evaluation of spillway adequacy for dams in these states, based on the most modern methods and scientific understanding available. To investigate the geographically and meteorologically similar Colorado and New Mexico, we have undertaken a cooperative study, the Colorado-New Mexico Regional Extreme ,Precipitation Study (CO-NM REPS). Of particular concern in both states are the physical limits on high-elevation rainfall amounts and the annual exceedance probability of the extreme rainfall amounts used for spillway design. The initial study plan for CO-NM REPS did not explicitly incorporate climate change influences in Probable Maximum Precipitation (PMP) estimates. Recognizing future risk from extreme precipitation may be different in a changing climate, the study's sponsors asked WWA's Jeff Lukas and Kelly Mahoney to take stock of the state of the science and practice in PMP estimation with respect to climate change in a white paper that has become a volume in the study final report. We completed an initial literature search and review in spring 2017, followed by a web-based survey of CO-NM REPS sponsors, researchers, technical advisory board members, and other stakeholders in summer 2017 to scope additional questions and issues of interest. We will submit the final volume in June 2018.

Field surveyors Nick Michael, Dave Salter and Michael Swinford run a level loop to establish current year elevations for tiltmeters, sensitive inclinometers designed to measure small structure changes, at Cherry Creek Dam near Denver, Colorado. Photo: U.S. Army Corps of Engineers

CIRES creates and fosters **institutional programs and teams** to continually improve our organization, mentor next-generation researchers, serve our scientists, and inspire collaboration and innovation.

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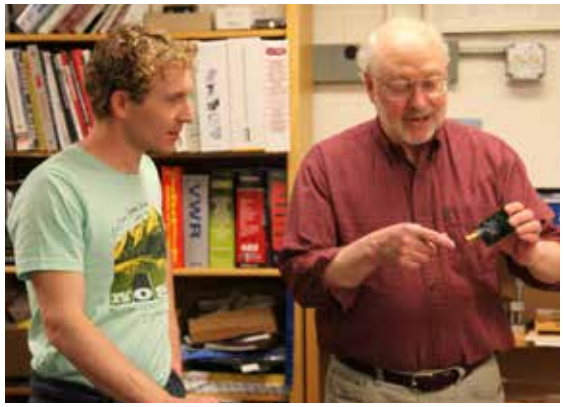

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Diversity and Inclusion

A NEW DIVERSITY AND INCLUSION INITIATIVE

CIRES has attended to diversity in outreach, undergraduate education, and community-facing science for decades. A new CIRES Diversity and Inclusion (D&I) program started in September 2017, focused on the CIRES workforce. The scope of the new program includes recruiting and search/hire processes; workplace inclusivity and culture; evaluation; and response to employee requests for innovations, programming, and support.

RECRUITING

We are developing relationships with more diverse communities of applicants and students, through partnership and collaboration with minority-serving science associations and with other geoscience organizations.

In 2018-19, CIRES D&I exhibited at the American Indian Science and Engineering Society and as part of the Young Scientist Symposium in Atmospheric Research at Colorado State University. Here in Colorado, in partnership with NOAA ESRL, we offered a number of student and faculty workshops. In 2018-2019, CIRES D&I is scheduled to exhibit as part of five, minority-serving science conferences in partnership with NOAA and other geosciences organizations.

HIRING

CIRES D&I is available to help search committees recruit a broad and deep applicant pool and to use processes which reflect best practices. In 2017-2018, CIRES D&I worked with the search committee for a faculty position in environmental economics to develop a large, more representative applicant pool, and with the Visiting Fellows Program to attract diverse candidates. Support for search committees may include attention to job ad inclusive language, materials and training for search committees, posting platform recommendations, and help broadening the reach of ads to potential candidates.

INCLUSIVITY/WORKPLACE CULTURE

To spark new conversations and develop skills for inclusivity at CIRES, we offered a set of training sessions in Spring 2018, in partnership with University of Colorado Boulder Office of Institutional Equity and Compliance and with the Center for Gender and Sexuality. Training topics included Bystander Intervention, Combating Harassment Policy and Reporting, and SafeZone training for LGBTQIA+ inclusion. A new slate of training events for the 2018-2019 fiscal year is being planned.

Garrett Campbell and Walt Meier of NSIDC choose gender pronouns to display on their nametags at the 2018 Rendezvous. Photo: Kathy Bogan/CIRES

At employee request, the CIRES Member's Council approved the inclusion of personal pronouns at the CIRES Rendezvous. Attendees could choose to display gender pronoun (he, she, they, ze) stickers on nametags.

In partnership with Office of Institutional Equity and Compliance and CU Institutional Research, CIRES deployed a workplace culture survey. The overall response rate was 60 percent. The results will be used to identify assets and issues at CIRES and to inform the CIRES D&I strategic action plan.

Diversity and 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; some highlights follow.

RESEARCH EXPERIENCE FOR COMMUNITY COLLEGE STUDENTS (RECCS)

In the summer of 2015, after a year-long pilot program, CIRES and the Institute of Arctic and Alpine Research (INSTAAR) received funding from the National Science Foundation to provide two additional years of the RECCS program, which gives summer research experiences to undergraduates from underserved communities. With this grant, CIRES' Education & Outreach group (page 38) 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.

More: http://cires.colorado.edu/education/outreach/projects/reccs.

Joseph Brown
Mentors: Mylène Jacquemart and Kristy Tiampo, CIRES/CU Boulder Geology
Project: Testing New Tools and Data Collection on Landslide Movement

James Butts
Mentors: Juliana Dias and John Albers, CIRES/NOAA
Project: North American Sub-Seasonal Climate Prediction Using Big Data

Jason Chambers
Mentor: Jen Kay, CIRES/CU Boulder ATOC
Project: Linearity of Cloud Feedbacks in Idealized Climate Modeling Experiments

Prudence Crawmer
Mentors: Rick Saltus and Manoj Nair, CIRES/NOAA
Project: Collecting Geomagnetic Data to Help Improve Navigation

Davin Duke
Mentors: Eleanor Browne and Jennifer Berry, CIRES/Chemistry
Project: Using Passive Samplers to Measure Organic Nitrogen in the Air

Jessica Ghent
Mentors: Katy Barnhart and Greg Tucker/CU Boulder
Project: The Impact of Ground Control Points on the Uncertainty of UAS-based Structure from Motion Topography

Mike Moore
Mentors: Aditya Choukulkar and Sunil Baidar, CIRES/NOAA
Project: Using Data from the Cloud Properties Experiment (CPEX) to Investigate How Aerosols Affect Cloud Formation

Susannah Rozak
Mentors: Jen Kay and Ariel Morrison, CIRES/CU Boulder ATOC
Project: Using Hand Sensors in an Experimental Setting to Test Student Engagement in Climate Change

Cora Rutledge
Mentors: Noah Fierer and Mallory Choudoir, CIRES/CU Boulder Ecology and Evolutionary Biology
Project: The Effect of Volatile Organic Compounds on Microbes

Kelly Sullivan
Mentor: Sam Califf, CIRES/NOAA
Project: Minimizing Satellite Data Error Caused by the Magnetosphere and Space Weather Phenomena

Sean Will
Mentors: Eric Small and Emily Fairfax, CIRES/CU Boulder Geology
Project: Impacts of Beaver Dams on Streamflow and Ground Flow Infiltration

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. More: http://resess.unavco.org.

CIRES Fellow Greg Tucker observes a debris flow basin en route to the launch point for a RECCS drone. Photo: Jessica Ghent/CIRES

Elizabeth Schaeffer
CIRES Mentors: Mike MacFerrin and Mike Willis, CIRES/CU Boulder Geology
Project: Exploring the Mechanisms and Causes of High Elevation Crevasses in the Interior of the Greenland Ice Sheet

Joel Johnson
CIRES Mentors: Kristy Tiampo and Magali Barba, CIRES/CU Boulder Geology
Project: Better Estimates of Creep Rate Along the Hayward Fault, CA, through High-Resolution DEMs and DInSAR

Diversity and Undergraduate Research

SIGNIFICANT OPPORTUNITIES IN ATMOSPHERIC RESEARCH AND SCIENCE (SOARS)

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

Pedro Brea
CIRES Mentors: Hazel Bain, Eric Adamson, CIRES/NOAA
Project: Using Machine Learning Techniques to Forecast Solar Energetic Particle Events

Ekaterina Lezine
CIRES Mentors: Sean Davis, Nick Davis, CIRES/NOAA
Project: Quantifying Spatial Sampling Error in the SWOOSH dataset from 1984 to 2004

Mia Murray
CIRES Mentors: Audrey Gaudel, Owen Cooper, Lesley Smith, CIRES/NOAA
Project: Ozone's Impact on Climate Change: Tropospheric Ozone Variability as Measured by Ozonesondes

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. More: https://www.colorado.edu/urop/

Abigayle Clabaugh
Mentor: Kris Karnauskas, CIRES/CU Boulder ATOC
Project: Modeling Effects of Climate Change on Ocean Acidification

2018 RESESS and SOARS interns participate in leadership training at Chautauqua Park during Orientation Week. May 22, 2018. Boulder, Colorado. Photo: Aisha Morris/UNAVCO

Seana Thompson
Mentor: Noah Fierer, CIRES/CU Boulder Ecology and Evolutionary Biology
Project: Panama Soils

Pim Maydhisudhiwongs
Mentor: Bruce Raup, CIRES/NSIDC
Project: Mapping and Documenting Glacial Boundaries Using Satellite Data

Stine Skalmerud
Mentor: Carol Wessman, CIRES/CU Boulder Ecology and Evolutionary Biology
Project: Can We Measure Tree Canopy Change with Accelerometers and Microclimates?

Graduate Student Research Awards

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

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

David Oonk
Advisor: Max Boykoff, Center for Science and Technology Policy Research, Environmental Studies
Topic: The Science Policy Nexus: Unconventional Oil and Gas and the Role of Science in Policymaking

Jennifer Berry
Advisor: Ellie Brown, Chemistry and Biochemistry
Topic: Sources of Organic Nitrogen Deposition in Sensitive High Alpine Ecosystems

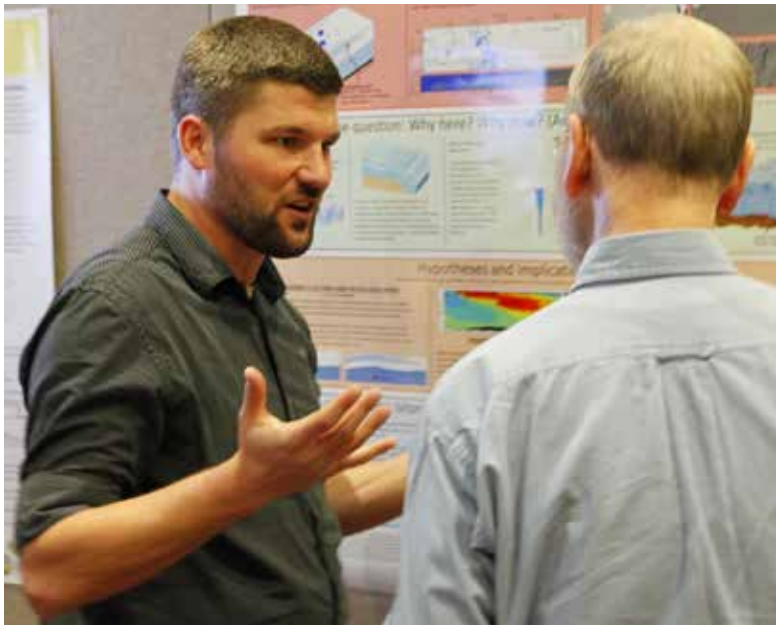
Angela Oliverio
Advisor: Noah Fierer, Ecology and Evolutionary Biology
Topic: Predicting the Distribution and Ecological Functions of Protists in Soils From Across the Globe

Lina Perez-Angel
Advisor: Peter Molnar, Geological Sciences
Topic: Pliocene Tropical Climate, Mountain Building, and the Closure of Central American Seaway

Kelsey Reeves
Advisor: Balaji Rajagopalan, Civil, Environmental, and Architectural Engineering
Topic: Modeling Variability in Surface Water Quality

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/science/pro/irp/.



Poster session for the Innovative Research Program, November 2017. Photo: Katie Weeman/ CIRES

2018 INNOVATIVE RESEARCH PROGRAM AWARDS

Do people or forests emit more monoterpenes? Detection of monoterpene emissions from volatile chemical products in urban areas
Investigators: Carsten Warneke, Brian McDonald, Matthew Coggon, Jessica Gilman

A terrestrial simulator of wildfire impacts on watersheds across the western United States
Investigators: Ben Livneh, Fernando Rosario-Ortiz

CMOPS: an optical particle sizer for coarse mode aerosols
Investigators: Hagen Telg, Allison McComiskey

Innovative approach to investigation of gas and aerosol emissions and oxidation products from volatile chemical products, consumer products, and human activity in indoor environments
Investigator: Jose Jimenez

New insights into sea ice processes through innovative use of new passive microwave remote sensing approaches
Investigators: Walt Meier, Mary Jo Brodzik

Quantifying the impact of water storage changes on earthquake seismicity from integrated satellite geodesy
Investigators: Kristy Tiampo, Steve Nerem

Demonstration of high spectral resolution lidar (HSRL) measurements of aerosols and clouds using a coherent Doppler wind lidar.
Investigators: Sunil Baidar, Alan Brewer, Paul Schroeder

Integrated Instrument Development Facility

CIRES chemist and instrument designer Don David and colleagues Dave Pappas and Xian Wu at the National Institute of Standards and Technology discovered a powerful new plated metal combination that superconducts at easily attained temperatures—paving the road for the next critical steps in the development of cutting-edge supercomputers. The combination is a sandwich of ultrathin rhenium between layers of gold, each measuring 1/1000th the diameter of a human hair. Photos: Katie Weeman/CIRES

The Integrated Instrument Development Facility (IIDF) is operated as a partnership of 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 125 years of experience designing and building scientific instruments.

IIDF staff have designed and built state-of-the-art instruments 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; ultrahigh vacuum chambers; TIG 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. More information at http://cires.colorado.edu/iidf.

IIDF director Don David, right, and machinist Danny Warren, pointing left, give a tour to high school students participating in the 2018 National Ocean Sciences Bowl at the University of Colorado Boulder. Photo: Katie Weeman/CIRES

Visiting Fellows

CIRES offers Visiting Fellowships at the University of Colorado Boulder. Every year, with partial sponsorship from NOAA, CIRES awards several fellowships to postdoctoral and senior/sabbatical visiting scientists. These fellowships promote collaborative and cutting-edge research. Since 1967, 350 people have been Visiting Fellows, including former CIRES Directors Susan Avery and Konrad Steffen. The following Visiting Fellows served all or part of their fellowship term from June 2017 to May 2018:

Alison Banwell

Postdoctoral Fellow
University of Cambridge

Term: May 2018 to April 2020

Project: The Formation of Surface Lakes on Antarctic Ice Shelves and their Impact on Ice-Shelf Stability

Sponsors: Waleed Abdalati, Ted Scambos

Alison Banwell is a glaciologist collaborating with Waleed Abdalati at CIRES and Ted Scambos at CIRES/NSIDC. Her project uses a combination of modeling, satellite remote sensing, and field-derived data analysis to investigate the formation of surface lakes on Antarctic ice shelves, and the effects of those lakes on ice-shelf stability. This is important because the most likely way for the Antarctic Ice Sheet to contribute to sea-level rise over the coming centuries involves the breakup of its ice shelves, which buttress approximately 75 percent of the ice sheet's edges and currently prevent the rapid discharge of inland ice into the ocean. A trigger of ice-shelf disintegration is thought to be surface-stress variations associated with surface meltwater ponding and draining, causing ice-shelf weakness, flexure, and potential fracture. For example, the widespread break-up of the Larsen B Ice Shelf in 2002 may have been partially triggered by the drainage of over 2,500 surface lakes.

Jennifer Henderson

Postdoctoral Fellow
Virginia Tech

Term: January 2017 to December 2018

Project: Identifying the Dynamics of Vulnerability in Community Water Usage along the Front Range

Sponsor: Lisa Dilling

Jen Henderson will work with CIRES Fellow Lisa Dilling, Director of the Western Water Assessment, and Rebecca Morss and Olga Wilhemi, of NCAR, to understand the complex nature of water-related vulnerabilities that arise in communities preparing for climate change and climate variability. She will study these dynamics of vulnerability through a qualitative, empirical analysis of current and future water use and management practices for two mid-size cities in Colorado. Henderson hypothesizes that this work will reveal how adaptations made to water use strategies in one place within the system may have unintended, and perhaps unseen, consequences at another point in the system. By looking at different stressors these communities experience, she hopes to make visible groups that have become more vulnerable to water issues and reveal common problems that transcend the situatedness of a particular issue and relevant dissimilarities that result in vulnerabilities of different types and scope. Henderson is looking forward to working with scholars in Boulder and communities across the Front Range to advance an understanding of local climate-related impacts and offer decision makers a valuable analysis of emerging vulnerabilities.

Fabian Hoffman

Postdoctoral Fellow
University of Hannover, Germany

Term: August 2017 to July 2019

Project: Entrainment and Mixing in Shallow Convective Clouds

Sponsor: Graham Feingold

Fabian Hoffmann is working with Graham Feingold and others at CIRES and NOAA to broaden our understanding of clouds in the climate system. He focuses on the processes of entrainment and mixing, i.e., the engulfment of cloud-free air into clouds. These processes affect the micro- and macrophysical properties of clouds by changing number and size of droplets and hence a cloud's ability to reflect sunlight as well as its probability to produce rain. For this purpose, Hoffmann is extending his Lagrangian cloud model, a novel method to represent cloud microphysics by individually simulated particles, by a detailed representation of entrainment and mixing. This approach not only fosters our process-level understanding of entrainment and mixing, e.g., on how and where mixing takes place inside a cloud, but also enables an assessment of the macrophysical properties of an entire cloud field, i.e., at a scale at which entrainment and mixing are usually crudely parameterized in other models.

Visiting Fellows

Elizabeth Maroon

Postdoctoral Fellow
University of Washington

Term: October 2016 to September 2018

Project: How Does the Atlantic Meridional Overturning Circulation Influence the Pace of Anthropogenic Surface Warming?

Sponsors: Jen Kay, Kris Karnauskas

Elizabeth Maroon is working with Jennifer Kay, Kristopher Karnauskas, and others at CIRES to study how the Atlantic Meridional Overturning Circulation (AMOC) interacts with the atmosphere to set the pace of global warming. Much of the excess heat trapped by greenhouse gases is absorbed by the ocean, which slows the rate of surface warming. As a result, the ocean plays an important role in setting how fast the surface warms. To improve our climate projections, we must have a full understanding of how the atmosphere and ocean interact to influence the rate of ocean heat uptake. The AMOC is a key component of the ocean circulation. While climate models show that the AMOC slows with greenhouse warming, it is not well understood how the AMOC influences ocean heat uptake. Maroon is studying how the AMOC's strength, heat transport, and circulation vary in coupled ocean-atmosphere climate models. Because the AMOC can influence both tropical and extratropical climate through its heat transport, the interaction of regional atmospheric climate feedbacks with the AMOC will also be examined. Maroon completed her Ph.D. at the University of Washington and was excited to join the research community at CIRES, especially because it was an undergraduate internship with CIRES scientists that started her career.

Ivar van der Velde

Postdoctoral Fellow
Center for Isotope Research, NED

Term: June 2016 to May 2018

Project: Using Atmosphere-Biosphere Data Assimilation to Improve Terrestrial Biosphere Models and the North American Carbon Balance

Sponsors: Stephen Montzka, John Miller

Ivar van der Velde is a meteorologist with a keen interest in the land-atmosphere exchange processes of atmospheric trace gases. He is working with John Miller and Stephen Montzka in NOAA's Global Monitoring Division to study the global terrestrial carbon dioxide sink, with a focus on North America. This sink remains uncertain in a warming world where droughts may be more extreme and more frequent. The impact of droughts is likely to be net carbon release, potentially leading to more extreme drought conditions. These feedbacks between the terrestrial carbon cycle and climate are poorly understood and represent a first-order uncertainty in climate prediction. It is therefore critical to improve the representation of the terrestrial biosphere in carbon-climate models. In the current project, van der Velde is focusing on the development of a data assimilation system that utilizes a novel combination of atmospheric CO_2 and $\delta^{13}C$ data to optimize well-known model parameters in terrestrial biosphere models. The main research goals are to improve our understanding of the large-scale moisture controls on carbon dioxide fluxes. This will be valuable for the plant-physiological research community and will help define where NOAA should measure CO_2 and $\delta^{13}C$ in the United States and around the globe.

Tara Webster

Postdoctoral Fellow
Cornell University

Term: August 2017 to July 2019

Project: Improving Biosand Water Filters using Insights from Microbial Ecology

Sponsors: Noah Fierer, Balaji Rajagopalan

Tara Webster is a microbial ecologist and environmental engineer. She is collaborating with Noah Fierer and Balaji Rajagopalan to improve our understanding of the microbial processes in biosand filters. Biosand filters hold great promise to provide clean drinking water in both developed and developing countries. Effective pathogen removal relies on the activity of a complex microbial community within the filter. However, little is known about the factors that shape microbial community structure and function in these systems. Currently, filter start-up and maintenance are based on empirical observations, leading to highly variable performance. To address this variability requires a better understanding of how filter design impacts microbial community development and pathogen removal. This research will determine how biotic and abiotic design decisions can shape microbial community structure to improve biosand filter performance. In partnership with a non-profit in Bangladesh, these results will be translated to the field where community-scale filter design and operation can be improved.

Visiting Fellows

Ian Willis

Sabbatical Fellow
Scott Polar Research Institute, University of Cambridge

Term: May 2018 to September 2019

Project: Meltwater Movement, Ponding and Refreezing on the Greenland Ice Sheet and Antarctic Ice Shelves

Sponsor: Mike Willis

Ian Willis is working with Mike Willis (no relation) to study water production, ponding, and refreezing in Greenland and Antarctic ice shelves, which have important implications for ice sheet/shelf mass balance, runoff, ice dynamics, and ultimately sea-level change. The first aim of his proposal is to amass a large, remotely zsensed dataset which will be used to quantify spatial and temporal patterns of surface and subsurface water extents across the firn zone of the Greenland Ice Sheet and across several Antarctic ice shelves. The recent advent of Google Earth Engine will help considerably with this task. The second aim of Willis' proposal is to work towards incorporating the horizontal advection of water and its storage, refreezing, and draining in snow/firn aquifers, on both the GrIS and AISs, into a numerical modelling framework. Such a model will help to better make sense of recent observations made on the GrIS and AISs, increase understanding of important hydrological processes operating on those ice masses, and ultimately enhance the ability to predict their future behavior.

Jody Wycech

Postdoctoral Fellow
University of Wisconsin

Term: October 2017 to September 2019

Project: Reconstructing Pliocene Precipitation: Constraining El Niño Teleconnections in a Warm World

Sponsors: Peter Molnar, Balaji Rajagopalan, Kris Karnauskas

Jody Wycech is working with Peter Molnar, Balaji Rajagopalan, and Kris Karnauskas to study the atmospheric teleconnections of El Niño during the Pliocene (5.3-2.6 Ma). The Pliocene is the most recent time interval in Earth history when global climate was warmer than the present, and as such is considered an analog to future climate conditions. Temperature reconstructions argue for a mean El Niño-like state during the Pliocene, but global precipitation anomalies produced by Pliocene El Niño are understudied. To this end, Wycech will reconstruct Pliocene rainfall in the southeastern United States and India, which respectively experience wetter conditions and a weaker summer monsoon during modern El Niño events. The Pliocene precipitation reconstruction will be completed using Ba/Ca ratios in the shells of marine protists (planktic foraminifera) recovered from sediments near river mouths, to gauge freshwater runoff. These results will provide novel insights into El Niño conditions in our future warmer world.

Researchers on a Greenland moraine. Photo: Benjamin Castellani/CIRES

Recognition and Reach

A group of CIRES scientists and engineers worked with a photographer from the *New York Times* to launch a Samsung 360 camera on the weekly ozonesonde balloon flight up to 100,000 feet on August 30, 2017. See the result at https://www.nytimes.com/video/science/100000005433524/noaa-ozone-balloon.html. Photo: Emrys Hall/CIRES

Selected Awards

The breadth and number of achievements by CIRES researchers and staff speak to the quality of research conducted at the Institute. From lifetime achievement awards to recognition of emerging young talent, CIRES scientists are among the best of the best at what they do.

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

Andrew Crotwell (GMD) for modernizing the core measurement systems of NOAA's global air sampling network, ensuring quality, reliability, and longevity of greenhouse gas data collected internationally.

Brian McDonald (CSD) for uncommonly creative, intelligent, and high-impact research to improve our understanding of how human activities affect air quality.

Carrie Morrill (NCEI) for a paradigm-shifting study of climate changes during the Last Glacial Maximum, and resourceful informatics work enabling paleoclimate research.

Andy Neuman and Richard McLaughlin (CSD) for development and nearly flawless deployment of a chemical ionization mass spectrometer, enabling new insights into the chemistry controlling atmospheric composition.

Service

Andrew Clarke (GMD) for a high-performance update of the meteorological systems at NOAA's baseline atmospheric observatories, serving the global science community.

Susan Lynds (Admin) for behind-the-scenes, often "heroic" evaluation work for researchers at CIRES, CU Boulder, NOAA, and the broader geosciences community—making great science even better.

CIRES MEDAL AND TECHNOLOGY TRANSFER AWARDS

CIRES scientists are often integral to NOAA award-winning science and engineering teams but cannot be given certain federal awards, such as the prestigious Department of Commerce Gold and Bronze medals and NOAA Technology Transfer Awards. The CIRES Director recognizes the extraordinary achievements of CIRES scientists working in partnership with federal colleagues.

CIRES Gold Medal

Athanasios Boudouridis, Sam Califf, Abram Claycomb, Stefan Codrescu, Jonathan Darnel, Vicki Hsu, Brian Kress, Larisza Krista, Paul Loto'aniu, Janet Machol, Juan Rodriguez, William Rowland, Daniel Seaton, Meg Tilton (NCEI) were part of a NOAA team that won a Department of Commerce Gold Medal for a successful GOES-R satellite launch, proving the nation's foundation for the world's highest quality weather monitoring and forecasting.

CIRES Technology Transfer Awards

Wayne Angevine, Laura Bianco, Timothy Bonin, Aditya Choukulkar, Irina Djalalova, Jeffrey Hamilton, Ming Hu, Eric James, Jaymes Kenyon, Terra Ladwig, Joseph Olson, Kathleen Lantz, Chuck Long, Katherine McCaffrey, Yelena Pichugina, and Tanya Smirnova (NOAA ESRL) were part of a team that won a NOAA Technology Transfer Award for improving forecasts of turbine-height winds and solar irradiance from the HRRR weather model to improve usage of renewable power by industry.

Paul Johnston and David Costa (PSD) were part of a team that won a NOAA Technology Transfer Award for designing, implementing, and operating a 21st-Century observing network to address water resource and flood protection issues in the Western United States.

INTERNATIONAL AWARDS

Noah Fierer, Joost de Gouw, José-Luis Jimenez, Mark Serreze, and Julienne Stroeve were recognized as 2017 Clarivate Analytics Highly Cited Researchers in their disciplines.

Shari Fox Gearheard (NSIDC) and the team behind the research project and book, *The Meaning of Ice,* were awarded the inaugural Mohn Prize in Tromso, Norway for groundbreaking contributions to our understanding of Arctic ice-dominated systems via a highly innovative combination of natural science, social science, and Indigenous knowledge.

Joost de Gouw (CU Boulder) and Barbara Ervens (CSD) were chosen by French President Emmanuel Macron's to serve on the "Make Our Planet Great Again" Climate Science Initiative Grant.

R. Michael Hardesty (CIRES) received a Lifetime Achievement Award from the International Coordination-group for Laser Atmospheric Studies (ICLAS) for sustained outstanding and innovative achievements in the areas of lidar techniques, technologies, and observations.

William Lewis Jr. (CU Boulder) was named a Fellow of the American Association for the Advancement of Science (AAAS), section on biological sciences.

Kristy Tiampo (CU Boulder) was awarded the Meritorious Service Award at the 2017 Canadian Geophysical Union meeting.

Greg Tucker (CU Boulder) was elected a Fellow of the American Geophysical Union.

Veronica Vaida (CU Boulder) was honored in a special "Veronica Vaida Feschrift" issue of the *Journal of Physical Chemistry*.

Elizabeth Weatherhead (GSD) received the Ken Spengler Award, for creating linkages and fostering open

communication about forecast improvements among the public, private, and academic sectors of the weather enterprise, from the American Meteorological Society. She was also elected a Fellow of the American Meteorological Society.

NATIONAL AND OTHER AWARDS

Ravan Ahmadov, Joost de Gouw, Bill Dubé, Stu McKeen, Christoph Senff, Colm Sweeney, Patrick Veres, Rebecca Washenfelder, Carsten Warneke, Abigail Koss, and Chelsea Thompson (CSD/GMD) were CIRES co-authors on an Outstanding Paper Award from NOAA OAR for: "High winter ozone pollution from carbonyl photolysis in an oil and gas basin," published in *Nature*.

CIRES Fellow **Stan Benjamin (GSD)** was promoted to NOAA Scientific and Professional (ST).

Pedro Campuzano Jost, José-Luis Jiménez, and Benjamin Nault (CU Boulder); Kara Lamb (CSD); and Christine Wiedinmyer (Admin) were part of a team awarded a NASA Group Achievement Award for their work on KORUS-AQ, an international cooperative air quality field study in Korea.

Annie Davis, Stephanie Evan, Shang Liu, Richard McLaughlin, Cathy Burgdorf Rasco, Eric Ray, Andrew Rollins, Troy Thornberry, Laurel Watts (CSD); Eric Hintsa and Fred Moore (GMD) were part of a team that won a NASA Group Achievement Award for outstanding

Award winners at the 2018 CIRES Rendezvous gather for a group portrait at the University of Colorado Boulder's Memorial Center. Photo: Katie Weeman/CIRES

achievements of the Pacific Oxidants, Sulfur, Ice, Dehydration, and Convection (POSIDON) Airborne Earth Science Mission Team.

David Costa, Leslie Hartten, Darren Jackson, Paul E. Johnston, Don Murray, and Dan Wolfe (PSD) were part of a NOAA team recognized with the 2017 NOAA Research Employees of the Year award for rapidly implementing and supporting a complex, multi-platform, multiorganizational field campaign to observe a rare, high-intensity El Niño event in the equatorial Pacific.

Athanasios Boudouridis, Sam Califf, Abram Claycomb, Stefan Codrescu, Jonathan Darnel, Vicki Hsu, Brian Kress, Larisza Krista, Paul Loto'aniu, Janet Machol, Juan Rodriguez, William Rowland, Daniel Seaton, and Meg Tilton (NCEI) shared a prestigious 2017 NASA Achievement Award for excellence resulting in the successful GOES-R satellite launch, providing the nation's foundation for the world's highest quality weather monitoring and forecasting.

Jeff Deems (NSIDC and WWA) received Honorable Mention from CO-LABS' Governor's Award for High-Impact Research, for his work in improving avalanche safety and water resource management.

Noah Fierer (CU Boulder) received the CU Boulder Provost's Faculty Achievement Award.

Anne Gold (Admin) received a CU Boulder Chancellor's Award for Excellence in STEM Education for her research into improving spatial visualization skills.

Anne Gold and Susan Sullivan (Admin), and colleagues received a Friend of the Planet Award from the National Center for Science Education for their work on the Climate Literacy and Energy Awareness Network (CLEAN).

Shilpi Gupta, Jonathan Joyce, Steve Kasica, Vincent Keller, Tony Liao, Ian McGinnis, Hilary Peddicord, and Beth Russell (CIRES in GSD); and Keith Searight and Jeff Smith (CIRA in GSD) were part of a NOAA team honored at the Ninth Annual CO-Labs Governor's Awards for High Impact Research for Science on a Sphere® and SOS Explorer™ data visualization systems used worldwide to educate the public about science.

CIRES researcher Alice Hill samples the hydrochemistry and isotopic composition of the largely inaccessible upper Maranon River, Peru. Photo: Henry Worobec/CIRES

Alice Hill (NSIDC) was awarded the Nature, Environment, Science & Technology Studio for the Arts fellowship (co-awarded with Media Studies Ph.D. student Toma Peiu) for work to explore the relationship of migrating waters and peoples in Central Asia's Aral Sea Basin.

Kristopher Karnauskas (CU Boulder) received a 2017 American Geophysical Union Ocean Sciences Early Career Award.

Jennifer Kay (CU Boulder) received the 2017 American Meteorological Society Henry G. Houghton Award, "for the innovative use of observations and global climate models to better understand the rapidly evolving climate of the polar regions."

Alia Khan (NSIDC) was named a 2017 Data Share Fellow by the U.S. Research Data Alliance.

Kathleen Lantz (GMD) and Eric James and Joseph Olson (GSD) shared the Utility Variable-Generation Integration Group (UVIG) 2017 Annual Achievement Award with colleagues from several institutions, for major contributions to advancing the state-of-the-art solar energy forecasting.

Ben Livneh (CU Boulder) received the Ralph E. Power Junior Faculty Enhancement Award from Oak Ridge Associated Universities.

Peter Molnar (CU Boulder) became a CU Distinguished Professor.

Carrie Morrill (NCEI) was awarded a 2018 Outstanding Information Technology and Engineering Employee Award from NESDIS for developing an innovative search capability within NCEI's Paleoclimatology web service, allowing customers to efficiently find, preview, and download data.

Philip Pegion (PSD) was part of a team that won a NOAA Administrator's Award for leading/executing the selection of the new dynamical core, the engine of a numerical weather prediction model, two years ahead of schedule.

Allen Pope (NSIDC) was named an Inaugural Fellow in the AAAS Community Engagement Fellows Program.

David Reynolds (PSD) was part of a team that won a NOAA Administrator's Award for advancing weather and climate models to balance flood and drought risks while providing water reliability for fish and people in the western United States.

Mark Serreze (NSIDC) was named CU Boulder College of Arts and Sciences Professor of Distinction.

Margaret Tolbert (CU Boulder) was part of a team that received a NASA Group Achievement Award for their efforts in the Mars Science Laboratory Extended Mission.

Christine Wiedinmyer (Admin) is a board member of the Earth Science Women's Network which was awarded a Presidential Award for Excellence in Science, Mathematics and Engineering Mentoring (PAESMEM).

Paul Ziemann (CU Boulder) was elected as a Fellow of the American Association for Aerosol Research (AAAR).

Events

ANALYTICAL CHEMISTRY SEMINARS

Joep de Bruin, Separation of NO_x emissions from drilling, and oil and gas extraction in the U.S. using monthly data from the Ozone Monitoring Instrument (3/19/18)

Daven Henze, International air quality, health, and climate impacts of cookstoves, diesel NOx, and other anthropogenic sectors via PM2.5 and O_3 (3/5/18)

Emily Fischer, Assessing the sources of elevated Front Range ozone based on observations from the Boulder Atmospheric Observatory (2/12/18)

Joost de Gouw, Atmospheric chemistry of volatile organic compounds (1/22/18)

Maggie Tolbert, Every drop counts...looking for water on Mars (1/22/18)

Aroob Abdelhamid, Measurements of positive ambient ions as part of HISCALE II field campaign (12/4/17)

Nathan Reed, Optimization of surface-initiated atom transfer radical polymerization for application to small analyte detection (11/13/17)

Sasho Gligorovski, Indoor air (photo)chemistry: A world-wide concern (10/13/17)

Dan Cziczo, Better understanding climate and atmospheric chemistry by understanding the formation of mixed phase clouds (10/9/17)

Paul Ziemann, Chemistry of organic compounds in the atmosphere and indoor air (10/2/17)

José-Luis Jiménez, Recent results and upcoming projects to investigate aerosol sources, properties, processes, and fate (10/2/17)

Julia Bakker-Arkema, Comprehensive analysis of the gas- and particle-phase products of VOC oxidation (9/18/17)

Nina Vance, Investigating emissions of ultrafine aerosols from consumer products: A study on 3D printers (9/11/17)

Qi Zhang, Regional influence of wildfires on atmospheric aerosol in the western U.S. and insights into emission and aging of biomass burning organic aerosol (7/12/17)

CSTPR NOONTIME SEMINARS

Rebecca Page, Finding new ground for advancing hydro-climatic information use among small mountain water systems (4/25/18)

Alexander Verbeek, Our lives in the 21st Century: The best of times or the worst of times? (4/11/18)

Anna Kukkonen, Discourse networks and climate change: Comparing media debates on climate change policy in Canada, the U.S., Finland, Brazil, and India (3/14/18)

Lori Peek, Extreme events reconnaissance: Social science and interdisciplinary research in the disaster aftermath (2/7/18)

DISTINGUISHED LECTURE SERIES

CIRES DLS

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.

Dr. Alan Robock
Climatic and humanitarian impacts of nuclear war (4/5/18)

Dr. Paul Wennberg
Improving air quality: Is less NOx always better? (2/16/18)

Dr. John J. Clague
Danger from the sea: Sea-level rise in a changing climate (11/3/17)

Dr. Benjamin Cook
The past and future of drought in the Western United States (9/29/17)

Katie Chambers, Flood modeling and early warning assessments for downstream communities of Koka Dam, Ethiopia (1/24/18)

Heather Bené, AAAS "Catalyzing Advocacy in Science and Engineering" workshop student competition panel discussion (11/29/17)

Andrew Rumbach and Esther Sullivan, The socio-spatial dimensions of disaster risk in mobile home parks: Learning from the 2013 Colorado floods (11/1/17)

Grant Couch, Climate and Congress: The making of a citizen (10/25/17)

Benét Duncan, Sustained assessment in the U.S. Southwest (10/18/17)

Lauren Gifford, Forests, finance, and conservation: A turn in U.S. climate policy (9/13/17)

SCIENCE ON TAP

Ethan Greene, Avalanche Science 101 (12/14/17)

Jim Roberts, How to make friends and influence wildfires (2/6/18)

Chrissy Henderson, Saving or historic treasures from corrosion (3/13/18)

Noah Fierer, The microbial ecology of our homes (4/3/18)

Brian McDonald, Matthew Coggon, and Jessica Gilman, Deodorant, cleaning products, and the virtue of smelling bad (6/12/18)

Mark Serreze, The Arctic meltdown: how we got there and what it means (4/10//18)

CRYOSPHERIC AND POLAR PROCESSES SEMINAR

Siri Jodha Singh Khalsa, Global efforts to broaden the benefits of research data to society (4/25/18)

Alia Khan, Chemical characterization of legacy and contemporary dissolved black carbon in the global cryosphere (4/20/18)

A field team tests the strength of a frozen meltwater lake on the McMurdo Ice Shelf Antarctica, January 2017. Photo: Alison Banwell/CIRES

Matthew Tooth, The application of statistical learning techniques to studying Arctic sea ice survival (2/21/18)

Kevin Schaefer, Why is there so much mercury in permafrost? (2/7/18)

Yasin Elshorbany, Committed carbon emissions and global warming due to the permafrost carbon feedback (1/24/18)

Catalina Oaida, Modeling snow in western U.S.: (i) improving and understanding dust-on-snow processes and (ii) developing a high-resolution hydrologic modeling and data integration platform (1/17/18)

Walt Meier, Known knowns, known unknowns, and unknown unknowns about uncertainties in passive microwave sea ice data (11/29/17)

Kang Wang, Was there a climate warming "hiatus" in the Arctic? (11/1/17)

Lutz Schirrmeister, Paleo-environmental studies on permafrost deposits in western Beringia: From field sampling to lab analysis to regional synthesis (10/25/17)

Zhixing Ruan, SAR remote sensing for monitoring mountain glacier surface movements in high mountain Asia (10/11/17)

Irina Overeem, Beyond water: Impact of Greenland's melt on its coastal sediment dynamics (10/4/2017)

Glenn Grant, Crunching ice: Compacting massive antarctic surface temperature datasets (9/27/17)

Matthew Druckenmiller, Ice for whales, ice for whaling: Observing the current state of an Arctic food shed (9/13/17)

Sebastian Schmidt, Understanding the atmospheric drivers of Arctic sea ice variability: the role of past and future aircraft experiments (9/6/17)

Lin Liu, Decadal changes of surface elevation over permafrost area estimated using reflected GPS signals (8/10/17)

HIGHLIGHTED EVENTS

Science on Tap

CIRES/NOAA researchers organized a series of monthly gatherings at Gunbarrel Brewing in Boulder, bringing together hundreds of science enthusiasts to discover the latest and greatest research happening on the Front Range. Guest presenters included CIRES Fellows Noah Fierer, Mark Serreze, and others (see page 59 for speaker list).

TEDxBoulder Salon

In March 2018, CIRES and NOAA scientists hosted an intimate community gathering at the NOAA campus focused on the fate of the ozone layer. The evening, entitled, "A World Avoided: How scientists helped prevent catastrophic destruction of the ozone layer," included a panel discussion by five CIRES, NOAA, and NASA scientists—and brought in about 50 attendees.

Brian Deese Keynote Address

The Center for Science and Technology Policy Research (CSTPR) celebrated its 15th anniversary by inviting Brian Deese, former science advisor to President Obama, to deliver the keynote address. Deese's talk brought in a near-full house to CU Boulder's Old Main Chapel.

Brave New Arctic Book Tour

CIRES Fellow and National Snow and Ice Data Center (NSIDC) Director Mark Serreze published *Brave New Arctic: The Untold Story of the Melting North* in early 2018 with Princeton University Press. Serreze went on a coast-to-coast book tour in May 2018.

The Mountains that Remade America Book Talk

CIRES Fellow and geology professor Craig Jones published *The Mountains that Remade America: How Sierra Nevada Geology Impacts Modern Life* in September 2017 with University of California Press. Jones completed a book tour in late 2017.

EDUCATION AND OUTREACH

Climate Literacy and Energy Awareness Network (CLEAN) Webinar series (4/18)

National Ocean Sciences Bowl 2018 Finals (4/18)

Trout Bowl (2/18)

Lens on Climate Change (7/17 and 3/18)

RECCS Summer Internship (6/17)

MISCELLANEOUS

Rollin Hotchkiss and George Annandale, Economics of sustainable reservoir sediment management (5/24/18)

CIRES Rendezvous 2018 (5/18/18)

Greg Morris, Sedimentation monitoring (5/10/18)

Rollin Hotchkiss and David Olson, Permitting for reservoir sedimentation management (4/26/18)

Steve Volz, NOAA Assistant Administrator for Satellite and Information Services (SIT) Climate and Eastern Ocean Systems/SIT NOAA meeting (4/23/18)

NASA, ESIP, and CU Boulder Earth Lab Machine Learning Career Panel (4/19/18)

Mark Serreze Book Talk: *Brave New Arctic* (4/19/18)

Graham Feingold, ACPC workshop (4/4/18)

TEDxBoulder Salon, CIRES/NOAA: A world avoided (3/29/18)

Tim Randle and Paul Boyd, Sedimentation management for multi-purpose reservoirs: A federal perspective (3/22/18)

Steve Miller, Coupled changes: Environment, policy, and innovation (3/5/18)

Matt Burgess, Surprising global tradeoffs and synergies between fisheries and conservation (2/26/18)

Greg Morris, Reservoir sedimentation management options and data needs (2/22/18)

George Annandale, Reservoir sedimentation management: Big deal! Why should we even care about it? (1/18/18)

IRP Reception and Poster Session (11/16/17)

Sheldon Drobot, Heidi Sherk, Benet Duncan, Joel Smith, Amber Ortega, CGA career panel (11/8/17)

Senator Steve Fenberg and Representative Edie Hooton, State Representative event (11/7/17)

Earth Lab science communication workshop (10/24/17)

CSTPR Open House, 15th anniversary of the Center for Science and Technology Policy Research with **Brian Deese**, CSTPR 15th anniversary keynote address: The case for clear-eyed optimism for future U.S. and international science policy (9/28/17)

Jen Kay, Films preview: Glaciers and sea ice and polar bears, oh my! (9/14/17)

Todd Hawbaker and Melanie Vanderhoof, Mapping burned areas using dense time-series of Landsat data (9/6/17)

David Parrish, A fresh look at dirty air: 40 years of effort to reach the U.S. ozone National Air Quality Standards (8/16/17)

International Glaciological Society International Symposium on polar ice, polar climate, polar change: Remote sensing and modeling advances in understanding the cryosphere (8/14/17-8/21/17)

Mahsa Mouissavi and Allen Pope, Polar sciences communications workshop (8/12/17)

Hartmut Herrmann, Aerosol particle organic mass formation: HOMs uptake, multiphase isoprene oxidation and cloud processing (8/9/17)

Keith Dixon, Examining the performance of statistical downscaling methods: Toward matching applications with the right tool (8/8/17)

Cindy Brekke, SnowEx workshop (8/8/17)

Bienvenido Leon, New coordinates for environmental documentary: How have nature and environmental documentaries changed since the internet arrived? (8/3/17)

Guy Brasseur, Ensemble forecasts of air quality in Asia: An operational multi-model approach (8/2/17-8/3/17)

Megan Melamed, Interdisciplinary Biomass Burning Initiative workshop (7/10/17)

Media

CIRES makes a robust effort to share the Institute's research findings and implications with the scientific community, decision-makers, and the public. During the reporting period, CIRES scientists earned coverage in: *Scientific American, New York Times,* CNN, *Washington Post, Popular Science,* Newsweek, National Public Radio, BBC, *The Guardian,* Fox News, *Forbes,* Buzzfeed, and many other local, national, and international outlets. Below are just a few news stories that gained outstanding attention between June 1, 2017 and May 31, 2018.

Ozone Treaty Taking a Bite Out of U.S. Greenhouse Gas Emissions

NOAA and CIRES scientists show 30-year old ozone-protecting treaty has also significantly reduced U.S. greenhouse gas emissions

August 2017

2017 Lancet Countdown on Health and Climate Change

CIRES' Max Boykoff contributed to a comprehensive, UK-led report on critical connections between climate change and human health

October 2017

Continued Emissions May Cause Global North-to-South Shift in Wind Power by End of Century

The rapidly growing wind energy industry may be challenged by changes in locations of wind resources

December 2017

CIRES Director Helping Set National Earth Science Priorities

New National Academies report prioritizes research to reduce climate uncertainty, improve weather forecasts, more

January 2018

"Building" a Future in Science with Construction-Based Toys

Spatial skills higher among those who played with construction-based toys and video games in childhood

February 2018

Medical staff treat an infant for malaria. Research from CIRES Fellow Max Boykoff was part of a report indicating climate change is unequivocally affecting the health of people around the world, with a disproportionate impact on vulnerable populations. The report appeared in the medical journal *Lancet* in October 2017. Photo: USAID

Sea Level Rise Accelerating

Research team led by CIRES fellow Steve Nerem detects an acceleration in the 25-year satellite record

February 2018

Consumer & Industrial Products Now a Dominant Urban Air Pollution Source

New study finds surprisingly high contribution from paints, pesticides, perfumes as vehicle emissions drop

February 2018

Detecting Methane from Miles Away

University of Colorado, CIRES, NOAA, and NIST team harnesses Nobel Prize technology to detect distant gas leaks

March 2018

Personal Plumes

Daily emissions from personal care products comparable to car emissions, contribute to air pollution in Boulder

April 2018

NOAA Finds Rising Emissions of Ozone-Destroying Chemical Banned by Montreal Protocol

May 2018

A Surprising New Superconductor

CIRES expert and NIST colleagues discover electroplated rhenium's unexpected superconductive characteristics

May 2018

Related paper in top 5% of all research outputs scored by Altmetric

Project Reports

Alana Wilson and Muhammed Esenamanov approach the Karabatkak Glacier to collect snow and ice samples as part of CIRES' CHARIS project. Photo: Alice Hill/CIRES

Project Reports by theme

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
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OAR	NOAA Office of Oceanic and Atmospheric Research
PSD	NOAA ESRL Physical Sciences Division
SWPC	NOAA NWS Space Weather Prediction Center

Project Reports, alphabetized

OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH (OAR)

NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SYSTEMS (NESDIS)

NATIONAL WEATHER SERVICE (NWS)

Project Reports: Air Quality in a Changing Climate

CSD-01: This is project is closed.

The work is now combined with other research in CSD-04, to ensure better alignment with planning and guidance documents of CSD and OAR.

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

CIRES Lead: Stu McKeen / NOAA Lead: Michael Trainer

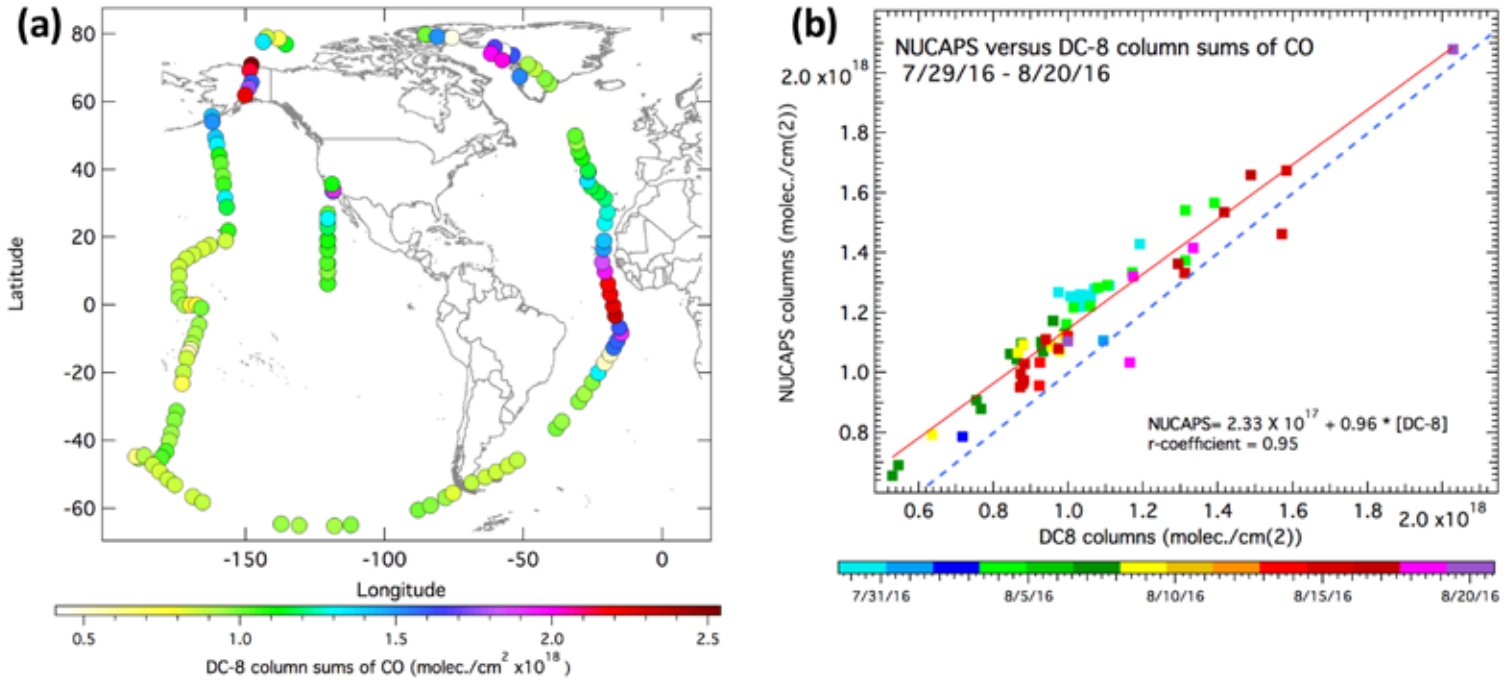
NOAA Theme: Climate Adaptation and Mitigation; Weather-Ready Nation

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

For the past three years, our team has worked cooperatively within the NOAA Unique Combined Atmospheric Processing System (NUCAPS) to assess the validity of experimental methane and carbon monoxide retrievals from combined microwave and infrared retrieval systems within the Visible Infrared Imaging Radiometer Suite (VIIRS) and the Cross-track Infrared Sounder (CrIS) onboard NASA's and NOAA's Suomi JPSS-1 satellite (https://jointmission.gsfc.nasa.gov/spacecraft.html). Retrievals of these constituents rely on a priori model estimates and altitude-dependent averaging kernels from radiative transfer calculations, and therefore contain inherent uncertainties that can only be characterized by comparisons with independent in-situ based observations. Though aircraft data we collected during NOAA field campaigns provide only snap-shots at a given times and places, they are still the most direct and accurate measurements for evaluation of satellite data. Specifically, the Atmospheric Tomography Mission (ATom, https://espo.nasa.gov/atom) used the NASA DC-8 aircraft for global atmospheric composition characterization, profiling continuously from 0.2 to 12 km altitude, from the Arctic to Antarctica during four different seasons between 2016 and 2018, traversing both the Pacific and Atlantic oceans. NOAA instrumentation onboard the DC-8 provided us with critical information on the vertical profiles of gas-phase species retrieved by VIIRS/CrIS during all the ATom missions. Our project consists of two components: We will evaluate a new high-spectral



CSD-02: (a) Location and magnitude of CO columns (below 11km) from measurements onboard the NASA DC-8 aircraft from 7/29/16 to 8/20/16 during the ATom-1 mission. (b) Scatter plot of CO column sums, NUCAPS retrievals versus NASA DC-8 measurements. Color bar indicates date. Image: CIRES/NOAA

resolution CO product from NUCAPS using NOAA data from the ATom-1 mission and examine NUCAPS CO retrievals during specific wildfire events to assess their utility in wildfire detection, plume height determination, and long-range transport.

From June 2016 to May 2018, we submitted quarterly reports to JPSS to document the progress of this cooperative project. In last quarter's report, we summarized comparisons of ATom-1 observations with retrievals for two flight days provided by the NUCAPS team. Since then, NUCAPS has provided retrievals for nine of the eleven possible flight days during the ATom-1 mission and a complete analysis has been performed. We used statistical comparisons of total columns (below 305 hPa or ~11 km altitude) for CO, CH_4, CO_2, SO_2, N_2O, HNO_3, O_3, and water vapor from ~130 vertical profiles collected between 7/29/16 and 8/20/16 to evaluate the corresponding retrieval data. Water vapor represents a useful reference variable when comparing statistics between species, since retrievals of H_2O from JPSS-1 are well established and known to be quite accurate. Meaningful correlations between ATom-1 total column amounts and the NUCAPS retrievals are only found for H_2O, CO and O_3. We further evaluated statistics over sub-layers of the total columns for these three species to identify biases or low correlations for specific heights, helping the NUCAPS team identify regions of the atmospheric where confidence in the retrievals is highest.

GSD-04: Improve Air Quality Predictions on Regional and Global Scales

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 and its feedback on meteorology for the purpose of making air quality and weather forecasts for regions of interest and at specific locations.

ACCOMPLISHMENTS

Li Zhang and others worked on the online coupling of inclusion of chemical modules GOCART into the NGGSPS FV3GFS-GSDChem model using NUOPC (National Unified Operational Prediction Capability). We have finished the major coupling, including development of the workflow for FV3GFS-GSDChem to run real-time forecast, postprocessing the chemical output. Currently, our CIRES researchers are working on transitioning the code to the FV3 master branch at NCEP/EMC.

Mariusz Pagowski has worked on following tasks for chemical data assimilation during the report year:

- Development of Ensemble Kalman Filter and variational assimilation of AOD to FV3-GOCART model
- Implementation of AOD forward operator in JEDI assimilation framework
- Development of assimilation scheme for variational smoke assimilation
- Implementation of AOD verification for a global model within MET software package
- Participation in development of forward operator for aerosol lidar backscatter assimilation

Ravan Ahmadov and Eric James, in collaboration with other researchers, accomplished the following milestones for experimental smoke forecasting:

- Developed a new biomass burning emissions parameterization for the HRRR-Smoke model, and updated the diurnal cycle and emission factors of the emissions.
- Added additional features to the HRRR-Smoke modeling system diagnostics, postprocessing and visualization (visibility etc.) of experimental smoke forecast products to meet various users' needs: https://rapidrefresh.noaa.gov/hrrr/HRRRsmoke/
- MODIS Terra and Aqua satellite fire radiative data have started ingesting to the HRRR-Smoke model.
- Set up a new smoke forecasting model based on the Rapid Refresh:
- https://rapidrefresh.noaa.gov/RAPsmoke/. The purpose of RAP-Smoke is to cover the entire North America domain (13.5 km resolution) and provide boundary conditions of smoke to HRRR-Smoke (3 km resolution).
- Compared the HRRR-Smoke simulated smoke concentrations and AOD with the in-situ and satellite data for August-September, 2017 time period, over northwestern U.S.
- Submitted a proposal to the JPSS PGRR program to continue working on the RAP/HRRR-Smoke development and verification.

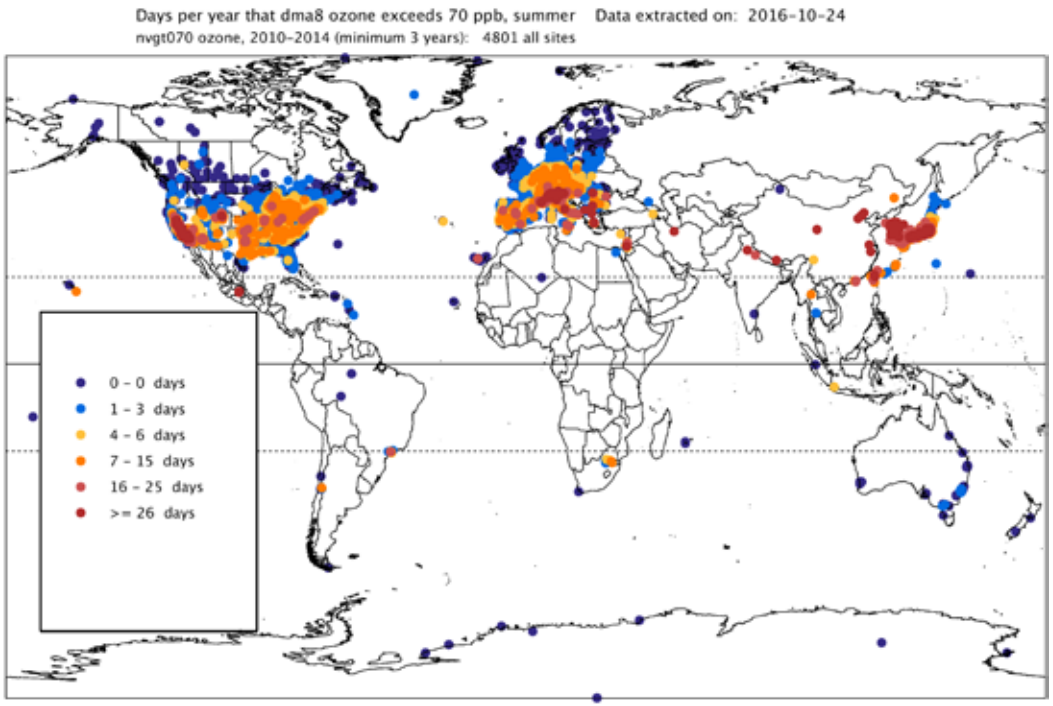
Ahmadov and others also worked on WRF-Chem model development and user support. We held a WRF-Chem tutorial in February 2018, in which we offered hands-on exercises to the tutorial participants.

ACRONYMS IN GSD-04

This report includes several key acronyms, defined in order for quick reading:

GOCART: Global Ozone Chemistry Aerosol Radiation and Transport
NGGPS: NOAA's Next Generation Global Prediction System
FV3GFS: Finite-Volume Cubed-Sphere Dynamical Core, Global Forecast System
GSD: Global Systems Division
NCEP/EMC: National Centers for Environmental Prediction/Environmental Modeling Center
AOD: Aerosol Optical Depth
JEDI: Joint Effort for Data Assimilation
MET: Model Evaluation Tools
MODIS: Moderate Resolution Imaging Spectroradiometer
JPSS: Joint Polar Satellite System
PGRR: Proving Ground and Risk Reduction
RAP: Rapid Refresh model
HRRR: High-Resolution Rapid Refresh model

Project Reports: Climate Forcing, Feedbacks, and Analysis



Number of days per year (averaged over 2010-2014) that the maximum daily 8-hour average ozone value exceeds 70 ppb (the US ozone standard) at 4801 sites worldwide. This plot shows ozone data from the TOAR Surface Ozone Database, which contains ozone metrics at all available ozone monitoring sites around the world.

CSD-03: Scientific Assessments for Decision Makers (IPCC, MP, U.S. Climate, U.S. AQ)

CIRES Lead: Owen Cooper / NOAA Lead: David Fahey

NOAA Theme: Weather-Ready Nation; Climate Adaptation and Mitigation

GOALS & OBJECTIVE

This project will provide credible assessments of environmental science relevant to decision making.

ACCOMPLISHMENTS

The Tropospheric Ozone Assessment Report (TOAR) is providing the first comprehensive overview of tropospheric ozone's present-day distribution and trends from the surface to the tropopause (the boundary between the troposphere and the stratosphere) using all available surface ozone observations. Our TOAR team is chaired by CIRES Senior Scientist Owen Cooper and is driven by the voluntary contributions of over 230 scientists and data providers from over 30 nations, and representing research on all seven continents. One of our major accomplishments was the creation of TOAR's Surface Ozone Database, which contains hourly ozone observations from over 9,000 sites worldwide. From these data, we calculated ozone exposure metrics consistently for all sites for subsequent analysis of the impacts of ozone on human health, vegetation, and climate (an example is shown in figure at left). The database also provides station metadata based on the information from global gridded datasets of human population, satellite-detected tropospheric NO2, a bottom-up surface emission inventory of nitrogen oxides, satellite detected land-use data, and satellite-detected nighttime lights of the world. Using these datasets, TOAR was able to classify sites as being rural or urban using an objective and consistent methodology.

We used output from the TOAR database to develop the analyses for the three TOAR papers that describe the global ozone distribution and trends relevant to human health, vegetation, and climate. For the first time, scientists have been able to conduct an observation-based assessment of the regions of the world with the greatest exposure to ozone, as well as the regions where ozone is decreasing or increasing (where monitoring data are available).

When we complete TOAR, it will consist of eight peer-reviewed publications in the non-profit, open access journal, Elementa: Science of the Anthropocene. By May 31, 2018, five of our eight papers were published (Chang et al. 2017, Fleming et al. 2018, Lefohn et al. 2018, Schultz et al. 2017, and Young et al. 2018) with one in-press and two more in preparation for submission to the journal.

The TOAR Surface Ozone Database became publicly available in August 2017 and researchers around the world are already downloading the data and using the metrics to conduct new research. Notably, Dr. Lin Zhang at Peking University, China, has a manuscript in preparation that compares the TOAR global data to recently available monitoring network data from China. The results confirm speculation that ozone air pollution events in China are more severe than in North America or Europe. Another important usage of the TOAR database has been its fusion with output from six global atmospheric chemistry models to produce the most accurate representation of global surface ozone yet achieved. The Global Burden of Disease (http://www.healthdata.org/gbd/about) is using the new product for their latest annual estimate of global human mortality due to ozone exposure.

Fleming, Z. L., R. M.Doherty et al. (2018), Tropospheric Ozone Assessment Report: Present-day ozone distribution and trends relevant to human health, Elem Sci Anth, 6: 12, DOI: https://doi.org/10.1525/elementa.273

Lefohn, A. S., et al. (2018), Tropospheric ozone assessment report: Global ozone metrics for climate change, human health, and crop/ecosystem research, Elem Sci Anth, 6: 28, DOI: http://doi.org/10.1525/elementa.279

Young, P. J, V. Naik et al. (2018), Tropospheric Ozone Assessment Report: Assessment of global-scale model performance for global and regional ozone distributions, variability, and trends, Elem Sci Anth, 6: 10, DOI: https://doi.org/10.1525/elementa.265

CSD-04: Effect of Emissions on Atmospheric Composition

CIRES Lead: Carsten Warneke / NOAA Lead: Tom Ryerson
NOAA Theme: Weather-Ready Nation; Climate Adaptation and Mitigation

GOALS & OBJECTIVE

This project will design and execute short-term field studies to characterize as completely as possible the chemical, physical, and dynamical processes that drive changes in atmospheric composition, and will use results from those field studies to understand the impacts of changes in atmospheric composition on important environmental issues, such as air quality and climate change.

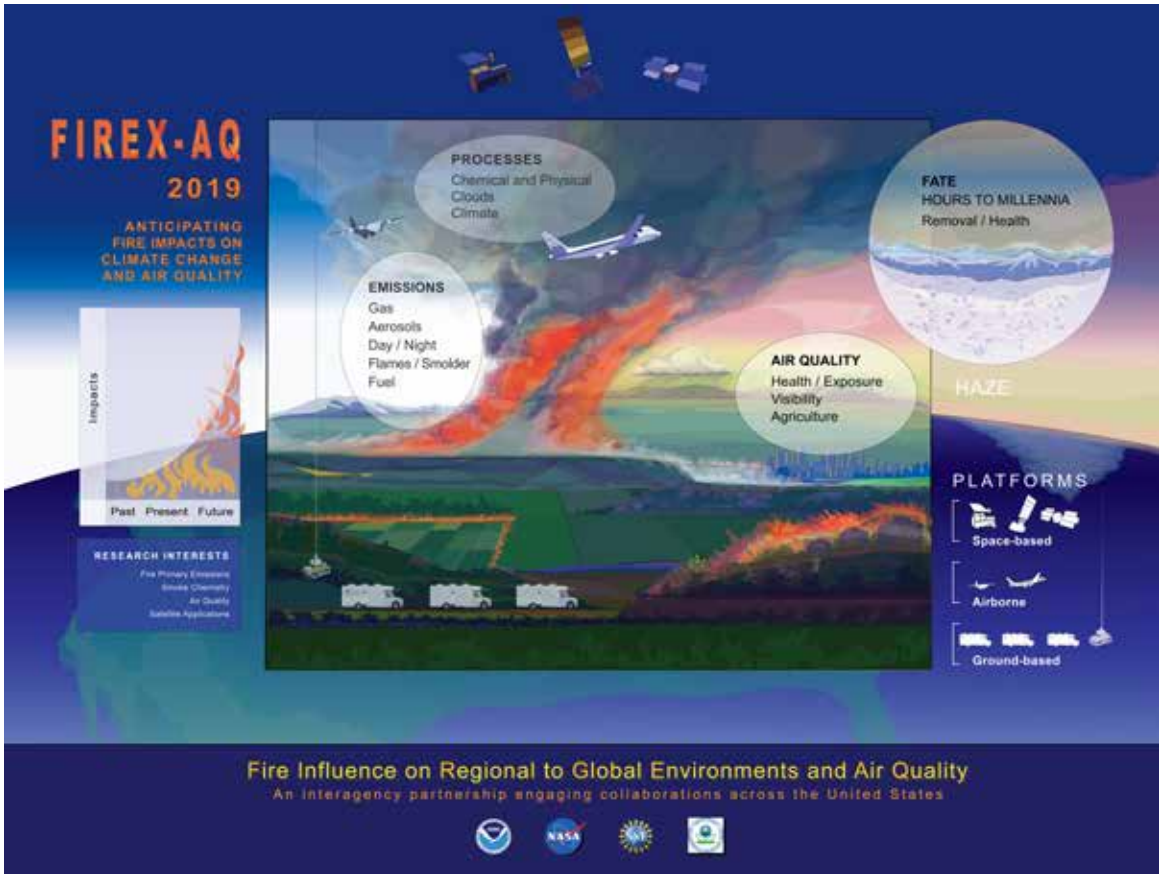
ACCOMPLISHMENTS

Biomass burning emissions: As part of FIREX (Fire Influence on Regional to Global Environments Experiment), our research team led extensive measurements at the Fire Science Laboratory in Missoula, Montana in 2016 to determine emissions of gases and aerosols from the most common fuels in the western United States. Our Firelab experiment brought together the largest set of common and novel instruments to look at biomass burning emissions in the greatest detail to date. We highlight two major findings here.

We had a special focus on emissions of volatile organic compounds (VOCs). Koss et al. (2018) collected measurements with a proton-transfer-reaction, time-of-flight mass spectrometer (PTR-ToF) and identified many VOCs with a higher certainty and detail than has previously been available. The interpretation of the PTR-ToF mass spectra accounts for nearly 90 percent of VOC mass detected by PTR-ToF across all fuel types and provided fire-integrated emission ratios to CO and emission factors of a large number of VOCs from 18 fuel types.

Sekimoto et al., (2018) analyzed the same dataset to understand the instantaneous variability in VOC emissions and to simplify the description of these types of emissions. Despite the complexity and variability of emissions, we found that just two emission profiles explained on average 85 percent of the VOC emissions across various fuels. In addition, the profiles were remarkably similar across almost all of the fuel types tested. We identified the two VOC profiles as high-temperature and low-temperature pyrolysis processes known to form VOCs in biomass burning. These processes do not correspond exactly to the commonly used flaming and smoldering categories, but change the way we understand VOC emissions from wildfires.

Oil & Gas production emissions: Our CIRES research team continued analysis of



CSD-04: FIREX-AQ image shows fire influence on regional to global environments experiment—and air quality. Image: CIRES/NOAA

SONGNEX (Shale Oil and Natural Gas Nexus) emissions data from oil and gas extraction operations. Peischl et al., (2018) calculated emission rates from the horizontal flux of methane and ethane in the planetary boundary layer downwind of five of oil and gas producing regions: the Bakken in North Dakota, the Barnett in Texas, the Denver Basin in Colorado, the Eagle Ford in Texas, and the Haynesville in Texas and Louisiana. We found methane leak rates between 1% and 5%, dependent on the basin. Ethane emissions from the Bakken and Eagle Ford regions combined account for 20% of anthropogenic emissions in North America.

Volatile chemical products: Our CIRES researchers led a groundbreaking study (McDonald et al., 2018) that found volatile chemical products (VCPs)—including pesticides, coatings, printing inks, adhesives, cleaning agents, and personal care products—now constitute half of fossil fuel VOC emissions in industrialized cities. Transport-derived emissions of VOCs have decreased owing to stricter controls on air pollution, so the relative importance of VCPs has increased. The high fraction of VCP emissions is consistent with observed urban outdoor and indoor air measurements. McDonald et al. (2018) show that human exposure to carbonaceous aerosols of fossil origin is transitioning away from transportation-related sources and toward VCPs. Existing U.S. regulations on VCPs emphasize mitigating ozone and air toxics, but they currently exempt many chemicals that lead to secondary organic aerosols.

Coggon et al. (2018) found that one of these VCPs—Decamethylcyclopentasiloxane (D5), widely used in personal care products—has mass emission rates comparable to that of benzene due to traffic. The diurnal emission pattern of D5 peaks between 6:00 and 7:00 am and subsequently follows an exponential decay with a time constant of 9.2 h, which can be explained by application of personal care products in the morning and subsequent slow evaporation throughout the day.

Atmospheric Tomography (ATom) Mission: Our team has very successfully participated in the Atmospheric Tomography (ATom) mission which deployed the NASA DC-8 aircraft mapping the global background atmosphere from the surface to ~12 km in all four seasons. ATom provides an unprecedented dataset to examine the distribution, transport, and processing of gases and aerosols throughout the global atmosphere.

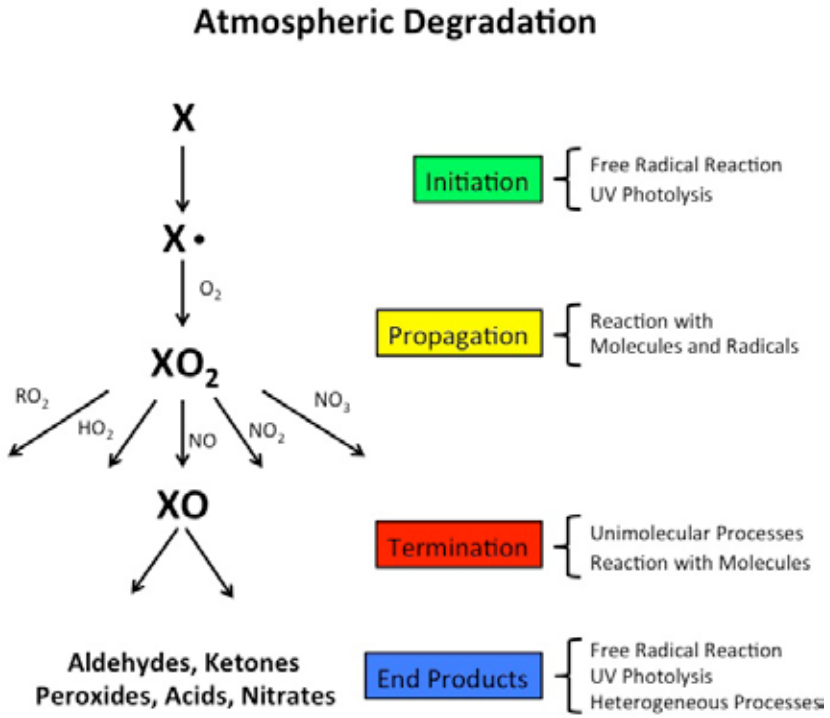
CSD-05: Laboratory Studies of Fundamental Chemical and Physical Processes

CIRES Lead: Dimitris Papanastasiou / NOAA Lead: Jim Burkholder

NOAA Theme: Weather-Ready Nation; Climate Adaptation and Mitigation

GOALS & OBJECTIVE

This research will produce fundamental information on photochemical and chemical reactions for trace species relevant to Earth's climate, air quality, and stratospheric ozone. The information is used to improve climate and air quality predictions and projections made by numerical models.



CSD-05: A trace gas (X) in the atmosphere undergoes transformation processes leading to a variety of stable endproducts. 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/NOAA

ACCOMPLISHMENTS

The 28th meeting of the parties to the Montreal Protocol on Substances that Deplete the Ozone Layer (Kigali, 2016) included a list of 274 hydrochlorofluorocarbons (HCFCs) to be controlled under the Montreal Protocol. We completed a comprehensive evaluation of the atmospheric lifetimes, ozone depletion potential (ODPs), and global warming potential (GWPs) of all 274 HCFCs to be included in the Montreal Protocol, using established empirical and theoretical methods. HCFCs within the same family (isomers) show a large ODP and GWP dependence on the molecular geometry of the isomers. The overall uncertainty in the derived GWP values is estimated to be on the order of 50%. If desired, to attain more accurate GWPs values, we would require fundamental laboratory studies to better define the reactivity and infrared absorption spectrum of the compound of interest.

Our team has continued evaluating the atmospheric fate and climate metrics for potential replacement compounds with a study on the reactivity of cyclic unsaturated hydrofluorocarbons. We evaluated the reactivity of cyclic-C_5F_8 and cyclic-C_5F_7H with OH radicals as well as their degradation products. We also completed infrared absorption spectrum measurements to combine with the estimated atmospheric lifetime and provide the global warming potentials of the compounds.

We evaluated a series of the persistent greenhouse gases perfluorinated amines (PFAm), $(C_xF_{2x}+1)_3N$ (x=2-5), which are used as heat transfer liquids. Our study evaluated various atmospheric removal pathways as well as the GWP values for these PFAms. Our findings suggest that the atmospheric lifetimes of PFAms are most likely determined by upper-atmospheric loss process, e.g. Lyman-a photolysis, with estimated lifetimes greater than ~3,000 years.

Our team completed a study on the atmospheric observation and lifetime of perfluorofuran (C_4F_4O). This study is the first to report the atmospheric observation of C_4F_4O, which is a persistent greenhouse gas. To better understand the climate impact of this compound, we evaluated the atmospheric removal pathways, measured the infrared absorption spectra, and estimated the global warming potential, GWP. Overall, we expect the climate impact of perfluorofuran to be small due to its low concentration in the atmosphere.

Permethylsiloxanes are used in many personal care products and have been recently detected in the atmosphere, where they decompose by reaction with OH radicals. The reaction products possibly contribute to new particle and secondary organic aerosol formation. In this project, we measured infrared absorption spectra of linear and cyclic permethylsiloxanes (a total of eight compounds) and their OH radical reaction rate coefficients (Bernard, et al. 2017.)

We investigated the reaction of ground-state nitrogen atoms, $N(^4S_{3/2})$, with nitrogen oxide, NO, and nitrogen dioxide, NO_2 at atmospherically relevant pressures and temperatures. Both reactions are key removal pathways for NO and NO_2 in the upper stratosphere and mesosphere. In this kinetic study, we monitored $O(^3P)$ production from these reactions in a flow tube apparatus coupled with resonance fluorescence detection. The results from this study clarify the large discrepancy in the rate coefficients reported in the literature for the $N(^4S_{3/2})$ reaction with NO and NO_2, and, for the first time, report the $O(^3P)$ product yield from the $N(^4S_{3/2})$ + NO_2 reaction.

We continued development of the total reactive nitrogen (N_r) method by extending its application to particle-phase compounds—and found the method was found to quantitatively convert (100±10%) all forms of nitrogen (except N_2 and N_2O) to nitric oxide (NO), by means of a high-temperature platinum catalyst, which was then sensitively measured by NO-ozone chemiluminescence. Our further work demonstrated that the same catalyst completely converted organic carbon to CO_2, and so can be used as a means to determine total organic carbon contained in aerosol particles. We successfully compared the N_r method to an independent mass-based aerosol measurement method, the particle-into-liquid-sampler electrospray mass spectrometer (PiLS ESI/MS), and the methods agreed within ±5% for single component particles.

PUBLICATIONS

Baasandorj, M., Marshall, P., Waterland, R. L., Ravishankara, A. R., and Burkholder, J. B. (2018). Rate Coefficient Measurements and Theoretical Analysis of the OH + (E)-CF3CH□CHCF3 Reaction, The Journal of Physical Chemistry A, 122, 4635-4646, 10.1021/acs.jpca.8b02771.

Bernard, F., Papanastasiou, D. K., Papadimitriou, V. C., and Burkholder, J. B.: (2018). Temperature Dependent Rate Coefficients for the Gas-Phase Reaction of the OH Radical with Linear (L2, L3) and Cyclic (D3, D4) Permethylsiloxanes, The Journal of Physical Chemistry A, 122, 4252-4264, 10.1021/acs.jpca.8b01908.

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Stockwell, C. E., Kupc, A., Witkowski, B., Talukdar, R. K., Liu, Y., Selimovic, V., Zarzana, K. J., Sekimoto, K., Warneke, C., Washenfelder, R. A., Yokelson, R. J., Middlebrook, A. M., and Roberts, J. M. (2018). Characterization of a catalyst-based conversion technique to measure total particulate nitrogen and organic carbon and comparison to a particle mass measurement instrument, Atmos. Meas. Tech., 11, 2749-2768, 10.5194/amt-11-2749-2018.

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

CIRES Lead: Karl Froyd / NOAA Lead: Dan Murphy

NOAA Theme: Weather-Ready Nation; 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

FIREX FireLab Study: As part of the FIREX project, our research team and collaborators investigated the relationship between the morphology and the scattering phase function of biomass burning aerosol from realistic laboratory fires (Manfred et al. 2017). We also used these biomass burning aerosol measurements to attribute the aerosol optical absorption tt brown and black carbon, and investigate absorbing species intermediate between brown and black carbon.

Remote sampling of mineral dust and other climate-relevant aerosol (ATom airborne mission): We completed the final two deployments of the NASA ATom field campaign to sample the vertical and geographic distribution of aerosol species in the remote Pacific and Atlantic

CSD-06: Looking down over the Antarctic Peninsula at sunset, researchers aboard the NASA DC8 aircraft sample climate-relevant aerosol and gases as part of the global ATom campaign. Photo: Karl Froyd/CIRES

basins. We measured aerosol size and composition for species with high relevance to global climate, including particle nuclei, mineral dust, biomass burning particles, and sea salt. Murphy et al. (2017) published an observation of an atmospheric particle containing enriched uranium. Our CIRES scientists and collaborators built a compact, semi-autonomous instrument to measure in-situ aerosol optical properties and successfully deployed it aboard the NASA DC8 aircraft during the ATom mission.

Bioaerosol detection: In collaboration with Massachusetts Institute of Technology researchers, we developed a fast response method to detect biological aerosol particles (bacteria, fungus, mold) in the atmosphere using chemical speciation. Methodology was published in Zawadowicz et al. 2017, and subsequent analysis to quantify bioaerosol over the continental United States is ongoing.

Representation of clouds in models

Advancements of Large Eddy Simulation: We developed, implemented, and tested a subgrid-scale model based on the linear eddy model (LEM) coupled with Lagrangian cloud microphysics (Hoffmann et al. 2018). This approach allows the representation of mixing at the cloud edge and its effects on cloud microphysics at scales which have not been accessible with standard for large-eddy simulation (LES). We also implemented a sophisticated two-moment bin microphysics scheme into our LES model. This scheme accounts for not only collision-coalescense but also breakup of droplets for interaction between bins.

Physics of Stratocumulus Clouds: We studied mesoscale organization in a stratocumulus cloud using LESs (Kazil et al. 2017). We found that the cloud radiative effect and other stratocumulus cloud properties depend on the aspect ratio (size) of mesoscale structures. This result informs climate models on biases in their representations of boundary layer clouds. Empirical relationships between stratocumulus cloud radiative cooling and cloud base updraft speeds are a potential approach to retrieve aerosol concentrations at cloud base from satellite observations, and to parameterize cloud base updraft speeds in climate models. We have analyzed LES to quantify these relationships and to characterize their response to meteorological conditions.

Aerosol-Cloud Interaction Observations and Modeling

ACI and the Albedo-Cloud Fraction Relationship: We tested and built a theoretical framework to quantify aerosol-cloud interactions (ACI) to facilitate the interpretation of satellite observations of albedo and cloud fraction (Feingold et al. 2017). Satellite-observed albedo and cloud fraction display a characteristic functional relationship. Our work demonstrates that with clear characterization of measurements and methodology, the radiative effect of aerosol-cloud interactions should be detectable using this theoretical framework. *Network Theory Analysis and Statistical Emulation of Stratocumulus Clouds:* We completed an analysis of the structure and arrangement of stratocumulus in LES output as a dynamic cellular network (Glassmeier and Feingold 2017). The network analysis finds the cellular pattern to be scale-invariant. A simple network model can explain the arrangement of cloud cells from stratocumulus-specific versions of cell division and cell merging. Statistical (Gaussian) process emulation was applied to derive stratocumulus properties from LESs. This approach provides new estimates of stratocumulus sensitivities and adjustments/buffering to meteorological and aerosol properties.

LES ARM Symbiotic Simulation and Observation: As a contribution to the Department of Energy LES ARM Symbiotic Simulation and Observation (LASSO) program, we evaluated a series of LES of shallow boundary layer clouds together with ground-based observations at the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site to understand the key parameters that control the cloud radiative effect. Statistical analysis allows us to quantify the extent to which the co-variability between the meteorology and the aerosol affect the detectability and quantification of the aerosol indirect effect at a midlatitude continental location like SGP (Glenn 2018).

Stratocumulus-to-Cumulus Transition by Drizzle: In Yamaguchi et al. (2017), we show fast transition to cumulus state from stratocumulus via aerosol-cloud-precipitation feedback with LESs. This is a new pathway of stratocumulus to cumulus transition otherwise it is slow and takes multiple days via entrainment of dry air by overshooting cumulus under stratocumulus.

Realistic Lagrangian Large Eddy Simulations: We developed a methodology to run LESs along air trajectories in reanalysis data to simulate boundary layer clouds. We tested the approach using satellite and radiosonde data and currently use it investigate the response of stratocumulus clouds to anthropogenic biomass burning aerosol.

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

CIRES Lead: Troy Thornberry / NOAA Lead: Ru-Shan Gao

NOAA Theme: Weather-Ready Nation; 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

Our team successfully deployed the NOAA CSD Wideband Integrated Bioaerosol Spectrometer (WIBS) on a NOAA Twin Otter for the Sea Ice project in July 2017. We frequently observed high bioaerosol loadings over the Arctic Ocean, associated with warm air temperatures and air flow from the North Slope of Alaska—likely indicating a substantial bioaerosol source from summertime tundra. Bioaerosol loadings in the marine boundary layer showed a weak positive correlation with lidar observations of algae in the ocean surface layer, reflecting a small but quantifiable marine source of bioaerosol. We are preparing a manuscript describing these findings.

Our analysis of water vapor, ice water content, and ozone measurements made during the Pacific Oxidants, Sulfur, Ice, Dehydration and cONvection (POSIDON) mission has revealed rapid transport of low O_3 mixing ratios from the marine boundary layer to the TTL (tropical tropopause layer) in deep convection over the western Pacific Ocean. We observed low O_3 values in clouds at altitudes up to near the tropopause and may provide a means for differentiating convectively detrained cirrus clouds from those formed in situ.

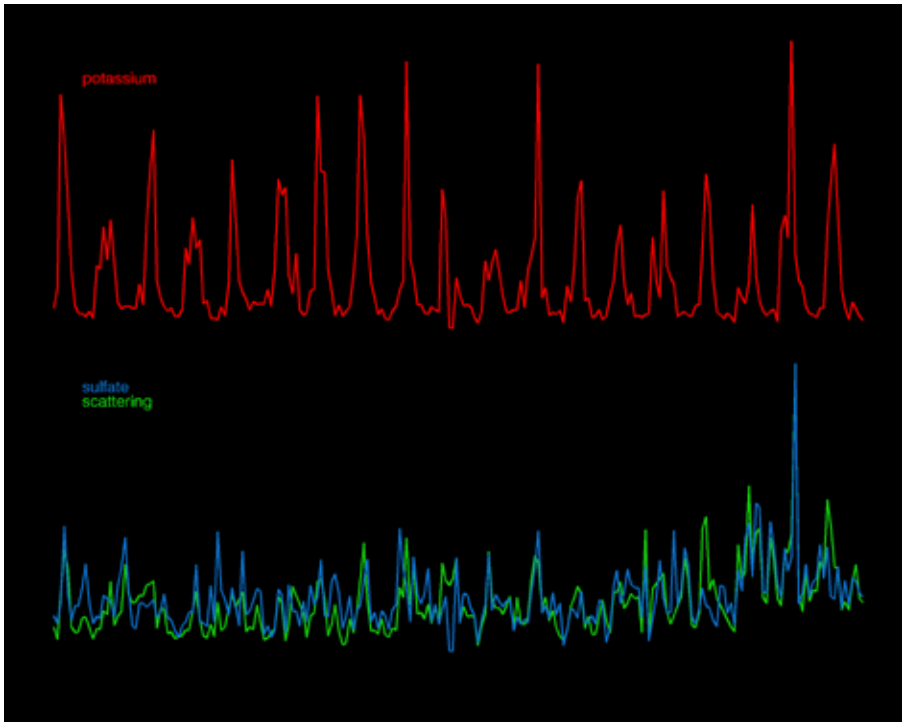
We integrated the NOAA CSD SO_2 and UASO_3 instruments and a Printed Optical Particle Spectrometer (POPS) onto the NASA Global Hawk for the NASA HOPE-EPOCH mission in July/August 2017. We conducted three, 20+ hour science flights—two into the Gulf of Mexico and one in the eastern Pacific Ocean—to study tropical cyclone development. The instruments performed well and our measurements will provide additional data on UTLS SO_2 and aerosols for comparison with the 2016 POSIDON data from the western Pacific.

CSD-07: An iceberg in the Southern Ocean seen from the NASA DC-8 on a flight from Christchurch, New Zealand, to Punta Arenas, Chile, during the Atmospheric Tomography (ATom) mission. These flights provided an unprecedented opportunity to study atmospheric chemistry in this previously undersampled region. Photo: Joseph Katich/CIRES and NOAA

We constructed a new, rack-mounted version of the NOAA SO_2 instrument and successfully deployed the instrument on the NASA DC-8 during the fourth deployment of the NASA Atmospheric Tomography mission (ATom-4) in April/May 2018. We are processing this data.

We deployed a NOAA CSD SP2 (Single Particle Soot Photometer) to measure refractory black carbon (BC) aerosol during the ATom-3 and ATom-4 deployments in October 2017 and April/May 2018, completing the seasonal sampling of the remote troposphere over the Pacific and Atlantic oceans. We are processing and finalizing this data.

Our analysis of SP2 measurements of BC during the NASA ATom-1 deployment in July/August 2016 revealed sharp contrasts in loadings between the remote Pacific and Atlantic oceans. While average BC concentrations over the Pacific were largely consistent with seasonally-matched data obtained previously in 2011, we observed substantially higher loadings in the low- to mid-troposphere over the Atlantic, due to strong regional sources and reduced convective removal in the tropics. Our comparison of the data to the AeroCom suite of models extends previous observations of a model upper troposphere high bias in BC over the Pacific to the Atlantic basin. Simultaneously, these direct BC measurements reveal large AeroCom ensemble underestimation of biomass burning BC in African continental outflow by nearly a factor of five. This high-BC loading region clearly dominates BC's direct radiative forcing over remote areas of the Pacific and Atlantic basins.



GMD-03: Time series of normalized monthly medians of aerosol optical properties and elemental concentrations. Top: aerosol light absorption coefficient and elemental potassium. Bottom: aerosol light scattering coefficient and elemental sulfur.

We have completed an analysis of the observed variability in refractory BC vertical profiles over a single site in South Korea during the NASA KORUS-AQ campaign in 2016. We coupled the BC measurements with back-trajectory analysis to demonstrate that both local and regional sources influenced the observed aerosol loadings, with significant vertical stratification of source contributions and variability attributable to meteorologically-driven changes in transport. South Korea, China, and Russia were the major source-region contributors to the BC direct radiative forcing in the region, and unique chemical tracer relationships were associated with transport from the different regions. These KORUS-AQ measurements provide us with a benchmark for future changes in regional BC emissions in East Asia, the most important global source region for anthropogenic BC.

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

This has been quite a productive year for our project. In the reporting period, our small group (two CIRES, one NOAA) has authored or co-authored eight articles in peer-reviewed journals relating to this project. There are several other papers undergoing revisions as described below. We also anticipate submitting a handful of additional manuscripts in progress this summer.

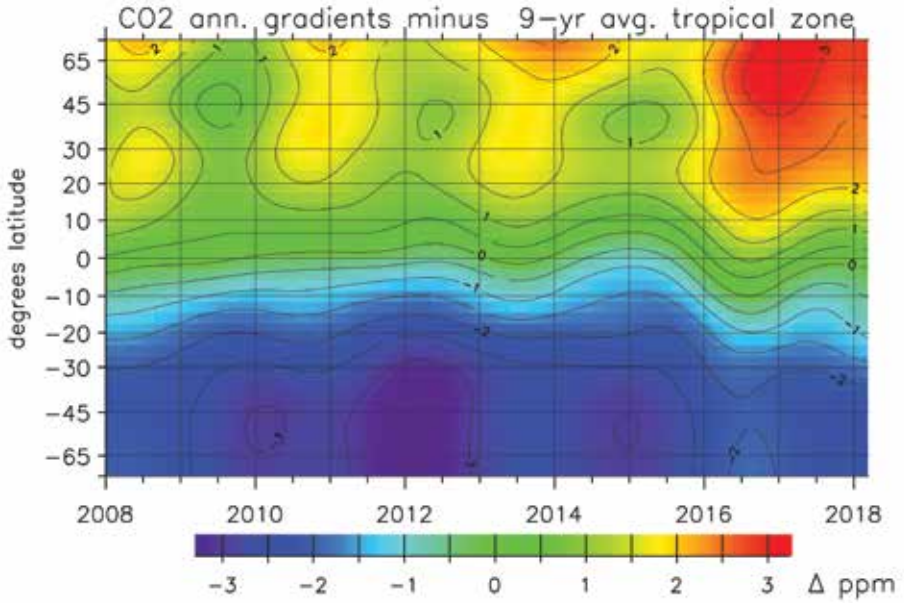
One project currently underway is an analysis of relationships between aerosol optical properties and aerosol elemental chemistry from long-term measurements at NOAA's Mauna Loa Observatory in Hawaii. We are working with the aerosol chemical composition data collected by the National Park Service at Mauna Loa and with NOAA's aerosol optical property measurements. A Monarch High School student intern is completing the primary analysis on this project.

Another project, funded by the Department of Energy's Atmospheric Science Research (DOE/ASR) program, finishes its second year in August 2018. During the first two years

we have developed a climatology of aerosol hygroscopicity based on in-situ humidograph measurements from 25 sites around the world. This was not a straightforward task, given the numerous differences between sites, instrument set-ups, file formats, different corrections to apply, site dependent characteristics, and so on. Now that the dataset processing is finally finished, we will use it for various scientific investigations in the third year of the project. We now have a manuscript draft describing the development of the hygroscopicity climatology. The hygroscopicity project is one part of a wider project to use surface in-situ measurements to evaluate global models.

The other part of the project looks at how well models simulate aerosol optical properties at low humidity conditions. The research on the low humidity model/measurement comparisons has advanced over the last year—and we have shared two manuscript drafts with the lead co-authors. In the last year, we've attended several workshops related to these two aspects of model evaluation research, and made numerous presentations on results at various international conferences.

To support long-term monitoring sites, we implemented a new version of the data acquisition software which is now running at all but two sites in the NOAA Federated Aerosol Network. An additional four sites in Oregon, Finland, Norway, and Germany have been added to the network. Our discussions with potential collaborators for a network sites in Slovenia and an additional site in Finland are ongoing. The NOAA Federated Aerosol Network (NFAN) site in Puerto Rico was decimated by the 2017 hurricane season, so, in collaboration with other agencies, we are working to get that back running and also add a second site on the island. While new sites are coming online, other sites have closed, including those in California, Oklahoma, and American Samoa.



GMD-04: North-south (moving) annual mean surface CO_2 gradients relative to a moving 9-year average of the tropical marine boundary layer zone (-15.5 to 17.5 deg. latitude). Note the larger gradient in late 2016 from northern high latitudes to the tropics, and the lower gradient from southern high latitudes to the tropics. Image: CIRES/NOAA

GMD-04: Studies of Greenhouse Gas Trends and Distributions

CIRES Lead: Gabrielle Petron / NOAA Lead: Pieter P. Tans

NOAA Theme: Climate Adaptation and Mitigation

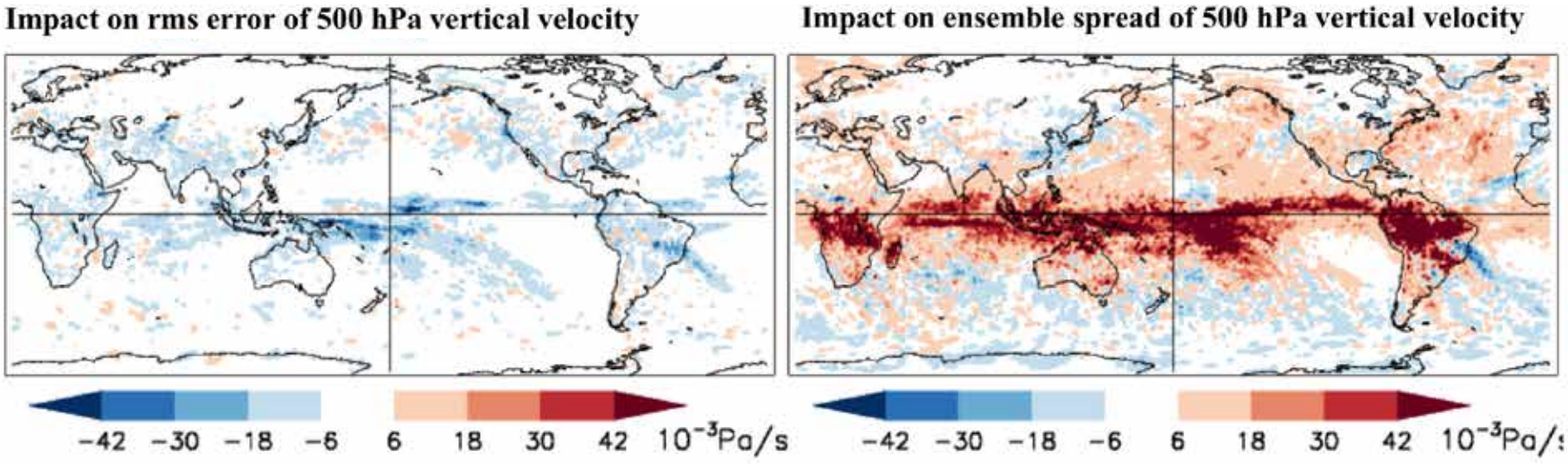
GOALS & OBJECTIVE

This project focuses on the global distribution of the anthropogenically influenced greenhouse gases: both the major ones (CO_2, CH_4 and N_2O) 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 group continues to produce calibrated measurements of long-lived GHGs at monitoring sites and for special projects. We regularly make all measurements publically available and always make data directly available from project PIs. These observations are the basis for various NOAA products, model and satellite data evaluation, and estimates of regional and global emissions and sinks using inverse modeling. Highlights from the past year include a complete upgrade of our World Meteorological Organization Central Calibration Laboratory (WMO CCL) analytical instrumentation for carbon dioxide (CO_2) and methane (CH_4) standard gas calibrations. Measurements from our global and North American networks show the large impact of the 2015-2016 El Niño on regional and global CO_2 fluxes and on larger CO_2 annual mean growth rate. Our detailed analysis of long-term gradients in observed and modeled CO_2 air column across North America has shown the importance of sampling in the boundary layer, where flux signals are largest, and the large impact of Eurasian summer boreal fluxes. Long-term gradients modeled with the CarbonTracker (CT) CO_2 data assimilation system compared well with observations supporting the use of CT to evaluate CO_2 column satellite products. We used SF_6, an anthropogenic tracer, to evaluate global models transport, and we release near-real-time CO_2 obspack data products on schedule. In a new, high-impact study, our long-term global measurements showed the surprising slowdown of CFC-11 decline (a potent greenhouse gas and stratospheric ozone depleting substance), implying new production despite an international ban.

Project Reports: Earth System Dynamics, Variability, and Change



PSD-20: The impact of stochastic parameterizations of diabatic processes on the Day-15 forecasts of mid-tropospheric (500 hPa) vertical velocity generated using NOAA's Global Forecast system (GFS) model at T254 (approximately 70 km grid) resolution. Results are shown for 80-member ensemble forecasts for 100 forecast cases in January-March 2016. The stochastic parameterizations reduce the root mean square error of the ensemble-mean forecasts (left panel) and increase the otherwise too small ensemble spread (right panel), and thus have a beneficial impact on both the deterministic and probabilistic forecast skill. Image: Sardeshmukh et al. in prep.

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

CIRES Lead: Prashant Sardeshmukh / NOAA Lead: Cecile Penland

NOAA Theme: Science and Technology Enterprise

GOALS & OBJECTIVE

This project will improve representation of extreme events in forecast models.

ACCOMPLISHMENTS

In the past year, our CIRES/PSD team performed several studies to assess the impacts of stochastic parameterizations of unresolved processes on global weather forecasts, using both the current (GFS) and forthcoming (FV3) versions of NOAA/NCEP's global models. In essence, the stochastic parameterizations amount to multiplying the model's deterministic parameterizations of diabatic tendencies at each model time step and each grid point on the globe by a random factor r between 0 and 2, whose space-time correlation structure is informed by observations, foundational theory, and off-line, ultra-high resolution numerical Large Eddy Simulation (LES) experiments.

In our NCEP/GFS model study (Sardeshmukh et al. in prep.), we generated two sets of 80-member ensemble 15-day global weather forecasts, with and without the stochastic parameterizations, for 100 forecast cases in 2016. We found the parameterizations improved the ensemble forecasts in two distinct ways: (1) by increasing the spread of the forecast ensemble to ensure that the observed future atmospheric state occurs more often within the projected range of future states, and (2) by reducing the error of the ensemble-mean forecast as the "best" forecast. We saw these remarkable improvements in almost all the weather variables examined, including near-surface air temperature, precipitation, and mid-tropospheric vertical velocity (figure above), and at almost all locations on the globe. We developed a simple explanation of these improvements in terms of a foundational theory of the "noise-induced drift" of the large-scale atmospheric circulation generated by the small-scale noise forcing associated with the stochastic parameterizations.

In our NCEP/FV3 model study (Bengtsson et al. in prep.), we did not specify the random factors r in the stochastic parameterizations explicitly. Rather, we generated them internally within the forecast model using a simple evolving "Game of Life" type cellular automaton (CA) model. The CA model mimics the "birth" and "death" of convective plumes within the full forecast model's grid boxes, and with the birth rates conditioned at

every full model time step on the vertical velocities sampled from a stochastically generated skewed (SGS) probability distribution discovered at PSD (Sardeshmukh et al. 2015). This CA-SGS stochastic parameterization significantly improved the representation of extreme precipitation in the FV3 model.

The clear positive impact on global weather forecasts obtained from implementing even such simple stochastic parameterizations highlights the sufficiency of adequately representing the statistics of the small-scale diabatic tendencies, rather than their detailed structure, in forecast models. The statistics gleaned from high-resolution observations and/or cloud resolving models and LES can be used profitably for this purpose. To this end, we have recently started an investigation of the probability distributions of high resolution vertical velocity observations collected at Darwin and in the VOCALs field experiment and comparing those distributions with LES distributions.

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

CIRES Lead: Darren Jackson / NOAA Lead: George Kiladis

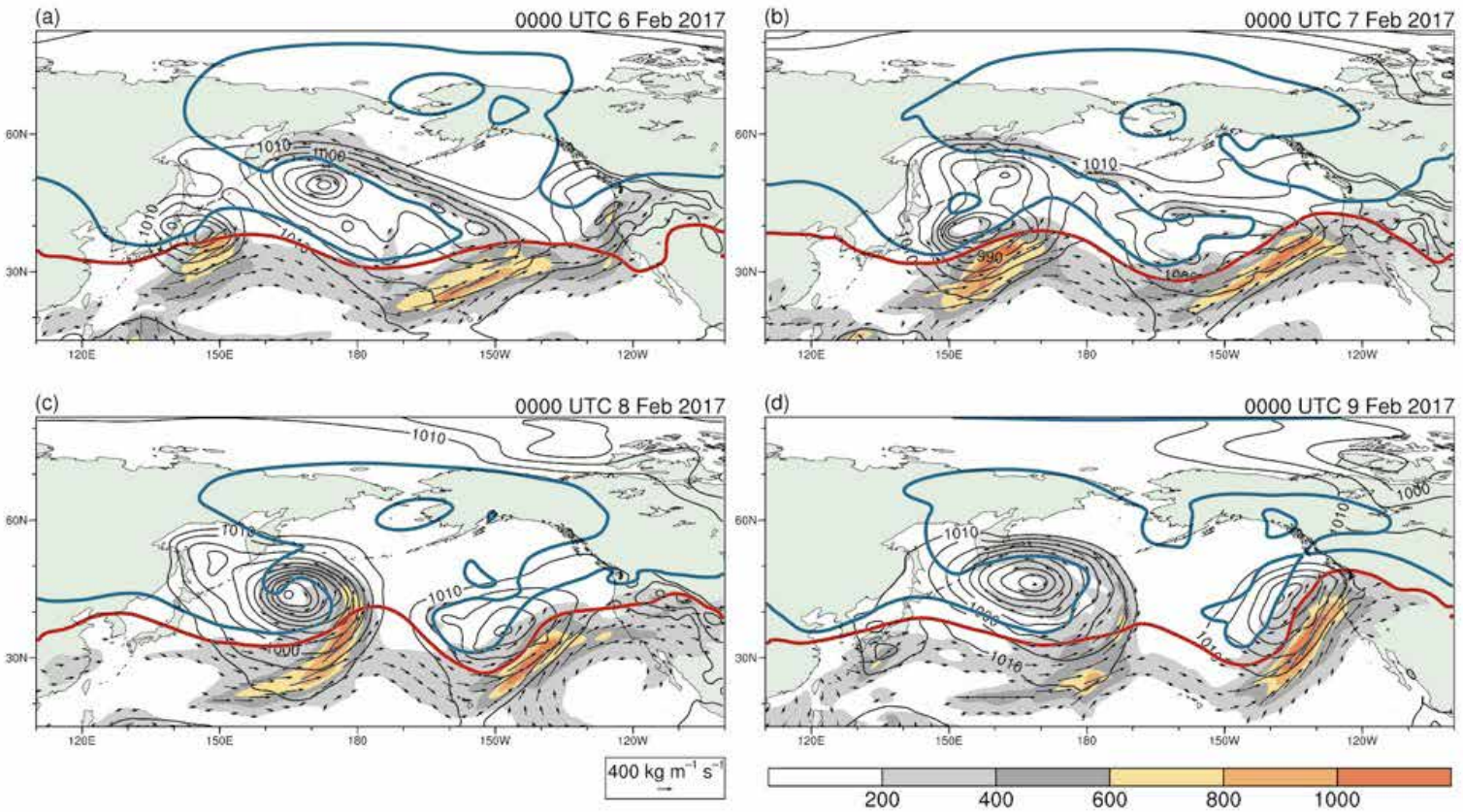
NOAA Theme: Science and Technology Enterprise

GOALS & OBJECTIVE

This project will better characterize heavy precipitation events by using observations to improve process understanding and will evaluate heavy precipitation distributions and forecasts in weather and climate models.

ACCOMPLISHMENTS

The two areas of research highlighted for our project are: results from the El Niño Rapid



PSD-22: The evolution of the synoptic-scale flow associated with a long-duration atmospheric river and an extreme precipitation event that occurred during 2-11 February 2017 based on the ECMWF ERA-Interim reanalysis. Analyses are shown for 0000 UTC on (a) 6, (b) 7, (c) 8, and (d) 9 February 2017 to highlight the period of heaviest precipitation. The analyses show the 1000–300-hPa vertically integrated water vapor flux (magnitude shaded in kg m−1 s−1 according to the color bar; vectors overlaid), sea level pressure (black contours every 5 hPa for values ≤ 1010 hPa), and the 310-K and 330-K isentropes (blue and red, respectively) on the dynamic tropopause, which denote the configuration of the polar and subtropical jet streams, respectively. Image: Benjamin Moore/CIRES

Response (ENRR) campaign described in a recently published journal article and an assessment of the influence large scale conditions have on atmospheric rivers that impacted the record 2016-17 winter season precipitation in California.

Our team working on the ENRR campaign, conducted during the 2015-16 El Niño event, sought to determine the response of El Niño on extratropical storms and U.S. West coast rainfall by collecting targeted observations from aircraft, ship, and radiosondes from the center tropical Pacific to the West Coast. NOAA deployed its Gulfstream-IV (G-IV) aircraft to obtain observations around organized tropical convection and poleward convective outflow in the tropical Pacific. We obtained additional tropical observations by radiosondes launched from Kiritimati, Kiribati, and the NOAA ship *Ronald H. Brown*, and in the eastern North Pacific by the NASA Global Hawk unmanned aircraft system. CIRES scientists and engineers played key roles in collecting the observations, assessing and managing the data, and analyzing the observations for preliminary scientific studies. The campaign demonstrated the capability of Federal and cooperative institute personnel at PSD to plan and execute a complex field program in less than six months—which is significantly less than typical campaigns. We showed the NOAA Global Forecast System (GFS) model with ENRR data underestimated the strength of the 200 hPa meridional divergence out of the Intertropical Convergence Zone, and we found 24-hour improvements in forecast error of global moist energy when assimilating ENRR dropsonde and radiosonde observations into the NASA Global Earth System (GEOS) Global Data Assimilation System (GDAS) collected from the campaign.

The winter season following the ENRR campaign (2016-17) experienced record seasonal precipitation for California due to frequent, long-duration atmospheric river events. In an intensive research effort at NOAA PSD, we focused on investigating the planetary- and synoptic-scale atmospheric processes that resulted in high-impact extreme precipitation events during that season. Our results indicate that the most significant, long-duration (i.e., >5 days) extreme precipitation events during the winter co-occurred with large-scale blocking patterns in the polar jet stream over the central North Pacific. In each of these events, a blocking pattern was established and maintained in connection with successive Rossby wave packets propagating southeastward across Eurasia into the western North Pacific. Theses wave packets resulted in the development of a major blocking ridge along the polar jet stream. The wave packets additionally induced downstream wave dispersion over the eastern North Pacific along the subtropical jet stream that "undercut" the higher-latitude blocking ridge. A slow-moving subtropical trough resulting from this undercutting wave dispersion then interacted with an equatorward-propagating polar trough on the eastern flank of the blocking ridge, resulting in the development of multiple successive cyclones off the U.S. West Coast. These cyclones were collectively associated with the formation and maintenance of strong and exceptionally persistent atmospheric rivers impacting Northern California. The atmospheric river in each extreme precipitation event was associated with extensive transports of moist air from the subtropical and tropical eastern North Pacific that sustained persistent heavy precipitation over Northern California. Impacts of the long-duration precipitation event shown in the figure evacuated over 180,000 people living downstream of the Oroville Dam in Northern California due to excessive runoff and significant damage to the main and emergency spillways of the dam.

PSD-23: Observe and Understand the Coupled Behavior of the Atmosphere over Land, Ocean, Ice, and Snow

CIRES Lead: Matt Newman / NOAA Lead: Chris Fairall

NOAA Theme: Science and Technology Enterprise

GOALS & OBJECTIVE

This project will accelerate advances in the observation-based understanding of high-impact weather and climate.

ACCOMPLISHMENTS

We conducted two major field programs under this project in 2016: the El Niño Rapid Response Experiment (ENRR) and the Southern Ocean Seagoing Air-Sea Flux System deployment as part of the Clouds, Aerosols, Precipitation and Atmospheric Composition Over the Southern Ocean (CAPRICORN) project. More information can be found at https://www.esrl.noaa.gov/psd/news/2016/020516.html and https://www.esrl.noaa.gov/psd/news/2016/042516.html.

We will conduct two additional projects related to monsoon intra-seasonal oscillations, Oceanic Control of Monsoon Intra-seasonal Oscillations in the Tropical Indian Ocean and the Bay of Bengal (MISO-BOB) and Propagation of Intra-Seasonal Tropical Oscillations (PISTON), from May to October 2018.

For ENRR, CIRES members in PSD were involved in observations from Christmas Island (Kiribati), the NOAA *R/V Ronald H. Brown,* the NOAA G-IV aircraft, and NASA's Global Hawk aircraft. The goal of ENRR was to capture observations of tropical convection and coupling to mid-latitudes during the strong El Niño in the winter of 2015-2016. ENRR data are available in the PSD archive. We have just started the research on the observations, but a few papers have been published on preliminary results; see below.

For CAPRICORN, PSD installed NOAA's seagoing Air-Sea Flux System on a new research vessel, the *R/V Investigator*, which is operated by Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO). PSD is collaborating with CSIRO and scientists from the Australian Bureau of Meteorology to investigate the interaction of air-sea fluxes and boundary layer clouds, which will help expand the very sparse database of measurements in the Southern Ocean. The cruise was south of Hobart, Tazmania, from March 12 to April 20, 2016. The PSD flux system operated at full efficiency; data are available at ftp://ftp1.esrl.noaa.gov/psd3/cruises/CAPRICORN_2016/Investigator/flux/. We have submitted one paper and will be submit another soon.

Bharti, Vidhi, Byron W. Blomquist, C.W. Fairall, Yi Huang, Alain Protat, Peter P. Sullivan, Steven T. Siems, and Michael J. Manton, 2018: Air-sea heat and momentum fluxes in the Southern Ocean. *J. Geophys. Res.*, submitted.

PSD-23: PSD installed NOAA's seagoing Air-Sea Flux System on the *R/V Investigator,* which is operated by Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO). Together with CSIRO and the Australian Bureau of Meteorology, PSD is investigating the interaction of air-sea fluxes and boundary layer clouds in the Southern Ocean. Photo: CSIRO

Bharti, Vidhi, Eric Schulz, Byron W. Blomquist, C.W. Fairall, Yi Huang, Alain Protat, Steven T. Siems, and Michael J. Manton, 2018: Assessing surface heat flux products with in-situ observations over the Australian sector of the Southern Ocean. *J. Geophys. Res.*, in preparation.

For the monsoon intra-seasonal oscillations projects, PSD and CSD sent a team to collect air-sea flux, cloud, and boundary-layer turbulence observations aboard the University of Washington ship *R/V Thomas G. Thompson*.

Our PSD/CIRES researchers traveled to Taiwan in May 2018 to install equipment on the ship and then participated in two cruise legs of the MISO-BOB program from May 31 to July 20, 2018. MISO-BOB focuses on the effects of river runoff and surface layer dynamics on ocean-atmosphere interaction in the Bay of Bengal. Large masses of atmospheric convection propagating from the Indian Ocean into and across the Pacific Ocean are a well-known precursor to extreme weather in the United States.

The second field program, PISTON, will be August 7 to October 17, 2018 in the Philippine Sea, focused on air-sea and land-sea interaction related to the northward propagation of the monsoon into the Philippines region. By improving our understanding of the convective and air-sea interaction processes, we can improve U.S. weather forecasts at 1-3-week timescales.

ENRR results were published in these papers:

Dole, R., et al. (2018): Advancing Science and Services during the 2015-16 El Niño: The NOAA El Niño Rapid Response Field Campaign. *Bull. Amer. Meteor. Soc.*, 99, 975-1001, doi: 10.1175/BAMS-D-16-0219.1.

Hartten, L. M., Cox, C. J., Johnston, P. E., Wolfe, D. E., Abbott, S., and McColl, H. A. (2018). Central-Pacific surface meteorology from the 2016 El Niño Rapid Response (ENRR) field campaign, *Earth Syst. Sci. Data,* 10, 1139-1164, https://doi.org/10.5194/essd-10-1139-2018.

Hartten, L. M., Cox, C. J., Johnston, P. E., Wolfe, D. E., Abbott, S., McColl, H. A., Quan, X.-W., and Winterkorn, M. G. (2018). Ship- and island-based soundings from the 2016 El Niño Rapid Response (ENRR) field campaign, *Earth Syst. Sci. Data*, 10, 1165-1183, https://doi.org/10.5194/essd-10-1165-2018.

PSD-24: Enhancing Predictability of Weather and Climate Extremes

CIRES Lead: Judith Perlwitz / NOAA Lead: Martin Hoerling

NOAA Theme: Science and Technology Enterprise

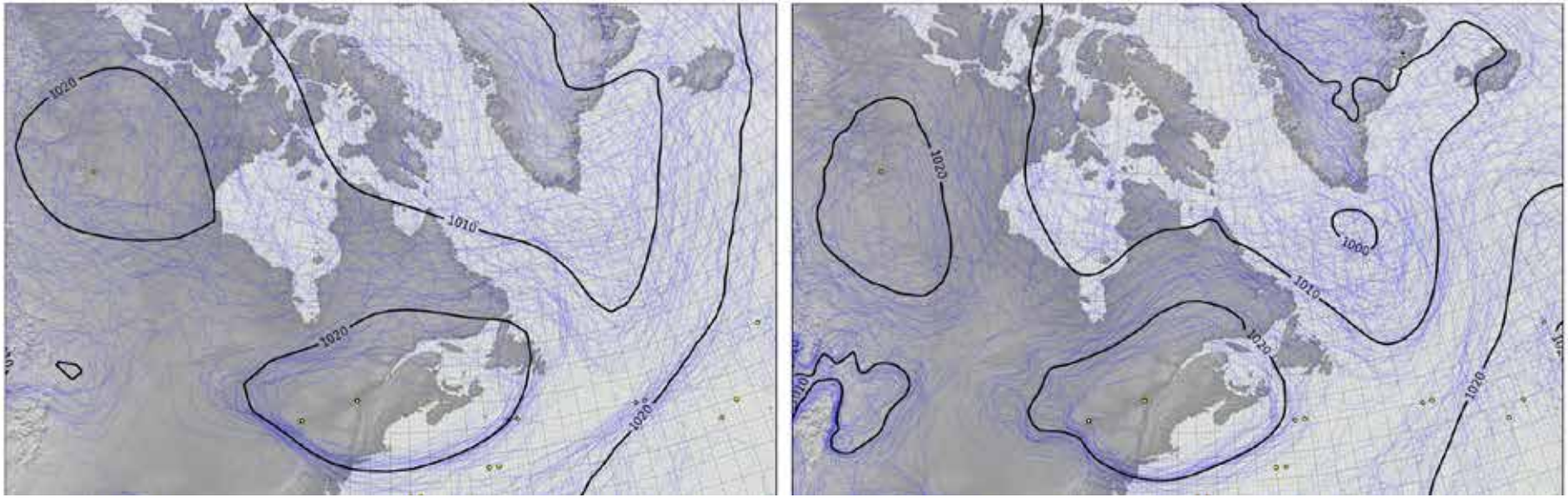
GOALS & OBJECTIVE

This project will improve understanding of extreme weather and climate events and an improved capability to predict them.

ACCOMPLISHMENTS

Research on changes in statistics of extremes

In the past year, our research team has completed two studies of changes in the statistics of extreme temperatures and precipitation around the globe over the past several decades. Our results highlight the challenges in capturing and projecting such changes in extremes using the current generation of climate models. For example, it is generally presumed that the likelihood of extreme warm spells around the globe has increased and will continue to increase due to global warming. However, we find that this is generally not true in three very different types of global observational datasets and uncoupled atmospheric model simulations of the 1959 to 2012 period with prescribed observed global sea surface temperatures, sea ice, and radiative forcing changes. While extreme warm spells indeed became more common in many regions, in many other regions their likelihood remained almost the same or even decreased from the first half to the second half of the period. Such regions of unexpected changes covered nearly 40 percent of the globe in both winter and summer. We found the basic explanation for this was a decrease of temperature variability in such regions that offset or even negated the effect of the mean temperature shift on extreme warm spell probabilities. This highlights the need for climate models to represent not just the mean regional temperature signals but also the changes in subseasonal temperature variability associated with global warming.



PSD-24: Sea level pressure from the 20th Century Reanalysis version 2c (left) and version 3 (right) on 8 September 1900 at 06 UTC. All (first) 56 ensemble members are shown by the thin purple curves in v2c (v3). The ensemble mean is shown by the thick black contours. A much stronger storm, more consistent with observational estimates, is analyzed by 20CRv3. Image: P. Brohan/UK Met Office

Research on attribution of extreme events

During the annual reporting period, we:

- Published paper on the drivers of 2016 record Arctic warmth. We concluded that about 60 percent of the 2016 Arctic warmth was likely attributable to human-induced climate change. Results also indicate that 30 to 40 percent of the overall forced Arctic warming signal in 2016 originated from drivers outside of the Arctic. Despite such remote effects, our model experiments reveal that the extreme magnitude of the 2016 Arctic warmth could not have occurred without consideration of the Arctic sea ice loss. (Sun et al. 2018, *Weather and Climate Extremes*).
- Submitted a manuscript on anthropogenic contributions to the intensity of the 2017 U.S. Northern Great Plains drought. We find it likely that anthropogenic forcing increased the intensity of this agricultural drought through aridification due to long-term increases in evapotranspiration over precipitation (Hoell et al. 2018, *Bulletin of the American Meteorological Society, Special Issue on Explaining Extreme Event of 2017*).
- Began research on reconciling Front Range Colorado extreme rainfall likelihoods, focusing on implications of different methods (presented poster and at EGU).
- Began research on diagnosing the role of temperature and precipitation in driving decadal droughts and low Colorado River flow.

Dataset/Model capacity building to advance research on predictability of weather and climate extremes

- Our CIRES/PSD scientists and a team of international collaborators have developed and begun to produce a newer, higher-resolution version 3 of the CIRES-NOAA-U.S. Department of Energy (CNE) 20th Century Reanalysis (20CRv3). This global atmospheric dataset will span 1851 to the present at three-hour resolution and provide improved estimates of the frequency and severity of extreme climate and weather events such as heat waves, hurricanes, droughts, and floods. It will also provide improved estimates of weather and climate variability from the surface of the Earth to the lower stratosphere. The 20CRv3 uses the latest version of the NCEP Global Forecast System atmosphere/land model at a horizontal resolution of spherical wavenumber 254 or about 50 km, with 64 levels in the vertical. We have rescued, digitized, and quality controlled millions of new observations, and made them available to the 20CRv3 analysis system from the International Surface Pressure Databank version 4, also generated by CIRES and collaborators. In addition to these advances, we have made substantial improvements in the data assimilation algorithm, including an increase

in the number of ensemble members from 56 to 80. This new algorithm and the increased ensemble size result in significantly improved estimates of the analyzed fields and their uncertainty.

- We made advancements of PSD's Facility for Climate Assessments (FACTS) by adding new model datasets and new features including multi-model and multi-ensemble comparisons. (https://www.esrl.noaa.gov/psd/repository/facts)

PSD-26: Next-Generation Global Prediction System

CIRES Lead: Phil Pegion / NOAA Lead: Jeff Whitaker

NOAA Theme: Science and Technology Enterprise

GOALS & OBJECTIVE

This project supports the objective of an integrated environmental modeling system by enhancing the predictive accuracy of earth system models through better use of observations (through data assimilation), improved modeling, and reliable forecast products (through post-processing).

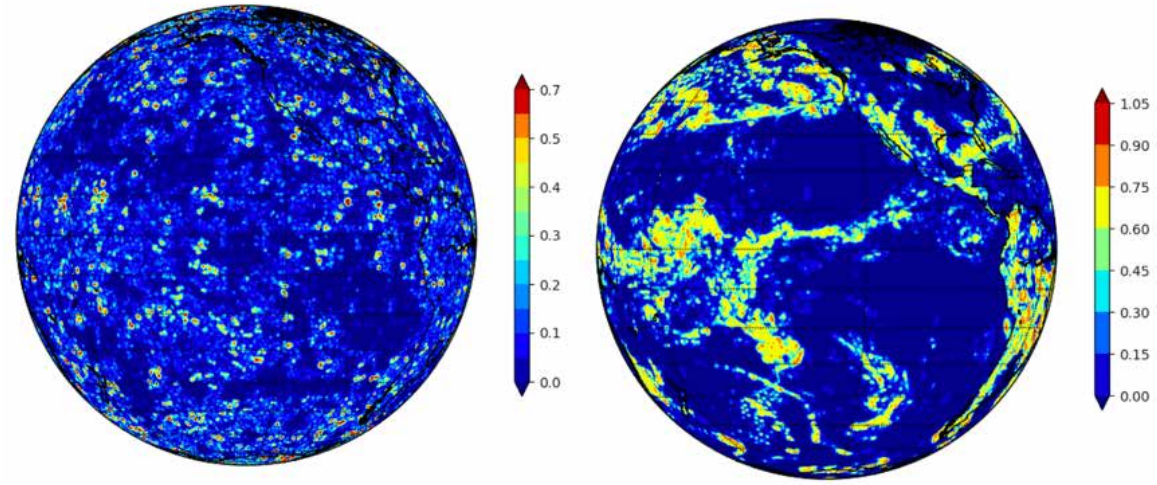
ACCOMPLISHMENTS

Our team is working closely with the National Weather Service to provide the necessary research and development to advance the next generation global predication system (NGGPS) and have the model ready for operational implementation in 2019. We have implemented the stochastic physics suite along with four-dimensional Incremental Analysis Update (4D-IAU) in test runs. The National Centers for Environmental Prediction's real-time parallel runs only contain a subset of the stochastic physics, and are not using IAU. Our additional tests with all of the stochastic physics enabled and using the 4D-IAU show a robust improvement to the model's first-guess fit to observations.

We needed to modify the stochastic physics suite due to computational instabilities that have appeared when the stochastic physics is enabled in areas of strong winds interacting with topography and strong convection over tropical cyclones. One of our fixes used the model's mountain blocking scheme to diagnose the 'dividing streamline,' which is the level that flow is block by mountains. Below this level, stochastically perturbed physics tendencies (SPPT) is not active. The result is a more stable model and only a slight impact on ensemble performance.

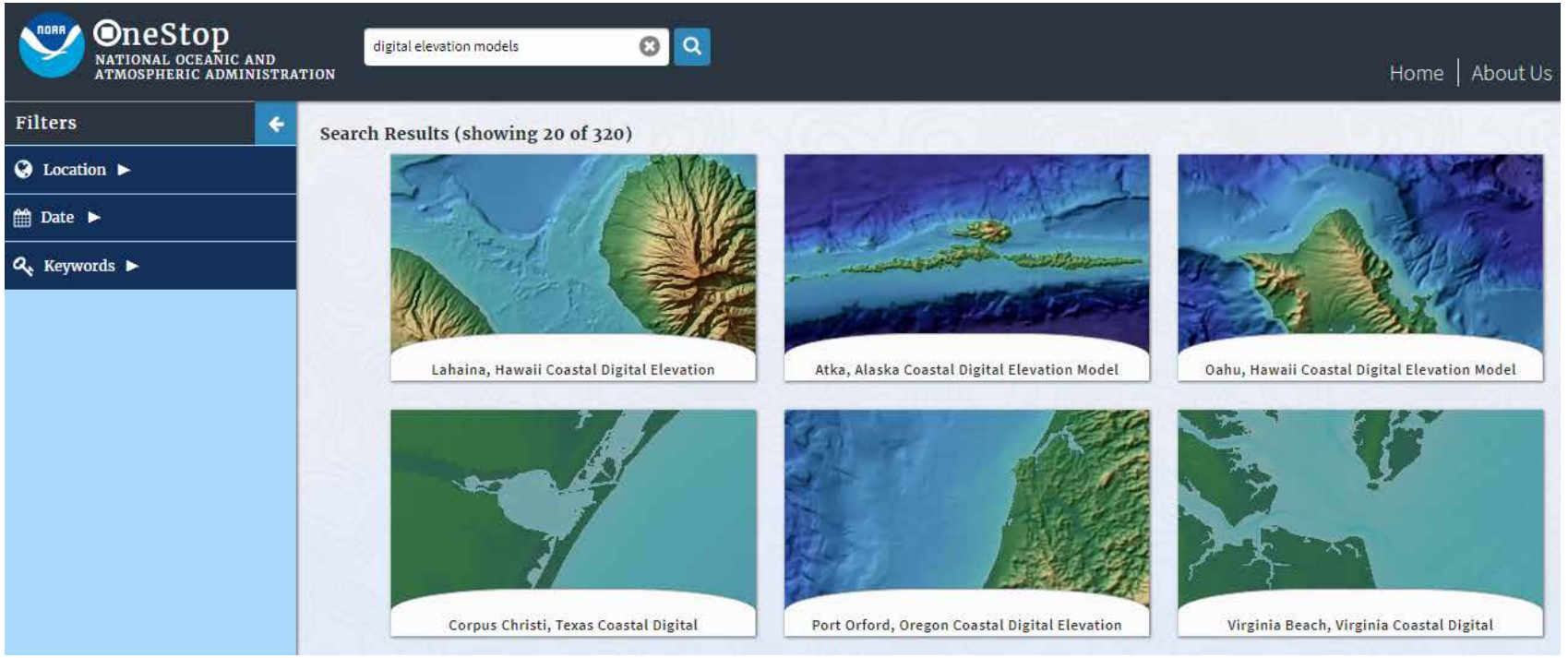
We have undertaken a new approach to stochastically perturbing convection. This approach dives directly into the convection parameterization and randomly draws the number of sub-cloud elements from a distribution. This distribution is defined by fitting the model's vertical velocity to a stochastically generated skewness distribution (SGS). The SGS does not make assumptions of the shape of the distribution, but relies on the actual moments of the data it is modeling. The information is propagated in space and time with the use of cellular automata (CA) that uses a set of rules to define how the individual cells live and die. The pattern generated by the cellular automata is shown in the left panel of the figure. The left panel shows the pattern when the CA conditioned on the model's vertical velocity. The random pattern show a more physical structure that coincides to the convectively active regions of the globe.

We have started production for the FV3GFS reanalysis after a series of sensitivity tests. The full stochastic physics suite and the 4D-IAU are active in the model and assimilation systems. Our sensitivity tests have been focused on addressing changes to the analyses bias to the changes to observing system changing over time (e.g. there are many more observations in 2017 than in 1999).



PSD-26: Cellular automaton field averaged onto the numerical weather prediction model grid. Left panel shows the free running cellular automaton given the initial condition of sub-grid plumes defined by the stochastically generated skewness distribution. Right panel shows the cellular automaton conditioned on SGS perturbed large scale vertical velocity. Image: Lisa Bengtsson/CIRES and NOAA

Project Reports: Management and Exploitation of Geophysical Data



NCEI-01: NOAA's OneStop data portal lets users quickly find or discover data related to geophysics, oceans, coasts, weather, and climate. Image: foam-cat agile team.

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

CIRES Lead: David Neufeld / NOAA Lead: Drew Saunders

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

In the 2017-18 reporting period, our CIRES software development teams supported projects for the NCEI Data Stewardship Division and the Center for Coasts, Oceans, and Geophysics (CCOG). Data stewardship efforts focused on finalizing an Enterprise Security and Remediation Advancement (ESRA) effort, a OneStop data discovery portal, and a new Mission Science Network (MSN) initiative. We geared CCOG activities toward updates to the Crowdsourced Bathymetry project and the Satellite Product Analysis and Distribution Enterprise System (SPADES).

OneStop announced the release of a new version of its data discovery portal on NOAA's data.noaa.gov domain in December 2017, and since it has averaged five times more traffic than the predecessor website, hosted on the same domain. After the initial release, our software development team has been working on a major upgrade to the site that greatly enhances the accessibility and usability of the site for people with disabilities as well as for sighted users.

Our team also supported MSN, a new initiative, that in part will create an end-to-end enterprise solution for ingesting, managing, and distributing NCEI's scientific data holdings. Early work has focused on the use of Kafka to support high volume data stream processing

capabilities and Kubernetes to support cloud based or on-premise based deployments of the software system.

For the ESRA project, we focused on deploying NCEI Colorado's current software systems to a new demilitarized zone of the network, migrating critical applications from Java 7 to Java 8, and testing and moving software off of RedHat Enterprise Linux (RHEL) 5 and onto RHEL 7, which is a more up-to-date and secure version of the linux operating system.

Along with our CCOG partners, we worked on SPADES and the crowdsourced bathymetry initiative (CSB) this past year. For SPADES, our developers focused on adding a Kibana-based log analysis and visualization capability that can be used to look at performance bottlenecks as the system scales to handle new scientific algorithms and increased loads. The CSB effort has been focused on hardening the system to allow a seamless transition from its pilot phase to a now operational status. This effort is also researching potential cloud capabilities to support expected further growth over time of this important effort to further map the world's oceans.

Our Geographic Information Systems team developed and enhanced numerous geospatial web services and interactive maps to improve data discovery and access for NCEI. This work includes a new set of services providing visualization and access to Visible Infrared Imaging Radiometer Suite nighttime lights products, including monthly composites and daily mosaics. We developed a new map viewer to support NCEI's role as the International Hydrographic Organization Data Centre for Digital Bathymetry, displaying all publicly available bathymetric data, including crowdsourced bathymetry, from U.S. and international sources. We developed a map viewer to support NCEI's participation in the tsunami modelling and warning community: the Caribbean and Adjacent Regions Tsunami Sources and Models viewer. Lastly, we made enhancements to the Passive Acoustic Data, Natural Hazards, Index to Marine and Lacustrine Geological Samples, and Bathymetric Data Viewers.

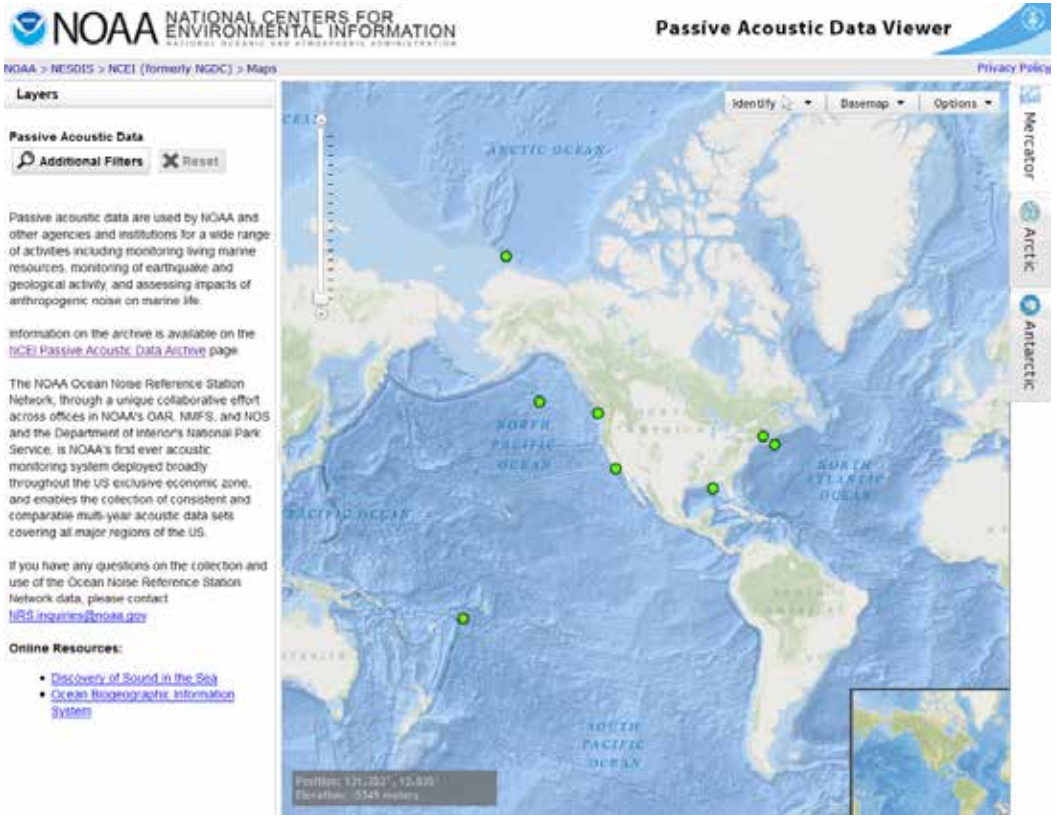
It's been a busy year for us supporting a broad array of scientific software development activities for NOAA's NCEI, and we are looking forward to new challenges in the coming year!

NCEI-02: Enhancing Marine Geophysical Data Stewardship

CIRES Lead: Carrie Wall Bell / NOAA Lead: Jennifer Jencks
NOAA Theme: Science and Technology Enterprise

GOALS & OBJECTIVE

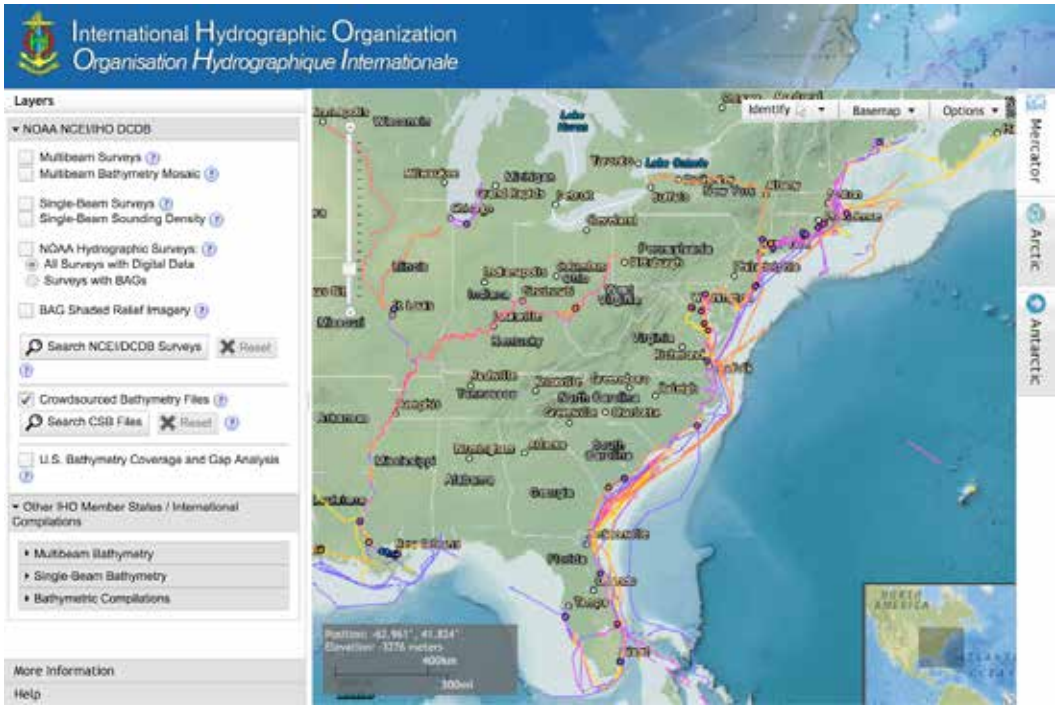
This project focuses on application of common management standards for environmental data supporting many NOAA research and operational endeavors. The project will reduce cost of data access through increased use of partnerships and integration of systems that leverage the value of data.



NCEI-02, Fig. 1: Updated web-based data access page for passive acoustic data archived at NCEI. Image: NOAA

ACCOMPLISHMENTS

Both national and international organizations contribute to and retrieve marine geophysical and geological data from the National Centers for Environmental Information (NCEI) interactive databases. NCEI provides long-term archiving, stewardship, and delivery of data to scientists and the public by utilizing standards-compliant metadata, spatially enabled databases, robotic tape archive, and standards-based web services. Since June 2017, our NCEI and CIRES data managers have added 58 multibeam swath sonar surveys (190,662 nautical miles) and 65 trackline (single-beam



NCEI-2, Fig. 2: IHO Data Centre for Digital Bathymetry map viewer with CSB tracklines enabled. Image: NOAA

bathymetry, magnetics, gravity, subbottom, and seismic reflection) surveys (418,609 nautical miles) conducted throughout the world's oceans to NCEI's global marine geophysical archives.

The water-column sonar data archive has expanded to over 53 terabytes of data and over 25 terabytes of data have been delivered to users around the globe. An annual increase of 19.7 TB in archived data volume reflects the use of new high-data-volume-producing sonar systems. In collaboration with NOAA Fisheries scientists, our CIRES Fisheries Acoustics team is making a major contribution to the active acoustic community through the development of "PyEcholab," an open-source, Python-based data processing toolkit for water column sonar data. Currently there are few open-source tools to analyze these complex data and PyEcholab aims to increase the use and accessibility of water-column sonar data.

The new passive acoustic archive progresses through a second NOAA Big Earth Data Initiative (BEDI) award. We have improved the archive's ingest process in addition to enhancing the web-based data access page and data delivery system (https://maps.ngdc.noaa.gov/viewers/passive_acoustic/; Fig. 1 on previous page).

Marine geophysical data archived at and delivered by our NCEI team support multiple ongoing U.S. mapping efforts, such as the NOAA Office of Ocean Exploration and Research, the Integrated Ocean and Coastal Mapping (IOCM) program and the International Hydrographic Organization (IHO) Crowdsourced Bathymetry (CSB) initiative.

The CSB project, championed by the IHO and funded by NOAA's Office of Coast Survey, aims to empower mariners to "map the gaps" within the current ocean floor coverage. Our pilot project, accepting data contributed by mariners through Rosepoint Electronic Navigation Systems, amassed over 115 million depth soundings from over 100 vessels across the globe. We scaled the crowdsourcing infrastructure and prepared the system for the transition from pilot project to operational data pipeline. This scaling included hardening the ingest and extract systems for increased volumes. In collaboration with NCEI GIS experts, we integrated the CSB map services with the IHO Data Centre for Digital Bathymetry map viewer (Fig. 2, at left).

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

CIRES Lead: Arnaud Chulliat / NOAA Lead: Rob Redmon

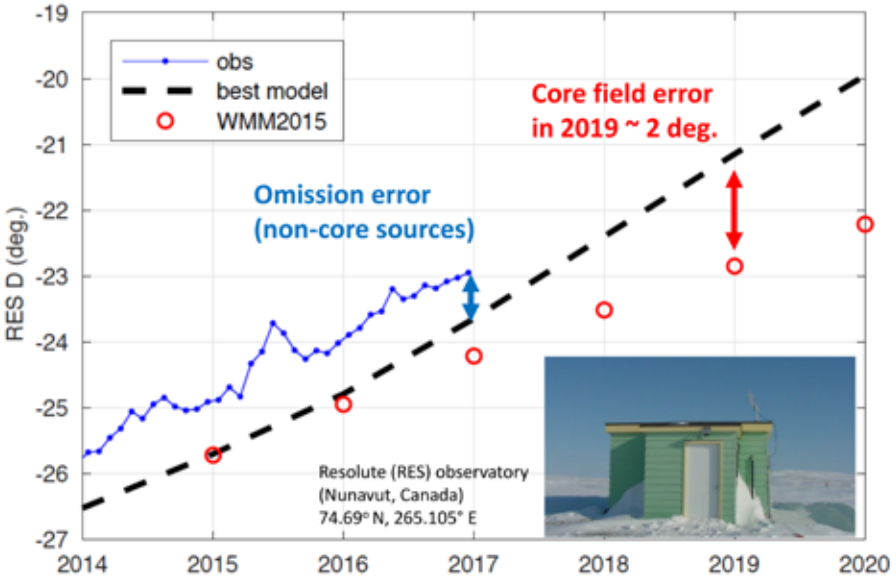
NOAA Theme: Science and Technology Enterprise

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

Our CIRES Geomagnetism Group develops various research and operational geomagnetic field models for NOAA, including the World Magnetic Model (WMM), the standard model used by the U.S. government for navigation, attitude, and heading referencing systems using the geomagnetic field. The WMM is also widely used by industries such as aerospace, energy, and consumer electronics. As part of its regular performance assessment of the WMM, our CIRES Geomagnetism team found that the latest WMM, released by NOAA in December 2014 with a five-year validity, exceeded one of the WMM performance specification tolerances in late 2017. This unexpected performance degradation was caused by fast-changing core flows in the North Polar region of the Earth's outer core. The increased error may adversely affect compass navigation in the Arctic region. NOAA



NCEI-03: Magnetic declination (angle between magnetic north and true north) predicted by geomagnetic field models and measured at an observatory in the Canadian Arctic. Due to fast-changing core flows, the estimated error of the latest World Magnetic Model (WMM), released in 2015, has been rapidly increasing in this area. The total WMM error at any given time is obtained by adding the core field error (red arrow or distance between the red dots and the black curve) and the error due to non-core sources (blue arrow or distance between the blue dots and black curve). Image: CIRES/NOAA

issued a message to WMM users informing them of the performance issue and an out-of-cycle model is expected to be released later this year.

The Enhanced Magnetic Model (EMM) is a high-resolution, spherical harmonic model of the static and slowly varying magnetic fields generated by the magnetized rocks in the Earth's crust and liquid flows in the Earth's core. In 2017, we released a new EMM—derived from the most recent data collected by the European Space Agency's Swarm satellite constellation and NOAA's recently updated Earth Magnetic Anomaly Grid—at 2-arcmin resolution. The EMM is used by government and industry for accuracy-sensitive navigation purposes, including in locations such as deep oceans where GPS is not available. Because EMM calculations require significant computational resources, we developed new, cloud-based application program interfaces (APIs) to provide fast and reliable access to NOAA's high-resolution models as part of a Big Earth Data Initiative (BEDI) project. The EMM API relies on a pre-calculated mesh in an ellipsoidal shell to achieve speed, and various strategies such as load balancing, real-time monitoring and instance cloning to ensure reliability.

Our team also developed the High Definition Geomagnetic Model (HDGM) and its real-time add-on (HDGM-RT), which relies on real-time Deep Space Climate Observatory (DSCOVR) and magnetic observatory data. The HDGM/HDGM-RT is used by the oil and gas industry to increase safety and efficiency of directional drilling. We updated it in December 2017 with the most recent ground and satellite data, as well as new software features. Our team works closely with industry to identify and minimize errors for each geomagnetic source, for example by having its models independently tested against measurement while drilling (MWD) data.

Our CIRES Geomagnetism team has been developing techniques to process magnetic field measurements from the Defense Meteorological Satellite Program (DMSP) in order to (1) assess the possibility of building core field models from non-dedicated magnetic satellite missions and (2) investigate changes in the core field during a three-year gap period when high-quality measurements from the CHAMP and Swarm satellites were not available. This work is ongoing and has led to the development of new methods to correct spacecraft fields in magnetic data. We anticipate the lessons learned from this work will assist in building future WMMs.

Besides developing geomagnetic field models, we also conducted research on ocean-induced and ionospheric magnetic fields, the equatorial electrojet, core field rapid variations, and global mathematical representations of the lithospheric magnetic field. In collaboration with NOAA, our team continued expanding its citizen science program CrowdMag, which now exceeds 25,000 users.

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

CIRES Lead: Nic Arcos / NOAA Lead: Kelly Stroker

NOAA Theme: Science and Technology Enterprise

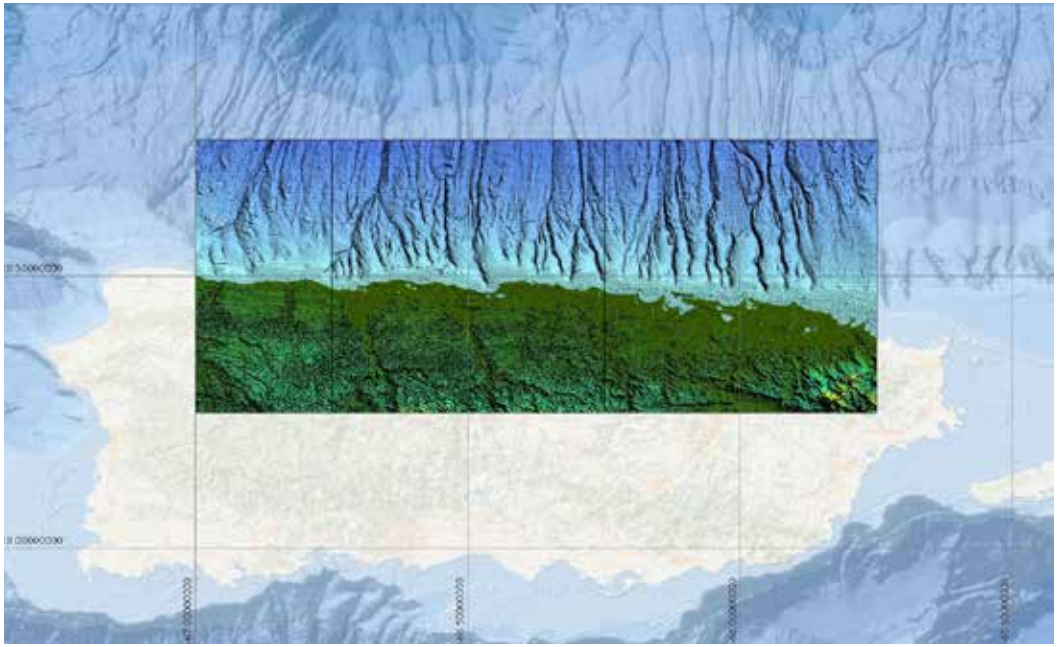
GOALS & OBJECTIVE

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

ACCOMPLISHMENTS

Our CIRES team updated and maintained the Historical Natural Hazards Event Database throughout the year based on new references, newly found references (e.g. historical documents), and new field studies. We updated the Global Tsunami Sources, Significant Earthquakes, and Significant Volcanic Eruptions maps that continue to be requested educational and training tools.

We developed the Caribbean and Adjacent Regions Tsunami Sources and Models (CATSAM) map viewer to provide modelers and hazard assessment professionals with an



NCEI-04: CIRES and NCEI have developed a tiled set of high resolution DEMs of the northern coast of Puerto Rico. The DEMs will enable modelers to improve coastal hazard mitigation efforts. Image: CIRES/NOAA

understanding of Intergovernmental Oceanographic Commission led tsunami modeling efforts, as well as how those efforts overlap with the NOAA's NCEI Global Historical Tsunami Database.

We enhanced the Natural Hazards Viewer to include a "Selected Significant Tsunami Events" feature. The feature highlights historical tsunami events by displaying a tsunami energy map, tsunami travel times, and observed wave runups. NOAA's Pacific Tsunami Warning Center (PTWC) provided the energy maps using the same forecast tool that it uses to determine tsunami hazards in real time for any tsunami today.

We published a pre-DART-era, bottom pressure recorder (BPR) data inventory timeline. The visual representation of data inventory and reported tsunami waves for coastal water level measurements has had two impacts: (1) identification of systematic gaps in the archive and initiation of efforts to recover these data, and (2) improved data exploration for users. We also published station pages providing time-series plots and direct access to unassessed data, quality-controlled data products, modeled tidal constituents, supporting metadata, and a list of reported tsunami events.

For the 2017 hurricane season (Harvey, Irma, Jose, and Maria), NCEI conducted quality control and analysis of tide gauge data and BPR records from the Caribbean, Florida, and the Gulf of Mexico.

Our team completed high-resolution tiled digital elevation models (DEMs) along the Hurricane Ike-impacted coast of Texas using the data development framework initially created under the Sandy Supplemental Appropriations Act of 2013. This framework allows for targeted rapid updates to the specific areas once new survey data becomes available. We updated the DEM tiles developed for the New York/New Jersey region with the most recent high resolution topographic-bathymetric lidar data and mulitbeam bathymetry from NOAA's National Ocean Service.

DEMs built for the the National Tsunami Hazard Mitigation Program (NTHMP) continue to be a priority task for us at NCEI. Over the last year, our CIRES staff at NCEI developed DEMs covering Alaska's Bering Sea, the north coast of Puerto Rico, Bellingham Bay, Washington, and the southwest coast of Florida.

Under funding from the Big Earth Data Initiative, NCEI and the NOAA Center for Tsunami Research rescued, documented, reformatted, and archived segments of marigrams on which are recorded measurements of the 1946, 1952, 1960, and 1964 tsunamis. This effort transforms fragile paper records to usable digital data. NCEI is also updating bathymetric DEMs for 71 U.S. National Estuaries. We completed hydrographic data collected after the original DEMs that are now are being incorporated into new models representing current coastal bathymetry.

NCEI-05: Enhanced Stewardship of Space Weather Data

CIRES Lead: Juan Rodriguez / NOAA Lead: Rob Redmon

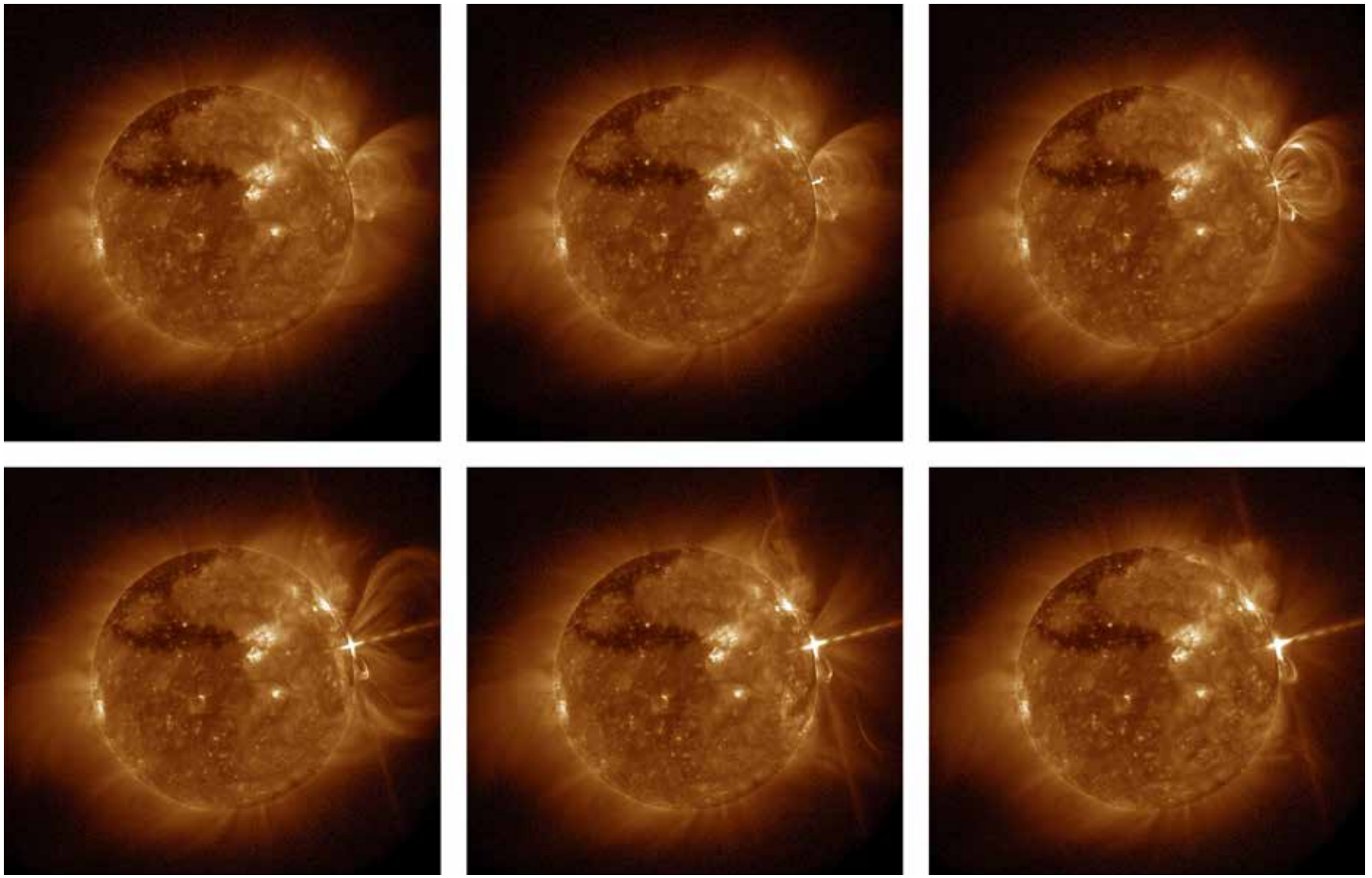
NOAA Theme: Science and Technology Enterprise

GOALS & OBJECTIVE

This project will enhance the quality, utility and accessibility of NOAAs space environmental data.

ACCOMPLISHMENTS

While the purpose of project NCEI-08 is to ensure that NOAA's SWPC receives high-quality real-time data from the GOES-R-series of spacecraft for its forecasts and alerts, this project focuses on archiving these data and reprocessing these and other NCEI space weather data holdings in order to improve their quality and usefulness. Working within NCEI, our CIRES personnel released to the public the first space weather data from GOES-16, from the high-energy Magnetospheric Particle Sensor (MPS-HI) and the Solar Ultraviolet Imager (SUVI) instruments. The first SUVI data



NCEI-05: Selected images of the large solar eruption and flare on September 10, 2017, in the 19.5 nm passband from the Solar Ultraviolet Imager (SUVI) on GOES-16. The upper left frame (15:18:24 UT) shows the corona just before the event onset. Image: Seaton and Darnel 2018, Fig. 4.

release was a special release of solar extreme-ultraviolet (EUV) images from the period of intense solar flare activity in early September 2017, in coordination with the publication by two CIRES scientists of the first peer-reviewed paper on SUVI observations (Seaton and Darnel 2018). The figure on the previous page, from this paper, shows SUVI images in the instrument's 19.5-nm passband of EUV light, during the powerful solar eruption and X8.2-class flare in September 2017. By comparison, the human eye is most sensitive to green light, around 545 nm.

The SUVI data are also the focus of one of NCEI's Big Earth Data Initiative (BEDI) projects. Making SUVI data both discoverable and accessible to the public poses a formidable challenge. Solar events that strongly influence space weather are relatively infrequent. Therefore, only a subset of SUVI's large data volume will be of strong interest to the space weather community. As a result, there is a need for intelligent strategies to help the public search and access these data. As a first step in this project, we have developed an algorithm that helps to classify SUVI images based on their importance to space weather. We designed the algorithm to be fast enough to classify images in real time. The degree of importance is highest when a flare or a coronal hole is detected. We will make such images immediately available on spinning disk—and all SUVI images will be archived on tape and accessible to the public.

One feature of real-time data that is essential for its use by SWPC makes it very inconvenient for use by the scientific community: the non-imagery data are transmitted to NOAA in Boulder in data files that contain 30 or 60 seconds of data. This means that a scientist would have to download as many as 2,880 data files or 'granules' just from one instrument to analyze a day of data—in a world where scientists commonly analyze years if not decades of data. Therefore, we have developed a highly general data aggregation software that NCEI is using to create daily data files from some 50,000 granules received per satellite per day. Our CIRES team also identified and reported gaps in the GOES-16 real-time data processing and managed the downloading of GOES-16 raw space weather data that would otherwise have been lost so that these gaps can be filled through reprocessing.

Although our emphasis during this period has been on the new GOES-R data, we have also contributed to a major NCEI achievement in salvaging and reprocessing of historical data, the completion of a BEDI project for the reprocessing of high-time-resolution GOES 8-12 magnetometer data. The existing, publicly available GOES magnetometer dataset is one of the most frequently cited space weather datasets. However, dating as far back as 1995, the GOES 8-12 data had never been processed at the highest resolution and were at risk of being lost. Such magnetic field data are essential for scientific studies of natural magnetic waves that control the levels of hazardous radiation in the Earth's radiation belts. Our CIRES contribution included: performing painstaking quality control on raw data copied from recalcitrant aging compact disks, developing metadata for this salvaged dataset, and archiving these reprocessed GOES magnetometer data.

PUBLICATION

Seaton, D. B. and J. M. Darnel (2018), Observations of an eruptive solar flare in the extended EUV solar corona, *Astrophysical Journal Letters*, 852:L9, doi: 10.3847/2041-8213

NCEI-07: Nighttime VIIRS product annual composite of the eastern United States. Stable lights are shown in yellow, gas flares as red, and boat detections in light blue, visually depicting the three VIIRS product lines, VIIRS Nighttime Lights, VIIRS NightFire, and VIIRS Boat Detection respectively. Image: CIRES/NOAA

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, our CIRES staff collaborated with NOAA scientists to continue improvements on product lines generated using nighttime data from the Visible Infrared Imaging Radiometer Suite (VIIRS) satellite sensor. This year brought new input data streams to work with. First, we launched a second VIIRS sensor, onboard the JPSS-1/NOAA-20 (J01) satellite in November 2017, which brought additional challenges and opportunities.

And secondly, in late 2017, the original VIIRS onboard the NPP satellite started collecting nighttime data in the M11 band at 2.2um.

To take advantage of these new data, we refined our VIIRS Nightfire (VNF) algorithm to accept this additional spectral band, culminating in the release of VNF v3.0 in December 2017. Upon beta-maturity of the J01 VIIRS in April 2018, VNF began generation for both the NPP and J01 VIIRS, giving two nightly global observations for fires, flares, and other combustion sources.

Our team continued global estimates for flared gas volumes by country. We updated flare locations using VNF for 2017. We use this new set of flare locations, along with the Nighfire-derived radiant heat values, to estimate country-level gas flaring volumes for 2017. VIIRS Nighttime Lights (VNL) monthly composite product generation continued and we released a second annual nighttime lights product for 2016 in May of 2018. The annual VNL separates ephemeral from persistent light sources, and separates lights from non-light areas. We have also made VNL products available via map services for easier public accessibility.

Finally, our VIIRS Boat Detection (VBD) product generation has been ongoing, with global processing of the historic record continuing, and we expected to complete it in the next year. We have put a near real-time alert service for VBD in place. The alert service sends notifications of boat detections within marine protected areas and other sensitive waters to subscribers. Fishery agencies are actively using this service to support their efforts in maintaining sustainable fisheries.

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

CIRES Lead: Juan Rodriguez / NOAA Lead: Rob Redmon

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

On a beautiful Florida afternoon March 1, 2018 at 5:02 p.m., we witnessed the successful launch of the GOES-S satellite on Cape Canaveral. The second satellite in the GOES-R series, GOES-S received its number (17), two weeks later after joining GOES-16 in geostationary orbit. This launch was particularly awe-inspiring in anticipation of the additional work our team faced in the on-orbit calibration and validation of the four space weather instruments on GOES-S—on top of the ongoing work getting the GOES-16 space weather data ready for use by NOAA SWPC and the public. During this period, our team has worked continuously to assess data quality, diagnose problems with the space weather instruments, and identify necessary fixes and upgrades to the first level of data processing algorithms. Many of the revisions we could only determine from analysis of instrument measurements after the satellites were on orbit. Our team completed the necessary calibration and validation work to make the data from two of the instruments to be ready for operational use: the high-energy Magnetospheric Particle Sensor (MPS-HI) and Solar Ultraviolet Imager (SUVI). We also helped bring the data from the other GOES-16 instruments to a high level of maturity such that they should be ready for operations before the end of 2018. For this work on GOES-16, our group was awarded CIRES Gold Medal Award at the 2018 CIRES Rendezvous—this medal reflects the Department of Commerce Gold Medal our federal colleagues received. This spring, our CIRES team has also collaborated with the GOES-R program on the release of the GOES-17 'first light' publicity images for the Magnetometer, Space Environment In-situ Suite (SEISS), and the Extreme Ultraviolet and X-Ray Irradiance Sensors (EXIS).

In addition to these calibration and validation responsibilities, our group is responsible for the development of the second level (L2) of space weather data processing algorithms, the products of which will be used directly by SWPC once they are transitioned to operations by the National Weather Service NWS. We successfully delivered the second and third (of three) phases of the L2 algo-

NCEI-08: United Launch Alliance Atlas V rocket carrying the NOAA GOES-S satellite very shortly after launch on March 1, 2018 at 5:02 PM EST, from Cape Canaveral, Florida. Photo: NESDIS/NOAA

rithms to the NWS on time in September and December 2017, respectively, for transition to operations. We have continued to make improvements to the L2 algorithm software to facilitate long term maintainability across some 20+ algorithms. We have also made scientific modifications to the algorithms to account for instrument problems discovered after examining on-orbit data, such as radiation spike detection in EXIS X-ray sensor data and a temperature-dependent correction to SEISS solar and galactic proton sensor data. We have developed all of these algorithms within the framework provided by NCEI's Satellite Product Analysis and Distribution Enterprise System (SPADES), a real-time space weather science processing demonstration system that CIRES has helped develop.

NCEI-09: Post launch celebration at Range Control at NASA Wallops Flight Facility after liftoff of the Orbital Cygnus OA-9 spacecraft. Photo: Justin Mabie/CIRES

NCEI-09: Enhanced Ionosonde Data Access and Stewardship

CIRES Lead: Justin Mabie / 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

Our team has accomplished a great deal in the last fiscal year. Our primary responsibility throughout the year is to ingest and disseminate ionosonde data and produce quarterly reports. We have maintained this task with some outages caused by Information Technology transitions that have occurred at NOAA. From June through October 2017, we dedicated all spare time to making observations of the 2017 eclipse. With Terry Bullett, we were the first to perform a temporary deployment of an ionospheric sounder for an experiment like this. We programmed the deployed instrument in southern Wyoming in a way that was locked to a similar permanent instrument in Boulder, Colorado—allowing two ionosondes to effectively act as four ionosondes. This was the first time these systems have been used in this way and represents a significant advance in ionospheric remote sensing. We successfully performed ionospheric observations during the eclipse and published the initial results in *Geophysical Review Letters.*

I (Justin Mabie) also travelled to Wallops Virginia in both November 2017 and May 2018 to perform field site and radar system repairs, and travelled to Puerto Rico in June 2018 to perform repairs caused by Hurricane Maria and to install a system that was previously in Colorado for repairs. I also performed experiments to observe the atmospheric response to two large rocket launches, conducted a field site survey for Arecibo Observatory, and advised them on installation of a permanent ionosonde at the site. I attended CEDAR (Coupling, Energetics and Dynamics of Atmospheric Regions) and URSI (Union of Radio Science International) international meetings. Finally we completed a draft of a paper on the effects on the atmosphere and radio wave propagation of rocket generated acoustic waves. We will submit the paper when the final co-author completes his review.

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

CIRES Lead: Carrie Morrill / NOAA Lead: Eugene Wahl

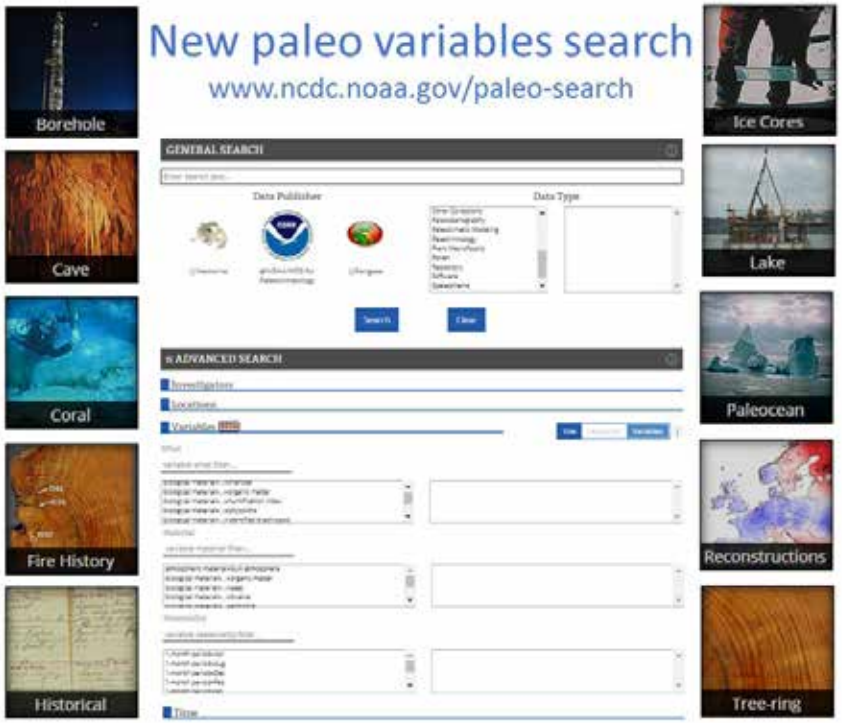
NOAA Theme: Climate Adaptation and Mitigation

GOALS & OBJECTIVE

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

ACCOMPLISHMENTS

We completed a multi-year project to provide new searching capabilities on the paleoclimate measurements that we archive as the World Data Service for Paleoclimatology (WDS-Paleo). The heterogeneity of paleoclimate variables is one of the biggest barriers to the development of accumulated data products and to the use of paleo data beyond the community of paleoclimate specialists. With the feedback of 25 subject matter experts from the broader paleoclimate community, we formulated a comprehensive thesaurus to describe the wide variety of measurements archived by the WDS-Paleo. The thesaurus contains more than 2,800 terms and their definitions. We selected from these terms to describe more than 100,000 time series at the WDS-Paleo. This information now powers a new search capability for measured variables that significantly outperforms previously available keyword



NCEI-11: The new search for paleoclimate variables is now operational and is accessible at www.ncdc.noaa.gov/paleo-search. Image: CIRES/NOAA

searching. Searches for commonly-requested variables such as "sea surface temperature" or "carbon dioxide" now yield about 10 times as many results as the keyword search did. In the first two months of use since becoming operational in late March 2018, our customers have chosen the new variables search over the keyword search 96 percent of the time, with more than 3,000 variables searches completed. Our team members working on this project received the NESDIS Outstanding Information Technology and Engineering Employee Awards of 2018 for "developing an innovative search capability within NCEI's Paleoclimatology web service and allowing customers to efficiently find, preview, and download data based on meaningful search criteria, thereby supporting NESDIS's and NOAA's goal to preserve and provide user-relevant data."

We completed version 2 of the Living Blended Drought Product, which consists of Palmer Modified Drought Index (PMDI) reconstructions for the last two millennia (0 CE – 1978 CE). 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. Building on the PMDI reconstructions for climate divisions released in version 1, our new version supports more applications by providing PMDI reconstructions on a half-degree grid that are calibrated to the most recent instrumental data. Integration of the paleoclimate data with the instrumental record places recent droughts into a longer-term perspective and enables research to understand and predict hydroclimate changes in the continental United States.

We also published research in *Geophysical Research Letters* detailing the causes of extreme wet conditions in the western United States at the Last Glacial Maximum (LGM) about 21,000 years ago. In contrast to longstanding scientific assessments that these wet conditions were caused by an increase in atmospheric moisture import to the region via storm tracks, our analysis of nine state-of-the-art coupled climate models participating in the Coupled Model Intercomparison Project (CMIP5) showed that, under the cold climate conditions of the LGM, reductions in atmospheric moisture export from this region played a significant role. We expect increases in atmospheric moisture export to be important in determining future water availability in the western United States as temperatures rise, so this result shows continuity from past to future in the mechanisms altering hydroclimate. This research formed the basis of a 2018 CIRES Outstanding Performance Award.

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

CIRES Lead: Barry Eakins / NOAA Lead: Robin Warnken

NOAA Theme: Science and Technology Enterprise

GOALS & OBJECTIVE

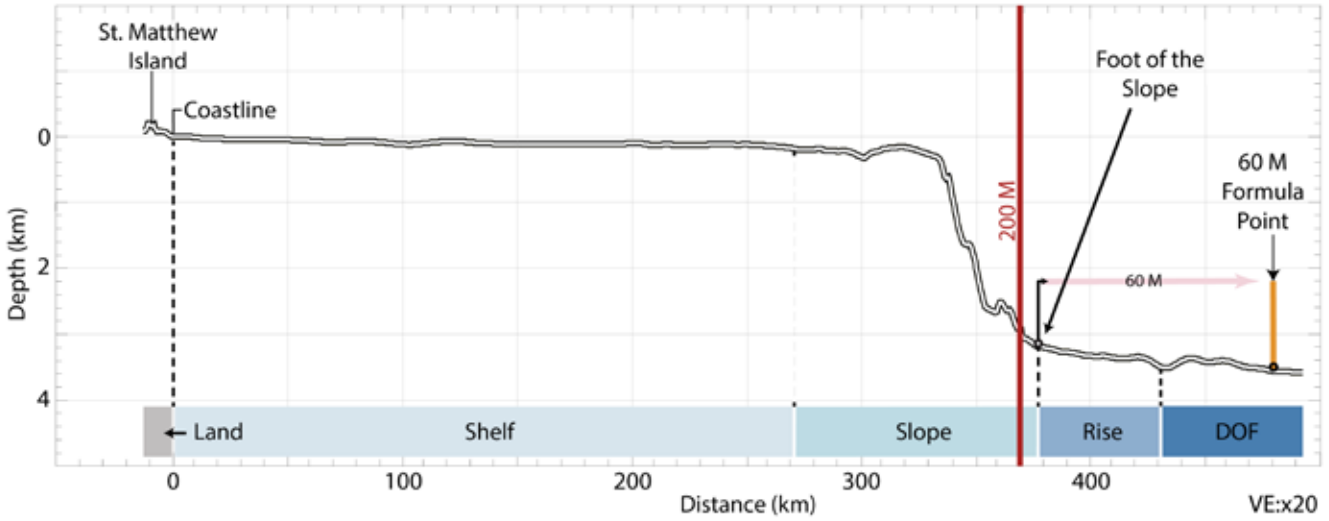
This project will determine and establish the outer limits of the seafloor over which the United States has sovereign rights for the purpose of exploring, managing, conserving and/or exploiting the natural resources of the seabed and subsoil.

ACCOMPLISHMENTS

Our CIRES team members in the U.S. Extended Continental Shelf (ECS) Project Office had several major accomplishments this year: improved ECS analytical methods, completed draft Submission documents for the Bering Sea and eastern Gulf of Mexico regions, and improved draft Submission documents for the Arctic and western Gulf of Mexico regions.

We improved several important ECS analytical methods, including developing a more systematic workflow for creating bathymetric profile figures, and refining the method for calculating robust foot-of-slope points (a critical element in determining the ECS). We improved the geospatial workflow for determining the base-of-slope zone, and applied planform curvature grids to highlight downslope processes in associated cartographic maps. We also explored scripting techniques utilizing python to automate figure production processes.

We applied the improved ECS analytical methods to bathymetric and seismic data in two U.S. regions: the Bering Sea and the Eastern Gulf of Mexico. We subsequently developed



NCEI-13: Bathymetric profile figure in the Bering Sea regional submission document that demonstrates that the U.S. satisfies the Test of Appurtenance—that continental shelf extends beyond 200 nautical miles (M) from shore. In this case, the outer edge of the continental shelf lies 60 M beyond the foot of the continental slope, and well beyond the 200 M limit. This test is an initial assessment conducted by the Commission of the Limits of the Continental Shelf prior to their review of a submission. Image: CIRES/NOAA

draft Submission documents —in close collaboration with U.S. ECS Project colleagues at NOAA, the University of New Hampshire, the U.S. Geological Survey, and Department of State—that describe those methods, and the legal and scientific justification for establishing the outer limits of the continental shelf in these two regions. The documents also included numerous, associated cartographic products (maps and other figures) necessary to demonstrate the ECS outer limits. We also improved the draft Submission documents for the Arctic and Western Gulf of Mexico regions, based on feedback from national and international experts.

Lastly, we developed a systemic approach for tracking references cited in the U.S. ECS Submission, and created a Submission style guide that standardizes abbreviations, definitions, citations, and other items across all ECS documents. Our team also created a new U.S. ECS Project hallway poster that is displayed at NCEI-CO.

NSIDC-03: Update, Improve, and Maintain Polar Region Datasets

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

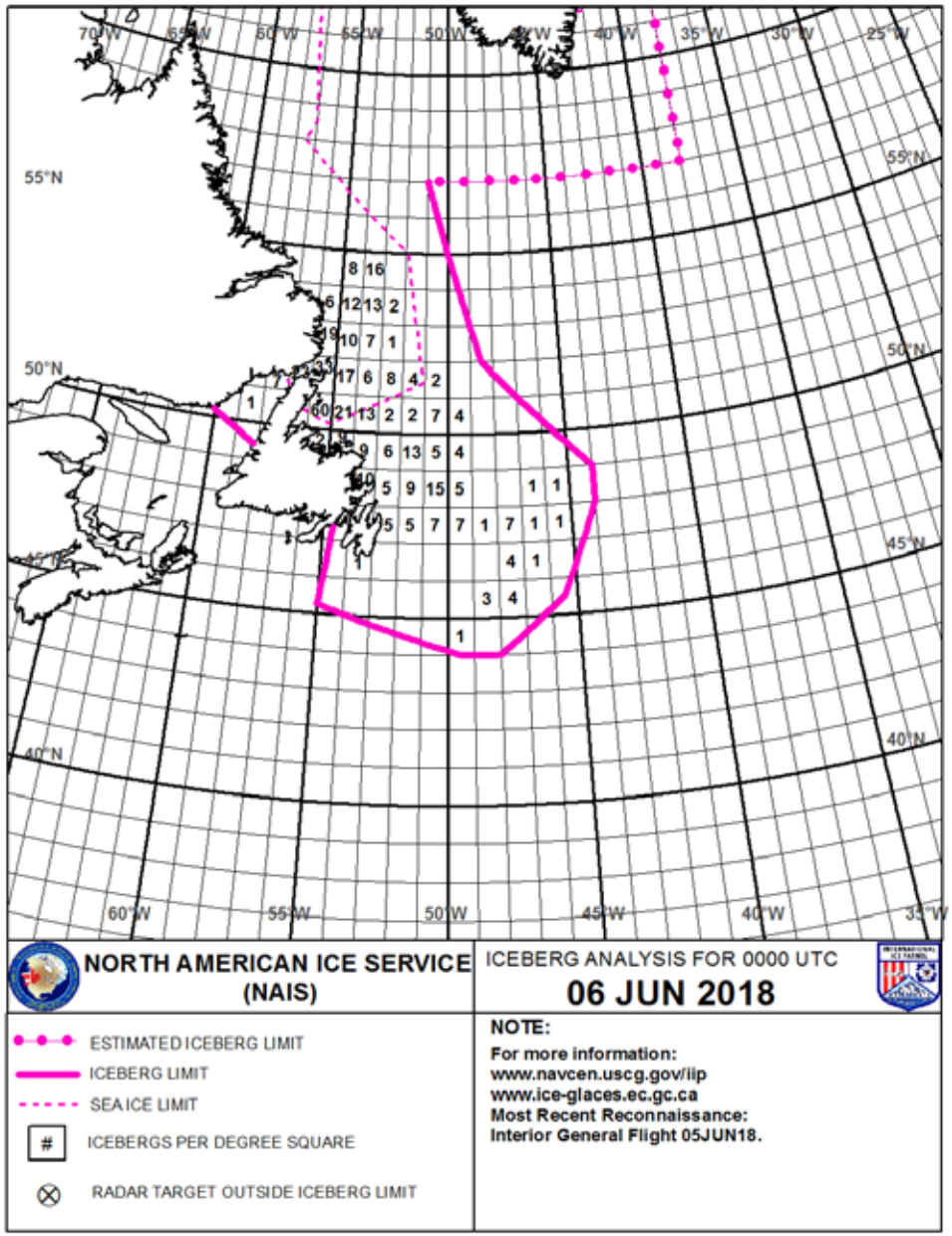
Over the reporting period, we made six posts to the NOAA@NSIDC data news page (http://nsidc.org/the-drift/data-set/noaa/) informing users about new products or additions or changes to the existing collection of polar region datasets. The NOAA program at NSIDC serves about 60 percent of the users who visit NSIDC's site and download data, therefore it is important to keep users informed. Some of the year's highlights follow.

NOAA/NSIDC Sea Ice Concentration Climate Data Record Updated

We made the revision change to incorporate a new version of the input data products, Bootstrap Sea Ice Concentrations from Nimbus-7 SMMR and Defense Meteorological Satellite Program SSM/I-SSMIS, and to update the data that use the SSMIS output to also use the SSMIS pole hole mask. In previous versions, we were using the larger SSM/I pole hole mask for these data, which was cutting out a section of valid data. In addition, this fixes a bug in the code that was causing some sections of the time series to not produce output files. Ann Windnagel gave a presentation on this work titled "Sea Ice Concentration CDR at the National Centers for Environmental Information" at the 2018 Sun-Climate Symposium in Lake Arrowhead, California. Note: SSM/I and SSMIS are Special Sensor Microwave / Imager and Imager Sounder.

Arctic Sea Ice Thickness Measurements from 1894 to 2011

In March, we announced the release of "On-Ice Arctic Sea Ice Thickness Measurements by Auger, Core, and Electromagnetic Induction," from the *Fram* expedition onward. In addition to sea ice thickness, the dataset provides sea ice freeboard and snow depth on sea ice. We compiled the archive from 44 different expeditions starting



with measurements from the Fram expedition in 1894 and 1895, then to the Maud expedition from 1922 through 1924, and continuing forward in time to observations from 2011.

Benjamin Holt, an investigator at the Jet Propulsion Laboratory, Pasadena, California, compiled these data. He saw a need to collect many scattered smaller collections into a larger archive that would receive metadata and documentation so data could be more easily found and used. In-situ sea ice thickness data can be used to validate algorithms for sea ice thickness data from satellite altimetry, infrared imagery, or emissivity. This collection joins other ice thickness data collections held by NOAA@NSIDC, including the following:

- Unified Sea Ice Thickness Climate Data Record, 1947 Onward
- Submarine Upward Looking Sonar Ice Draft Profile Data and Statistics
- Morphometric Characteristics of Ice and Snow in the Arctic Basin: Aircraft Landing Observations from the Former Soviet Union, 1928-1989
- AWI Moored ULS Data, Greenland Sea and Fram Strait, 1991-2002
- SCICEX: Submarine Arctic Science Program

International Ice Patrol (IIP) Iceberg Sightings Database Updated through the 2017 Iceberg Season

NOAA@NSIDC documents, archives, distributes, and maintains these data in cooperation with the U.S. Coast Guard. The IIP has been collecting information on iceberg activity in the North Atlantic since 1913, and this database contains data from these sightings, starting in 1960. The IIP data files include latitude and longitude of sighted icebergs, coded iceberg size and shape class, and date and time of the sighting. These data have always been of interest to operational concerns and are getting increasing attention as the number of icebergs in northern shipping lanes has seen recent increases (see figure at left).

Satellite Data Rescue for NOAA

Garrett Campbell, with help from undergraduate students, has rescued early NOAA satellite data from the Environmental Science Services Administration (ESSA) series. A successful proposal for NOAA Big Earth Data Initiative support is allowing him to continue the work to recover NOAA 1,2,3,4 Infrared and Visible High Resolution Data, 1972-1977. He presented a poster on this work

NSIDC-03: Aerial patrols to count icebergs build the data used in charts like this North American Ice Service iceberg analysis. NOAA@NSIDC archives the iceberg sightings (time and position) that are charted for the safety of ships at sea. Image: https://www.navcen.uscg.gov, accessed 5 June 2018

at the 2017 Fall AGU meeting. If we can complete all proposed work, a near continuous 1966 into 1979 NOAA operational meteorological satellite data record will be available.

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

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

Activities of the NCEI Arctic Team ramped down in 2017 and 2018. The team no longer has regular meetings by teleconference. As available time and funding for team activities continue to shrink, it becomes even more important to network both formally and informally across NOAA offices and across agencies to improve access to, and utility of NOAA NCEI Arctic data. That is a major focus of this project.

CIRES' Florence Fetterer represented the NCEI Arctic team in work on climate indicators lead by NOAA's Diane Stanitski. This culminated in submission of a paper (Stanitski et al.) to *Climatic Change* and a poster by Fetterer et al. summarizing the work at the April American Association of Geographers meeting (figure).

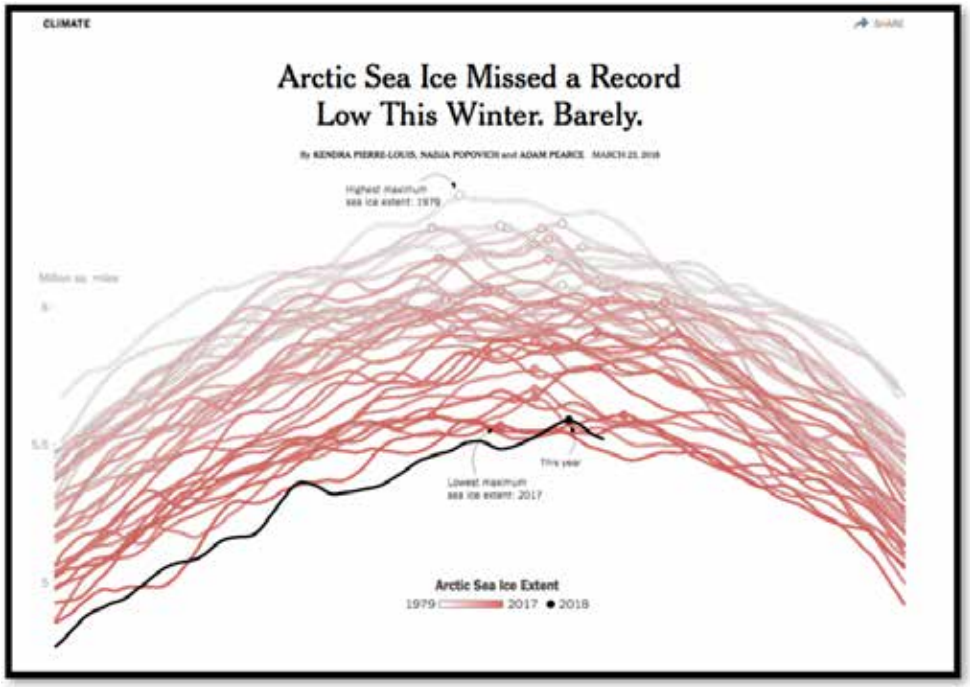
NOAA@NSIDC maintains the International Ice Charting Working Group pages (https://nsidc.org/noaa/iicwg/), and has direct ties with the NOAA/Navy/Coast Guard National Ice Center (NIC) and the NOAA National Weather Service Sea Ice Program operational groups. We publish and archive several products in collaboration with NIC.

NSIDC Director Mark Serreze and CIRES' Florence Fetterer attended the 8th Symposium on the Ice Diminished Arctic, hosted by the U.S. National Ice Center and the U.S. Arctic Research Consortium. Fetterer is coauthor on a talk given at the symposium on whether sea ice extent in particular regions of the Arctic could be a leading indicator of navigability in the Beaufort Sea. The work used Gridded Monthly Sea Ice Extent and Concentration, 1850 Onward, a NOAA@NSIDC dataset. While in Washington, DC, we took the opportunity to spend a day on the Hill visiting with staffers in Congressional offices.

In August, we met with two analysts as well as the science lead, LT Emily Motz, from the U.S. National/Naval Ice Center to share information about the products of theirs that we archive and distribute. We are now archiving additional NIC products, including their weekly hemisphere-wide analyses and their daily marginal ice zone product. These products offer better accuracy and resolution than most satellite data-derived products.

In September 2017, U.S. Representitive Jared Polis visited NSIDC, and Fetterer had the opportunity to stress that our work was valued for practical applications. For example, staff with NOAA Fisheries in Alaska use our sea ice data to help forecast the timing of Chinook salmon runs on the Yukon River; since they started using the data, their forecasts have improved considerably.

We prepared a poster giving an overview of NOAA@NSIDC in advance of April 2017's visit to NCEI Center for Coasts and Ocean Geophysics by the NCEI Director Mary Wolgemuth and Assistant Administrator for Satellite and Information Services Stephen Volz. Wolgemuth and NCEI Acting Deputy Director Eric Kihn visited NSIDC as well.



NSIDC-04: Indicators assist in communicating complex system behavior. Arctic sea ice extent is a conceptually simple climate indicator that can convey complex system behavior when rendered skillfully. The seasonal cycle, the short term variability that results from dynamics, and the year-to-year trend of less ice due to long term thermodynamic forcing are all represented in this figure from the *New York Times*. This figure was used in a poster titled Selecting Indicators for Understanding Arctic Change and Its Implications. Image: Used with permission of the *New York Times*, **https://nyti.ms/2G7O3lX,** accessed 25 Mar 2018

Project Reports: Regional Sciences and Applications

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

CIRES Lead: Yelena Pichugina / NOAA Lead: Alan Brewer

NOAA Theme: Weather-Ready Nation

GOALS & OBJECTIVE

This project will investigate atmospheric composition, dynamics, and transport processes from the surface to the upper troposphere, and characterize biological productivity in the uppermost ocean layer. These studies have particular relevance to air quality, climate, ocean ecosystems, and renewable energy.

ACCOMPLISHMENTS

Under this project, our scientific research included studies to investigate atmospheric processes in the boundary layer, the troposphere, and ocean ecosystems using state-of-the-art lidar technology.

During several field campaigns, we deployed various types of lidars on the ground or on aircraft to study transport processes of ozone, characterize wind flows in complex terrain, evaluate the performance of numerical weather prediction (NWP) models to forecast the wind and turbulence structure in the vicinity of wind farms, and study plankton layers in the Arctic Ocean.

We used measurements from two unattended NOAA scanning Doppler lidars and a Halo StreamLine scanning lidar deployed to three sites in the Columbia River Gorge during the second **Wind Forecast Improvement Project (WFIP-2)** to analyze the temporal and site-to-site variability of the wind profile in the first several kilometers above ground level (AGL), to better understand physical processes related to terrain effects, weather conditions, and presence of wind farms. Continuous measurements over an 18-month period provided a comprehensive dataset we used to validate NWP model wind forecasts and evaluate model accuracy over days, months, and seasons, as well as for periods of interesting meteorological events including wind ramps, cold fronts, or marine intrusion events observed in the study area. We analyzed verification metrics such as bias, root mean square error (RMSE), mean absolute error (MAE), and the correlation coefficient between observed and modeled wind variables as a function of height, time, and forecast hour, revealing meteorological features that are not well represented by models and provide insight into potential model improvements.

We deployed the NOAA **Oceanographic Lidar (OL)** to the Arctic in the summer of 2017 to study the effects of retreating sea ice on subsurface phytoplankton layers. The lidar also detected aerosol structure above the ice by using in-situ and OL measurements from a NOAA Twin Otter aircraft.

During the **Fires, Asian, and Stratospheric Transport - Las Vegas Ozone Study (FAST-LVOS)** in May and June 2017, we deployed two lidar systems: the Tunable Optical Profiler for Aerosol and ozone (TOPAZ) ozone lidar and an upgraded version of the NOAA-developed Micro-Pulse Doppler (MicroDop) lidar. We deployed these systems to the Las Vegas Valley, providing ozone profiles from near the surface to 5-8 km above ground level and vertical wind speed and turbulence profiles. We completed these lidar measurements by in-situ chemistry observations with the Chemical Sciences Division mobile van and onboard the Scientific Aviation Mooney aircraft. In addition, our NOAA Global Monitoring Division colleagues launched ozonesondes. The main objective of FAST-LVOS was to better

CSD-08: Aditya Choukulkar setting up a NOAA 200S scanning Doppler lidar at the Arlington research site in the Columbia River Basin during the second Wind Forecast Improvement Project (WFIP2). Photo: Scot Sandberg/NOAA

understand the major sources of surface ozone in Clark County, Nevada—in particular, the contribution of stratosphere-to-troposphere transport, long-range transport from Asia and wildfire emissions. Our lidar measurements clearly documented several cases of entrainment into the boundary layer and subsequent mixing to the surface of high-ozone layers aloft that were of stratospheric, Asian, or wildfire origin. This entrainment process was facilitated by the very deep boundary layers (up to 5 km above ground level) that are typical for the Las Vegas area in late spring and early summer.

During the **Land-Atmosphere Feedback Experiment (LAFE)** we deployed a NOAA Doppler wind lidar to the Department of Energy Atmospheric Radiation Measurement Climate Research Facility Southern Great Plains Megasite, along with several other types of lidars and remote sensing systems, to collect a dataset for studying feedback processes between the land surface and the atmosphere. We are using simultaneous measurements of land-surface fluxes as well as horizontal and vertical transport processes in the atmospheric convective boundary layer for verifying simulations of land-atmosphere feedback in large-eddy simulation and mesoscale models.

Our team continued to participate in the multi-year **Indianapolis Flux Study (INFlux)** collecting high-resolution wind field measurements, as well as vertical velocity variance and aerosol backscatter signal strength profiles with two Doppler wind lidars. Our team collaborated with Pennsylvania State University and NOAA Global Monitoring Division scientists to develop and evaluate methods for measurement and modeling of greenhouse gas fluxes from urban environments.

In the 2017-18 reporting period, our engineering teams focused on the development and testing of a new version of the state-of-the-art **MicroDop** lidar, a compact and robust Doppler lidar system with increased sensitivity compared to commercially available systems. Results from several short-term experiments, in which we deployed the MicroDop lidar on the ground or on a NOAA Twin Otter aircraft, show high measurement precision and excellent pointing accuracy, making the MicroDop lidar ideally suited for airborne and shipborne deployments in upcoming field studies.

PSD-19: Improving Wind and Extreme Precipitation Forecasting

CIRES Lead: Laura Bianco / NOAA Lead: Kelly Mahoney

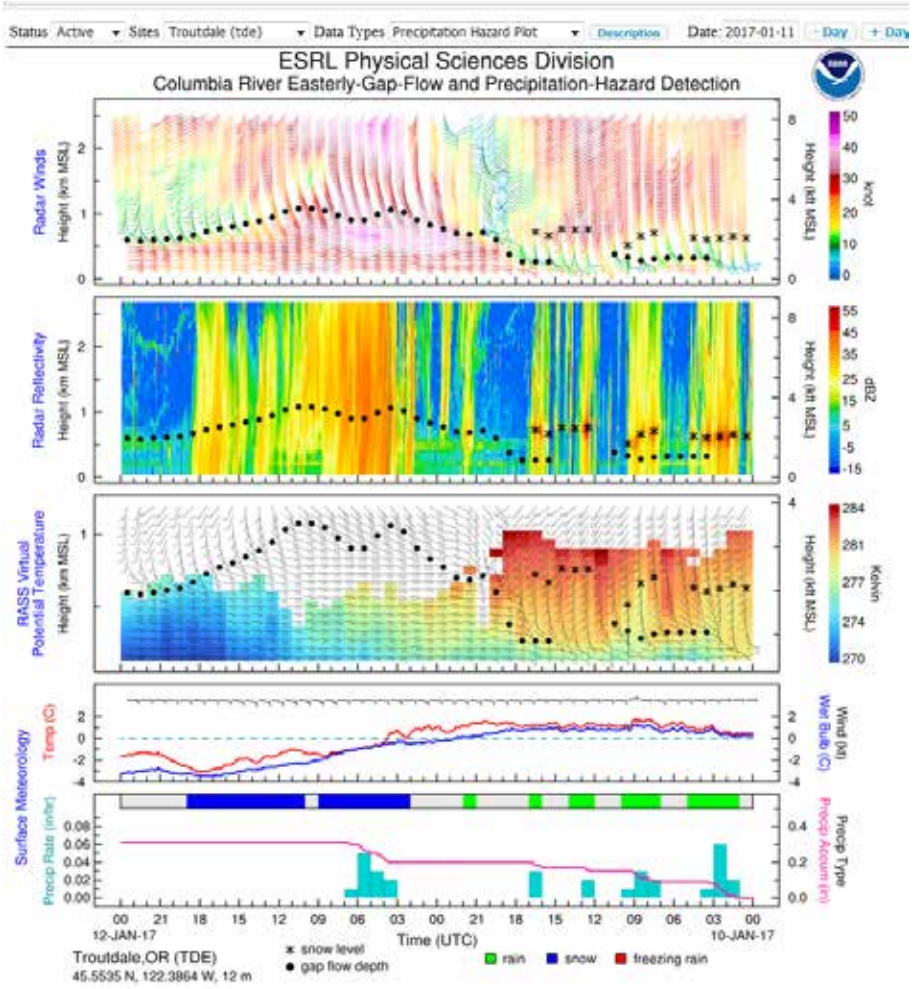
NOAA Theme: Science and Technology Enterprise

GOALS & OBJECTIVE

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

ACCOMPLISHMENTS

Our goal is to improve understanding of moist processes in the Pacific Northwest,



PSD-19: An example of the real-time online data product at Troutdale, Oregon, in January 2017. First panel: Time-height cross section of hourly wind profiles (snow level and top of the gap flow are marked with stars and solid black dots, respectively). Second panel: Time-height cross section of radar reflectivity. Third panel: Time-height cross section of hourly wind profiles and virtual potential temperature. Fourth panel: Time series of hourly surface wind velocities, 2-min-resolution temperature (red), and wet-bulb temperature (blue). Fifth panel: Hourly precipitation type and precipitation rate, and 2-min-resolution precipitation accumulation. Image: CIRES/NOAA

augmenting the second Wind Forecast Improvement Project (WFIP2) Columbia River Regional Project.

WFIP2 is a multi-institutional program to improve NOAA's short-term weather forecast models and increase understanding of physical processes that affect wind energy generation in regions of complex terrain (Pacific Northwest with a focus on the Columbia River Gorge).

Our project builds on WFIP2 to:

- Enhance WFIP2 observations with a focus on moisture
- Examine large-scale dynamics and moisture transport upstream and downstream of the Gorge
- Assess model performance of quantitative precipitation forecasts (QPF) in selected extreme precipitation events
- Compute surface energy and moisture budget

During the past year, we achieved several accomplishments in this project; two are highlighted below.

The first is our development of a real-time, hourly-updated, online graphical data product that displays the depth and strength of easterly gap flows in the Columbia Mountain Gorge (the only major gap in the Cascade Mountains) concurrently providing information on the precipitation type. This product will be particularly helpful during late autumn and winter, when easterly gap flows can cause hazardous and damaging weather (snow, freezing rain, and strong winds) in the Portland-Vancouver Metropolitan area. The product is available online (www.esrl.noaa.gov/psd/data/obs/datadisplay/) to help forecasters at the Portland National Weather Service Forecast Office monitor cool season easterly gap flow events in order to provide situational awareness and guide warnings to the public about potential weather-related hazards. Additionally, forecasters can use this product to qualitatively assess forecast models during these hazards. An example of the real-time online data product at Troutdale, Oregon, in January 2017 is presented in the figure.

The second area of research we highlight here is our computation of surface energy and moisture budgets using measurements of surface energy fluxes (turbulent and radiative) and other atmospheric and soil parameters in the Columbia River Gorge areas during the WFIP2 field campaign. We used these measurements to study the surface energy budget (SEB) and surface fluxes over different temporal scales (half-hourly, daily, monthly, seasonal, and sub-annual [10-month]) and over different soil surfaces (dry, wet, and frozen). This study shows that while the sum of the turbulent sensible and latent heat fluxes systematically underestimate the available energy at half-hourly time scales, on average, the energy imbalance is significantly reduced at daily, weekly, and monthly averaging timescales. Moreover, the SEB can be closed within reasonable limits on seasonal and sub-annual timescales. We are also working on comparison of numerical weather prediction model fluxes and balances with these observations and results.

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

CIRES Lead: Amy Solomon / NOAA Lead: Janet Intrieri

NOAA Theme: Science and Technology Enterprise

GOALS & OBJECTIVE

This project will improve predictions of Arctic sea ice on an extended weather scale by identifying critical physical processes, characterizing process-level model deficiencies, and improving model representation of key processes.

ACCOMPLISHMENTS

Our CIRES team members in the NOAA Earth System Research Laboratory (ESRL) sea ice forecasting team provided experimental daily 10-day forecasts of Arctic weather and sea-ice evolution to stakeholders for the 2017 freeze-up season and has been providing daily forecasts starting on April 1, 2018. The forecasts downscale global 0.5-degree GFS (Global Forecast System) forecast fields for lateral forcing of high-resolution (10-km) regional, coupled-model Arctic forecasts. The forecast model is called the NOAA/ESRL Coupled Arctic Forecast System (CAFS). The current configuration of the model includes the POP2 dynamical ocean model, the CICE5 sea ice model, the NCAR CLM4.5 land model, and the WRF3.6 ARW atmospheric model, coupled with the NCAR CPL7 model. Those acronyms are described at the end of this entry. This year we extended the domain to include the Bering Strait, to provide additional guidance to the NWS, and to include the Fram Strait, which lies in the domain of the planned Multidisciplinary Drifting Observatory for the Study of Arctic Climate campaign (MOSAiC). NOAA ESRL is using the CAFS forecasts to identify sources of skill on subseasonal time-scales due to coupled ocean-ice-atmosphere processes and by stakeholders as model guidance for sea ice forecasts. Our CAFS team worked with the NWS to redesign the web portal where CAFS products are made available to the community (https://www.esrl.noaa.gov/psd/forecasts/seaice). We provide figures and animations from the real-time, 10-day forecasts for sea ice, atmosphere, and ocean variability—as well as an archive of model output for users to download.

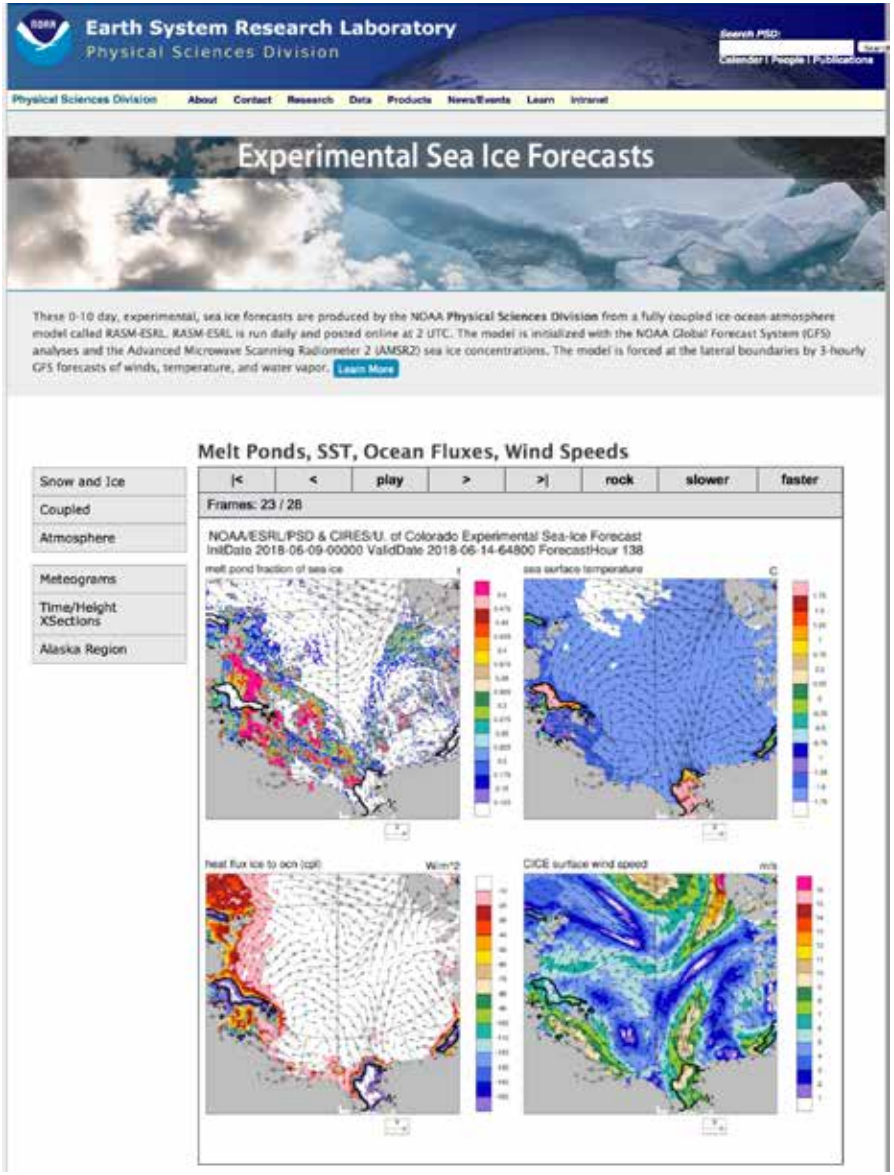
This fiscal year our team experimented with using sea ice thickness measurements from the European Space Agency's CryoSat-2 and Soil Moisture and Ocean Salinity (SMOS) satellites and the NASA Jet Propulsion Laboratory Multi-Scale Ultra-high Resolution Sea Surface Temperature (MUR) sea surface temperatures and sea ice concentrationto identify potential improvements in skill.

Currently, We are completing five studies:

(1) to quantify the impact of initializing the forecasts with Cryosat-2 and MUR on forecast skill

(2) to quantify the impact of lower-level atmospheric jets on sea ice evolution

(3) to quantify the impact including a more realistic representation of Pacific intermediate waters on forecast skill



PSD-21: Image of NOAA/ESRL Coupled Arctic Forecast System web portal.

ACRONYMS IN PSD-21

POP2: NCAR Community Earth System Model version of the Los Alamos National Laboratory Parallel Ocean Program ocean model Version 2

CICE5: Los Alamos Sea Ice Model Version 5.13

NCAR CLM4.5: NCAR Community Land Model Version 4.5

WRF3.6 ARW: The Advanced Research Weather Research and Forecasting Modeling System Version 3.6

(4) To assess model simulations of near-surface atmospheric stratification in the marginal ice zone

(5) To identify processes that limit the skill of the forecasts during the anomalous November 2017, when the Chukchi Sea was observed to be ice-free for the first time in the observational record

The first four studies focus on the 2015 freeze-up season when the Office of Naval Research SeaState campaign took detailed measurements of the ocean-ice-atmosphere system.

We have been working with the Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC) to create an improved Arctic Ocean reanalysis by assimilating campaign measurements in the Chukchi and Beaufort Seas during the summer/fall of 2015. We compiled a database of the measurements and it was assimilated into the 1/12-degree ocean reanalysis by the CMCC. Our team is currently assessing the impact of the additional measurements on the reanalysis and the forecasts when using these improved initial conditions.

This fiscal year we initiated a NOAA Arctic Testbed activity to conduct experiments on ensemble forecast techniques for Arctic short-term forecasts. These experimental forecasts use a subset of the NOAA Global Ensemble Forecast System members as lateral forcing for the high-resolution coupled system. We are using observations (such as International Arctic Buoy Programme buoy measurements) as metrics that quantify skill statistics. NOAA ESRL is working closely with the National Weather Service to identify critical products to inform weather and sea ice forecasting as well as to assess and analyze ensemble member products and utility.

Our CAFS forecasting team is contributing to the Year of Polar Prediction (YOPP) activities by uploading real-time drift forecasts from the fully-coupled model forecasts for buoys in the Beaufort, Barents, and Chukchi Seas to the YOPP Sea Ice Drift Forecast Experiment (SIDFEx). SIDFEx is a systematic assessment of drift forecasting capabilities in advance of MOSAiC.

In addition, we provided real-time forecasts of sea ice properties (strain rate, lead opening rate, etc.) to the Navy in support of the ICEX campaign in the Beaufort Sea in March 2018, as model guidance for potential danger due to ice movement and lead openings.

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

CIRES Lead: James Scott / NOAA Lead: Michael Alexander

NOAA Theme: Climate Adaptation and Mitigation

GOALS & OBJECTIVE

This project will provide guidance for assessing impacts on short term and long-term changes to large marine ecosystem environments in the United States.

ACCOMPLISHMENTS

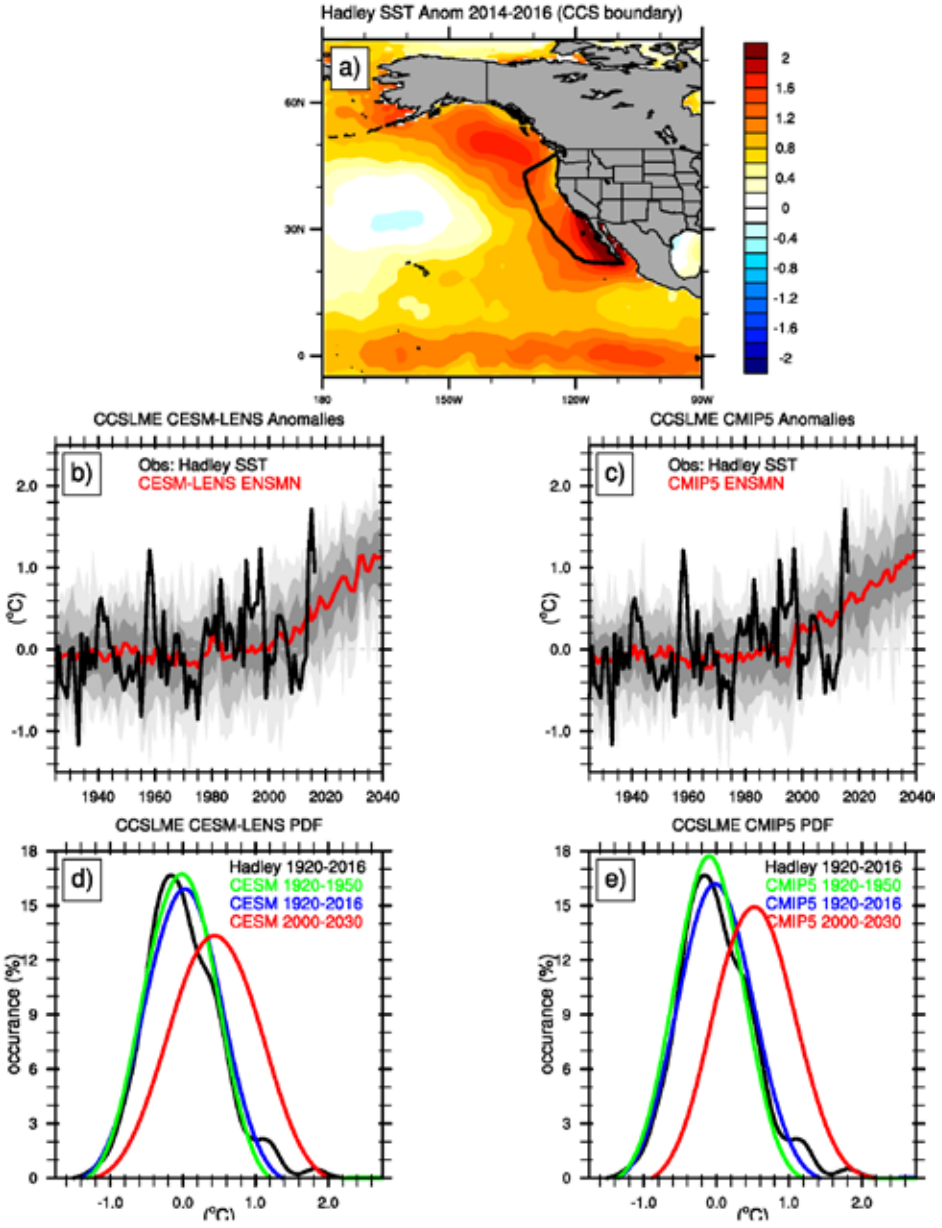
We have coordinated these CIRES contributions with NOAA project lead Michael Alexander. We published two papers (in preparation in 2017) in early 2018 on climate variability in marine ecosystems, with significant contributions from CIRES scientists Antonietta Capotondi and James Scott:

Turi, G., M. A. Alexander, N. S. Lovenduski, A. Capotondi, J. D. Scott, C. Stock, J. Dunne, J. John, and M. Jacox (2018). Response of O_2 and pH to ENSO in the California Current System in a high-resolution global climate model. *Ocean Sci.*, 14, 69-86, https://doi.org/10.5194/os-14-69-2018.

For this paper, we used a high-resolution global model to study the influence of El Niño/La Niña events on ocean biogeochemistry in the California Current System. The mean surface oxygen (O_2) response extends well offshore, where the pH response occurs within ~ 100 km of the coast. The surface O_2 (pH) is primarily driven by temperature (upwelling) changes. Below 100 m, anomalously low O_2 and low pH occurred during La Niña events near the coast, potentially stressing the ecosystem.

Alexander M. A. , J. D. Scott, K. D. Friedland, K. E. Mills, J. A. Nye, A. J. Pershing, A. C. Thomas, (2018). Projected sea surface temperatures over the 21st century: Changes in the mean, variability and extremes for large marine ecosystem regions of Northern Oceans. *Elementa: Science of the Anthropocene*, 6(1):9, DOI: http://doi.org/10.1525/elementa.191

We used global climate simulations to assess the impact of increasing greenhouse



PSD-25: (a) Observed (HadISST) 2014–16 mean northeast Pacific SSTa (°C) relative to the 1920–2016 mean. Black line outlines the CCLME. (b),(c) CCLME annual mean SSTa (°C) from HadISST (black line), model ensemble mean (red line), and range of individual ensemble members in percentiles (gray shading): 25%–75% (dark), 10%–90% (medium) and 0–100% (light). (d),(e) Smoothed histograms of CCLME annual mean SSTa (°C) for 1920–2016 observations (black) and from all model ensemble members during 1920–50 (green), 1920–2016 (blue) and 2000–30 (red). Histograms were calculated using a SSTa bin width of 0.2°C. Model values are from (b),(d) CESM-LENS and (c),(e) CMIP5 Observed annual mean CCLME SSTa in °C (and standardized units) were 1.15°C (2.2σ), 1.71°C (3.3σ), and 0.95°C (1.8σ) in 2014, 2015, and 2016, respectively. Image: Jacox et al. 2018.

gas forcing on sea surface temperatures in the 21st Century. Most of the northern oceans exceed the warmest historical year between 2070-2099. The warming could result in poleward migration of some fish species, which has already been documented in North American and European large marine ecosystems (LME) and could lead to profound changes in the structure of marine ecosystems that could necessitate a reevaluation of LME boundaries.

We also published new work with contributions from CIRES' James Scott in 2018:

Le Bris, A., K. E. Mills, R. A. Wahle, Y. Chen, M. A. Alexander, A. J. Allyna, J. G. Schuetz, J. D. Scott, and A. J. Pershing (2018). Climate vulnerability and resilience in the most valuable North American fishery. *PNAS,* published on-line, https://doi.org/10.1073/pnas.1711122115.

Managing natural resources in an era of increasing climate impacts requires accounting for the synergistic effects of climate, ecosystem changes, and harvesting on resource productivity. Coincident with recent exceptional warming of the northwest Atlantic Ocean and removal of large predatory fish, the American lobster has become the most valuable fishery resource in North America. Using a model that links ocean temperature, predator density, and fishing to population productivity, we show that conservation efforts to protect large lobsters in the Gulf of Maine lobster fishery resulted in the record-breaking landings. This study demonstrates that proactive conservation measures can increase the resilience of commercial fisheries to climate change.

We published new work with contributions from CIRES' James Scott and Gaelle Hervieux in early 2018:

Jacox, M. G., M. A. Alexander, N. J. Mantua, J. D. Scott, G. Hervieux, R. S. Webb, and F. E. Werner (2018). Forcing of multiyear extreme ocean temperatures that impacted California Current living marine resources in 2016 [in: Explaining extreme events of 2016 from a climate perspective, *Bulletin of the American Meteorological Society*, 98, S27-S33, doi: 10.1175/BAMS-D-17-0119.1.]

Recent record high sea surface temperature anomalies (SSTa) in the California Current Large Marine Ecosystem produced dramatic impacts on marine life. While effects on many species and fisheries may have been short-lived, salmon fisheries, for example, were heavily impacted in 2016 due to multiyear persistence of unfavorable conditions. Negative impacts on CCLME salmon fisheries are likely to persist until at least 2019, as poor stream and 2014-2016 ocean conditions directly influence the 2016-2019 Chinook salmon abundance. climate model ensembles suggest that anthropogenic warming increased the likelihood of the 2014–16 SST extremes through both a shift to a warmer mean state and an increase in temperature variability. Recent extreme ocean temperatures off the U.S. West Coast, which significantly impacted many marine species and fisheries, were caused by the confluence of multiple complementary natural drivers and were likely exacerbated by long-term anthropogenic warming.

CIRES scientist Sang-Ik Shin and James Scott began work to examine climate change impacts to the ocean ecosystems along the east coast of the United States using a high resolution regional ocean model (ROMS) that is forced with atmospheric conditions in 2070-2099 as predicted by three models in the Climate Model Inter-comparison Project 5 (CMIP5). The ROMS model is much higher resolution (10km) than the ocean models used in CMIP5 and will give a better representation of climate change impacts to ecosystems very near the shoreline.

Researchers sample bacteria on a ginkgo tree in the Arnold Arboretum, Boston, Massachusetts in July 2012, part of a trip to characterize the bacterial communities inhabiting all aboveground locations of three ginkgo trees. Photo: Jon Leff/CIRES

Project Reports: Scientific Outreach and Education

GSD-02: Andy Wang of CIRES Financial Services Department tries out the virtual reality glasses of the SOS Explorer at the 2018 CIRES Rendezvous. Photo: Katie Weeman/CIRES

GSD-02: Science Education and Outreach (SOS®)

CIRES Lead: Beth 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

Our team had continued progress and growth for Science On a Sphere® (SOS) and SOS Explorer (SOSx) in the last year. We released patches to SOS version 5.2 in September and November 2017. We made a new release, SOS version 5.3, available in February 2018, with a patch available in April 2018. This new version of the software included improved software security, while the SOS Spotlight—a new way to highlight current events and special datasets—has improved graphics, a high-resolution library for sites with 4k projectors, and better usage statistics.

During this time period, we installed 12 new SOS systems in the United States, India, Australia, Denmark, and the People's Republic of China, bringing the total number of completed installations to 157. SOS was also featured at the USA Science and Engineering Festival in Washington DC.

We held quarterly education forums for members of the SOS Users Collaborative Network, with themes ranging from recent dataset releases to educational activities during hurricanes to a workshop recap. The next workshop is planned for November 2018 and planning is already underway.

We made a new version of SOSx Lite, the freely distributed introductory version of SOSx, available in July 2017. This new release ensured that SOSx Lite had the same look and feel as SOSx and made it compatible with touchscreens. We released new versions of the full version of SOSx in November 2017 and May 2018. Features included improved virtual reality functionality, better 3D models, 360-degree picture and video support, compatibility with smart boards and interactive projectors, software auto-updates, and improvements to the TourBuilder.

NOAA also used SOS Explorer as the centerpiece for American Geophysical Union Fall Meeting, National Space Symposium in the NOAA NESDIS booth, National Association for Independent Schools Annual Conference, Association of Science and Technology Centers Annual Conference, and the American Meteorological Society Annual Conference. To support the latter, we created a special tour focused on satellites and satellite data.

Our team focused more on web-based data visualization with the release of the HRRR-Smoke website and through collaboration with the National Weather Service on Weather Archive and Visualization Environment (WAVE). HRRR-Smoke features on-the-fly rendering of high-resolution model data over time, as well as a modern look-and-feel, layering, and transparency.

Research into "Big Data" technologies has been another focus for us this year. As model and satellite data continue to be produced at higher and higher resolutions, traditional computing methods are quickly becoming insufficient for the needs of weather data consumers. We are beginning to prototype and identify solutions that will allow NOAA to thrive in exascale-level computing in the future.

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

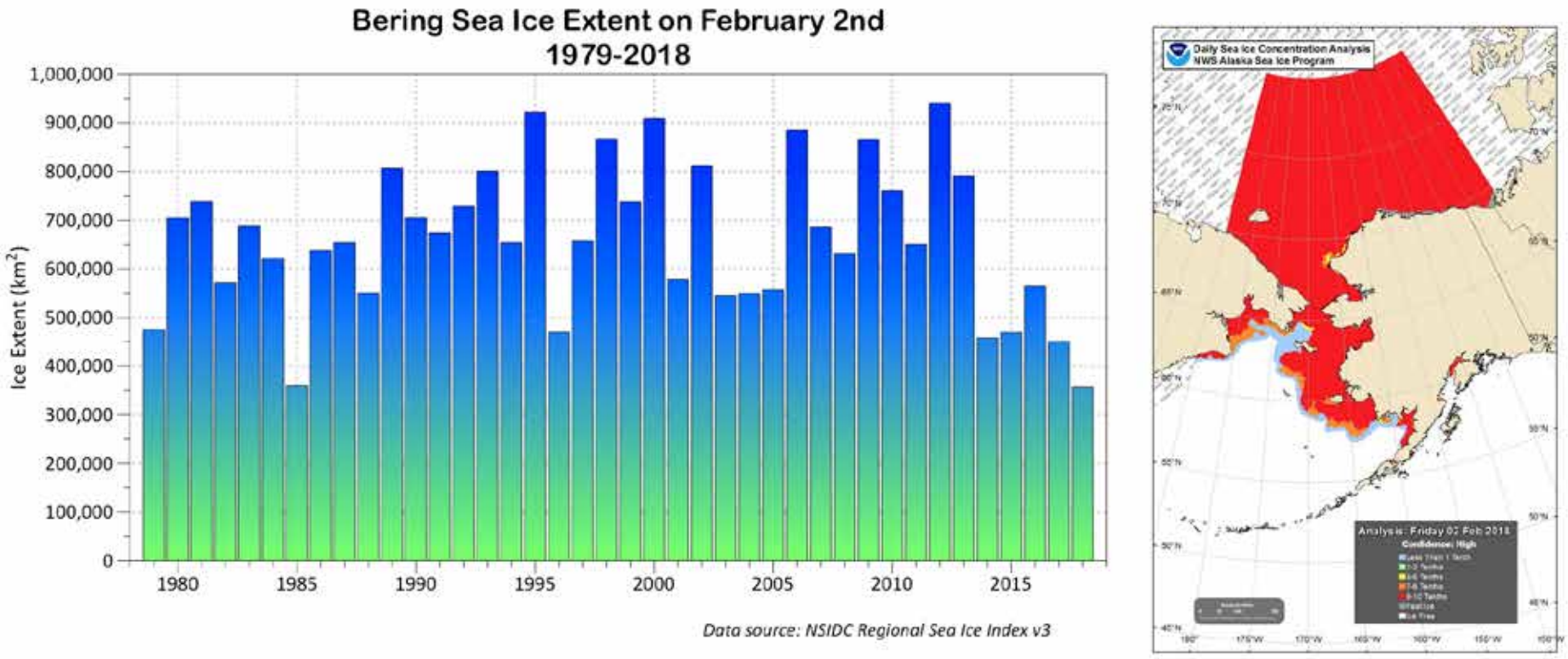
CIRES Lead: Florence Fetterer / NOAA Lead: Eric Kihn
NOAA Theme: NOAA Engagement Enterprise

GOALS & OBJECTIVE

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

ACCOMPLISHMENTS

About 3,000 users download Sea Ice Index data each month, and many times that view it online. Arctic Sea Ice News and Analysis (https://nsidc.org/arcticseaicenews/) as well as NOAA's Arctic Report Card (http://arctic.noaa.gov/Report-Card/Report-Card-2017) and Climate.gov (https://www.climate.gov) rely on the Sea Ice Index to track ice. Rick Thoman, with the National Weather Service Alaska region, uses the regional SII record to put into longer-term context the remarkable lack of sea ice in the Bering Sea in 2017 and 2018 (see figure on next page).



NSIDC-01: Throughout the winter of 2017 into 2018, Bering Sea ice extent was quite low. Here, National Weather Service Alaska climatologist Rick Thoman presents a figure based on the Sea Ice Index regional data, to illustrate the persistence of these recent low wintertime extents. Image: Rick Thoman/NWS

In October, we achieved our goal of releasing Version 3.0. An announcement provides details: "V3 changes the way the monthly average area and extent data values are calculated […] The change is in response to questions about what seemed to be an inconsistency between daily and monthly values. When users summed daily values and then divided by number of days in a month to get a monthly average value, that number was different, and sometimes quite different, from the monthly average numbers we presented. Both the V2 and V3 methodologies are valid and defensible ways of representing passive microwave-derived sea ice concentration data, but the goal of this change is to better match the understanding of the user community as the product evolves through time."

This was a major change to a data product that is in the public eye and often under intense scrutiny by a wide user base. For this reason, we documented the change to include publication of a separate report (Windnagel et al. 2017) that offers additional analysis on why V3 ice areas are higher than V2 and V3 extents are lower than V2, along with a simple example. With our update to V3, we cannot identify any considerable differences in conclusions about the overall trends in sea ice area or extent.

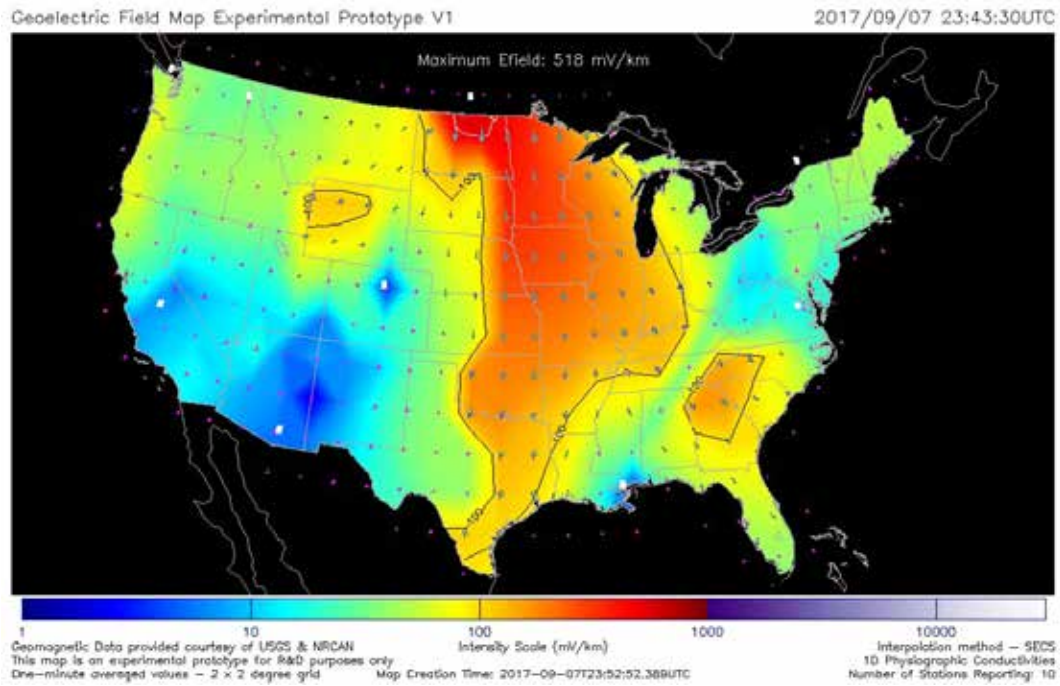
In the previous reporting year, our goal for this product was to port the production code to Python so that it would be easier to update and maintain. We completed that earlier work, which meant the update to V3 could be accomplished efficiently.

Our other accomplishments included updating September and March Sea Ice Index animations in NSIDC's Google Earth compatible collection and updating all images to Sea Ice Index Version 3.

Project Reports: Space Weather Understanding and Prediction

NCEI-06: Satellite Anomaly Information Support

This project is closed; it has been combined with NCEI-05, in accordance with some reorganization at NOAA NCEI.



SWPC-01: Geoelectric Field prototype from www.spaceweather.gov Image: David Stone/CIRES

SWPC-01: Space Weather Information Technology and Development

CIRES Lead: David Stone / NOAA Lead: Steven Hill

NOAA Theme: Science and Technology Enterprise

GOALS & OBJECTIVE

This project will maintain and modernize the information technology systems required to support the research and operational activities at the Space Weather Predication Center. The objective is a world class Space Weather Prediction center based on highly reliable and functional development, transition, and maintenance processes.

ACCOMPLISHMENTS

Our team developed the system for processing and displaying real-time interplanetary magnetic field and solar wind data from the NOAA Deep Space Climate Observatory (DSCOVR) satellite stationed at the L1 Lagrange point. These data are the most important drivers for generating alerts of an impending geomagnetic storm that could impact the Earth, which is the Space Weather Prediction Center's primary mission.

We transitioned the new Regional Geoelectric model and display products to the public experimental website. The new model displays the Geoelectric Field as a measure of the induction hazard to artificial conductors, such as electrical power lines, that results from Geomagnetic Activity, and can be used to estimate the amount of current induced by integrating along the conducting pathway (see figure at left).

We provided a development infrastructure and core functionality for the coupled Whole Atmosphere Model, Ionosphere Plasma Electrodynamics (WAM-IPE) in preparation for running the model in full operations on the supercomputers at the National Weather Service (NWS). We targeted code handoff and running WAM-IPE in a full test operational mode for first calendar quarter of 2019.

Our team successfully upgraded SWPC's Space Weather Data Store (SWDS) for development and staging. This central, persistent store for all space weather datasets is a critical part of the lab's information and technology architecture. The previous server was circa 2008 technology, while the new system is less than a year old and implements a better separation between the different environments.

We assisted SWPC in building the lab's first Continuous Integration environment using Jenkins to automate the test and build process for Spacecraft Environmental Anomalies Expert System–Real Time (SEAESRT). We are now using the Jenkins pattern to successfully improve development turnaround and and more rapidly respond to business changes.

Additionally, we sponsored professional training for the lab in Jenkins, Git version control repositories and Agile team methodologies.

We provided timely operational support for the following critical systems and maintained high customer satisfaction:

- SWPC's Public website (www.spaceweather.gov)
- NASA Advanced Composition Explorer (ACE) processor
- Deep Space Climate Observatory (DSCOVR) ground data system
- Geostationary Environmental Satellite (GOES) processor and preprocessor
- WSA-Enlil (Wang-Sheeley-Arge Model)
- D Region Absorption Predictions (D-RAP)

- Geospace Model processor
- North American Total Electron Content (NATEC) U.S. and North America products
- Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics (CTIPe) processor
- Air Force and Institute for Science and Engineering Simulation (ISES) Message Decoder (AIMED) processor
- SWPC's Microsoft SQL Server Space Weather Data Store (SWDS)

SWPC-02: Enhancement of Prediction …

This project is closed due to reorganization of projects at NOAA SWPC.

SWPC-03: Space Weather Modeling

CIRES Lead: Timothy Fuller-Rowell / NOAA Lead: Rodney Viereck

NOAA Theme: Science and Technology Enterprise

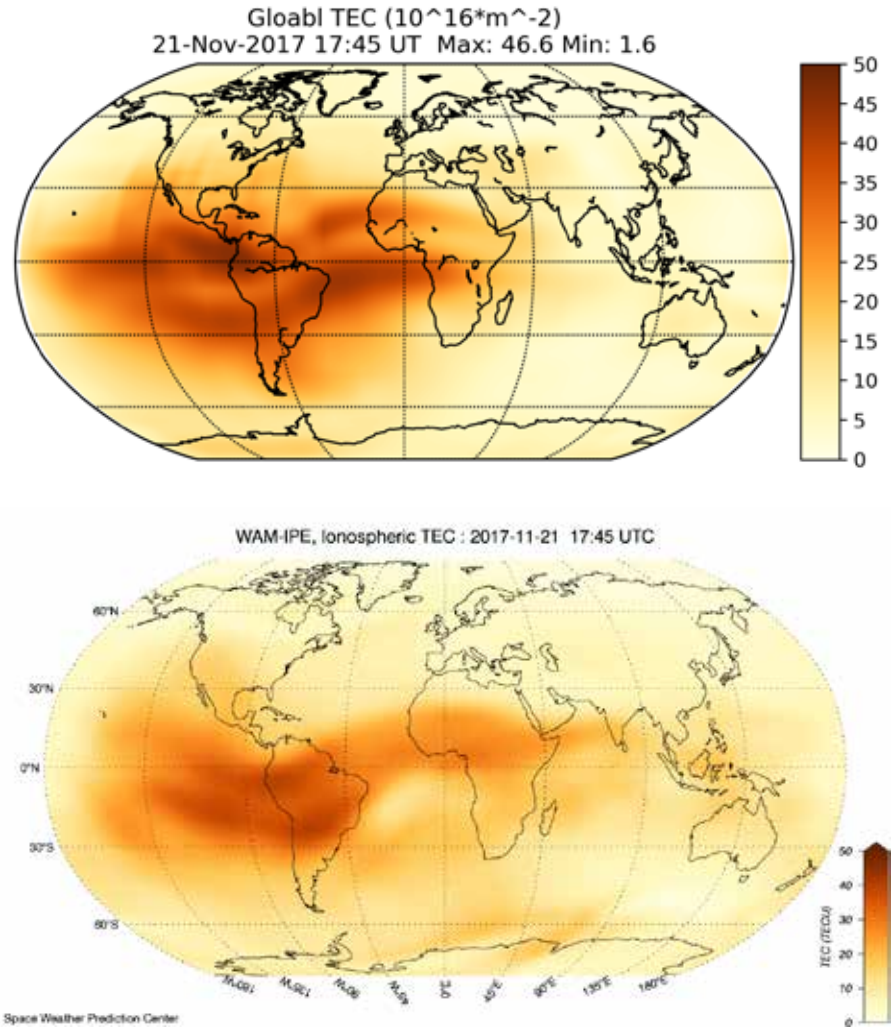
GOALS & OBJECTIVE

This project will improve the Nation's preparedness for space weather storms affecting communication, transportation, and other U.S. infrastructure. The objective is to have a highly functioning Space Weather Forecast Office with improved forecasts based on guidance from the best models and products available.

ACCOMPLISHMENTS

We have been running a whole atmosphere model (WAM) coupled to a global ionosphere-plasmasphere-electrodynamic (IPE) code in a semi-operational, real-time mode since October 2017. WAM is a whole atmosphere extension of the National Weather Service (NWS) Global Forecast System (GFS) operational weather model, extending the top boundary from 60 km in GFS to ~600 km in WAM. WAM uses the NWS data assimilation (DA) scheme in order to follow real changes in tropospheric weather. The DA enables the model to follow changes in tropical convection, sudden stratospheric warming, and other tropospheric weather features. WAM is coupled to IPE one-way using the Earth System Modeling Framework (ESMF); WAM provides the thermospheric properties of wind, composition, and temperature, so IPE can respond to changes in terrestrial weather propagating upward and driving thermosphere and ionosphere variability.

Our WAM-IPE semi-operational system uses all the data from the NWS operational numerical weather prediction data assimilation system. In addition, we use the ground-based observations of the 10.7 cm solar radio flux and the DSCOVR satellite solar wind and interplanetary magnetic field observations as indicators of solar and geomagnetic activity. The space weather products from the coupled model include the global distribution of



SWPC-03: Snapshot of the total electron content from the coupled system (upper panel) at 17:45 UT, showing structure and variability induced by the forcing from the lower atmosphere. For comparison, the lower panel shows the observed TEC derived from a data assimilation model combining all the ground-based observations of TEC from dual-frequency Global Navigation Satellite Systems (GNSS) receivers and the radio occultation data from the one remaining COSMIC satellite. Image: CIRES

vertical total electron content (TEC), the magnitude of the peak in the plasma density (NmF2), and the height of the peak (hmF2). The products are updated every 15 minutes. The product also includes the departure from the average of these three variables over the previous 10 days, to illustrate whether the predicted state is significantly disturbed at the current time.

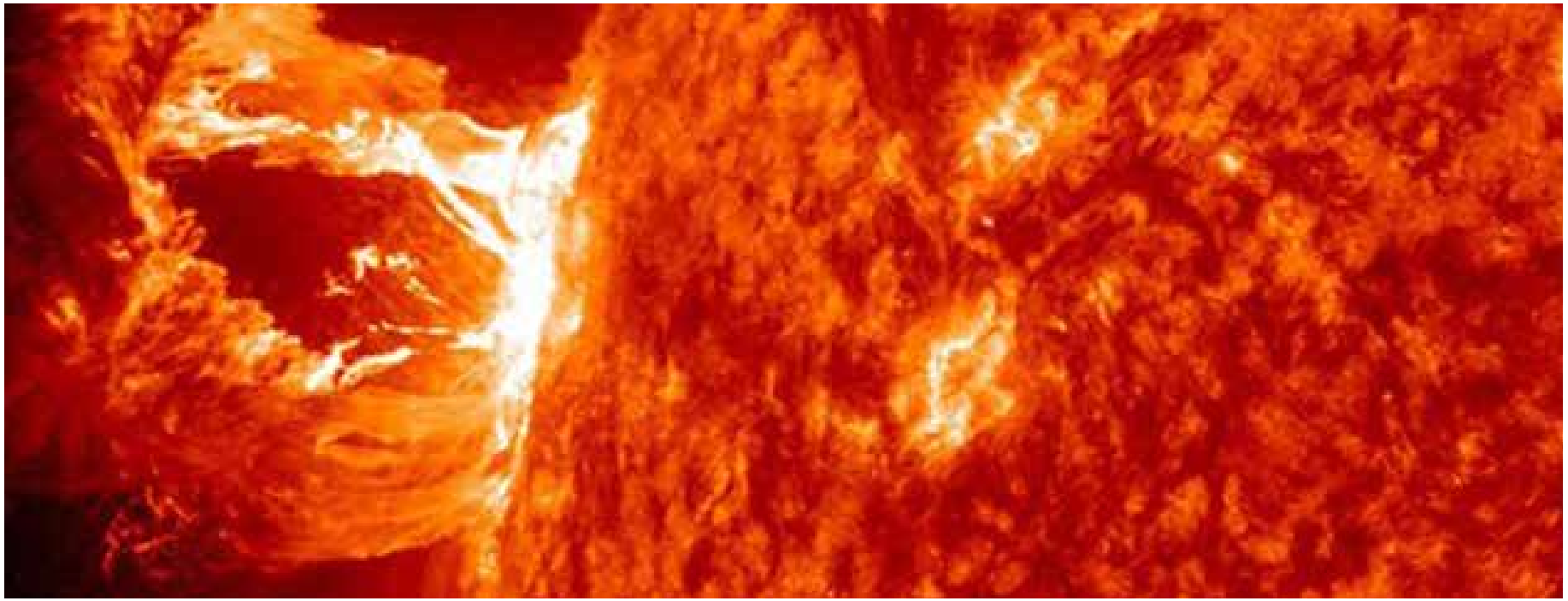
The figure on the previous page is an example of the TEC from the coupled system (upper panel) at 17:45 UT. The geomagnetic conditions and solar activity are relatively quiet at this time, and the pattern would have been smooth and benign if the model had only been forced by the solar and geomagnetic space weather drivers. This one snapshot, however, shows structure and variability induced by the forcing from the lower atmosphere. We are validating and verifying the predictions of the system by comparing with ground-based TEC observations, shown in the lower panel. We derived the observed TEC map from a data assimilation model combining all the ground-based observations of TEC from dual-frequency Global Navigation Satellite Systems (GNSS) receivers and the radio occultation data from the one remaining COSMIC satellite.

We are validating the real-time system for both quiet and disturbed solar and geomagnetic activity. The storm time response has initially been verified for the March 17, 2013 St. Patrick's Day geomagnetic storm. The system predicted the development of the storm-enhanced density (SED) at mid to high latitudes in the north and south hemispheres, in good agreement with observations. The thermospheric heating at high latitudes also drove the neutral circulation, and the neutral composition changes, with strong longitude dependence. In particular, the decrease in the ratio of thermospheric oxygen to molecular nitrogen over the Australian sector was well represented, which caused significant depletions in plasma density.

The final product will include a three-day forecast.

SWPC-04: Geospace Modeling Effort

This project is closed due to reorganization of projects at NOAA SWPC.



A solar flare. Photo: Space Weather Prediction Center

Project Reports: Stratospheric Processes and Trends

CSD-09: Upper Tropospheric and Stratospheric Radiative, Dynamical, 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), dynamical coupling between the stratosphere and troposphere, and ozone layer chemistry.

ACCOMPLISHMENTS

In 2017 and 2018, our research team made numerous contributions to improve understanding of the processes that impact transport and constituent distributions in the upper troposphere and stratosphere. One of our most notable achievements was a study that identified an unexpected increase in emissions of CFC-11, a regulated ozone-depleting substance, after 2012. Our involvement in this surprising discovery, which was published in *Nature* (Montzka et al. 2018), was to help quantify the contribution of stratospheric circulation variability to this apparent emissions increase.

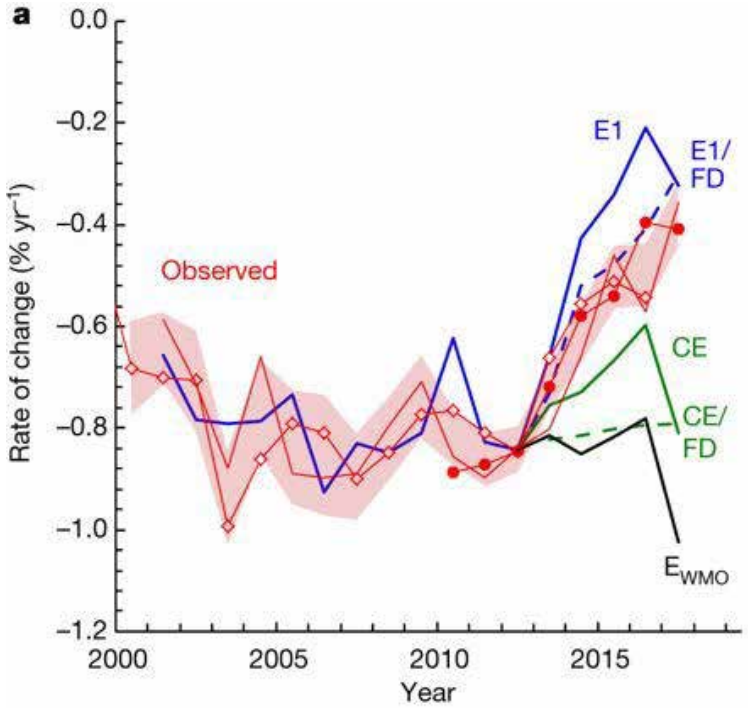
We also made significant advances in understanding recent variability in atmospheric reanalysis representations of dynamical variables, water vapor, and ozone in the stratosphere to evaluate their use in constraining past atmospheric variability and trends. In 2017-2018, we led and contributed to several studies that evaluated the fidelity of reanalysis representations of dynamical variables, ozone, and water vapor (Fujiwara et al. 2017; Long et al. 2017; Davis et al. 2017).

Our team also used satellite data, models, and reanalyses to better understand changes in the edge of the tropics and potential linkages between tropospheric and stratospheric circulation changes (Davis et al. 2018; Seviour et al., 2018; Staten et al. in press; Adam et al. submitted; Davis et al. submitted; Grise et al., submitted; Waugh et al. submitted). Additionally, we also made progress in evaluating surface impacts of Northern Hemisphere stratospheric final warmings. Two papers are currently in preparation that address the predictability of final warmings on sub-seasonal to seasonal timescales and their subsequent impacts in springtime.

In 2017, we also made progress in interpreting tracer-tracer relationships in aircraft measurements and chemistry-climate model simulations. By examining relationships between ozone and N_2O in long model simulations, we demonstrated a novel way of diagnosing ozone recovery, but found that the changes seen in aircraft tracer-tracer relationships over the last few decades are most likely due to internal variability. In performing this analysis, we also found a drift in the NASA Microwave Limb Sounder (MLS) satellite N_2O measurements and have been in discussion with the NASA MLS team to try to diagnose and remedy the problem.

We made progress in understanding aerosol impacts on the stratosphere. We published an aerosol modeling study in *PNAS* that showed the Asian Monsoon region contributes a large fraction of the background aerosol to the Northern Hemisphere (Yu et al. 2017), comparable to the contribution of small volcanoes over the decade from 2000-2010.

Finally, in addition to improving understanding of stratospheric dynamic and chemical processes, we also made progress towards improved observationally-based estimates of Earth's energy budget by devising a new method of attributing decadal changes in global temperature (Larson et al. 2017).



CSD-09: Global rates of change of CFC-11 derived from observed (red) and simulated (blue, green, black lines) mole fractions, adapted from Montzka et al. (Nature, 2018). Simulations were performed by CIRES researchers using the Community Atmosphere Model (CAM) nudged to the MERRA2 reanalysis meteorology (MERRA, Modern-Era Retrospective analysis for Research and Applications), and emission histories either from the three-box model (blue lines labelled E1) or E1 emissions kept constant at the 2012 rate after 2012 (green lines labelled CE). Our simulation with the latest World Meteorological Organization emission projection based on observations until the end of 2012 using the Whole Atmosphere Community Climate Model (WACCM) and MERRA1 reanalysis is shown as the black line.

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

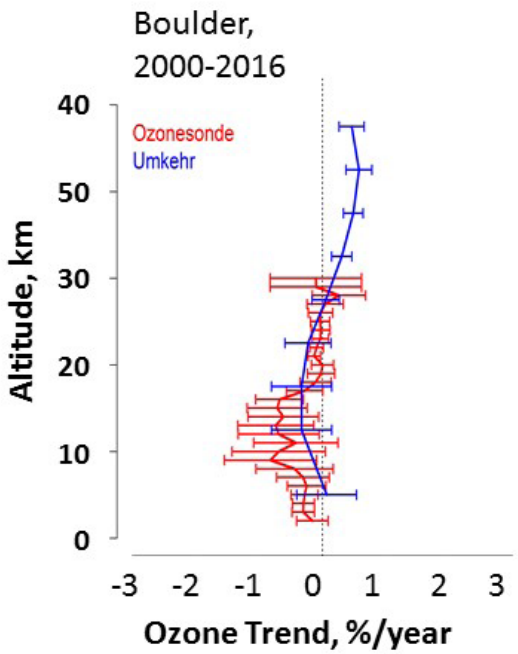
This project addresses changes in the chemistry of the stratosphere that affect ozone depletion, which supports estimates of the types of adaptation and mitigation that will be necessary to stabilize ozone in the stratosphere.

ACCOMPLISHMENTS

The World Meteorological Organization/United Nations Environment Program (WMO/UNEP) Ozone Assessment 2018 relies on an accurate evaluation of ozone profile trends. These trend results are of utmost importance in order to evaluate the success of the Montreal Protocol and determine the path to the future recovery of the ozone layer.

We set up the SPARC LOTUS (Stratosphere-troposphere Processes and their Role in Climate/Long-term Ozone Trends and Uncertainties in the Stratosphere) activity two years ago to evaluate the quality of observational records, evaluate statistical trend models, and determine an approach to evaluate the uncertainties in the combined trends from satellite and ground-based records. CIRES' Irina Petropaviovskikh is one of the co-leads for the SPARC LOTUS activity. Out of the total 43 ground-based ozone profile records for LOTUS and WMO/UNEP 2018 ozone trend assessments, our CIRES members in NOAA's Global Monitoring Division provided 7 ozonesonde, 6 Umkehr and 14 Dobson total column records. We advanced multiple satellite ozone records in recent years by correction of drifts (i.e., OSIRIS and MIPAS, acronyms defined below), reduction in the sampling biases (i.e., SAGE II), addition of four extra years in established satellite records (i.e., Aura MLS, Aura OMI, etc.), and addition of new satellites (i.e., NPP OMPS).

The SPARC LOTUS activity compared combined satellite and ground-based ozone data records with the CCMI-REF2 models and found general agreement in longterm changes, with the exception of ozone changes found in the lower stratosphere, where data indicate continuous depletion of ozone (Fig. 1, above).



GMD-02, Fig. 1: Trends in ozone derived from ozonesonde (red) and Umkehr (blue) records from Boulder, Colorado. Horizontal bars indicate uncertainties of the derived trends percent per year. Image: CIRES/NOAA

Resolving the difference between observations and models will require us to revisit the merging process and the use of the ground-based data records to validate stability of satellite combined records. Comparisons of multiple regression models through sensitivity tests led us to design a consensus regression model that was used in the LOTUS activity to process all records for trends. Assessment of stability in the combined satellite and ground-based records and evaluation of representativeness of the ground-based records in the broad-band trends helped us interpret results of trend analyses. All analyzed records produce similar spatial patterns in stratospheric trends. Our LOTUS assessment finds high confidence in positive trends of ~3.0 percent per decade in the upper stratosphere over the northern middle latitudes, while lower confidence is found for positive trends of ~2.1 percent and ~1.3 percent per decade in the middle latitudes of the Southern Hemisphere and Tropics, respectively.

We will publish the report on the SPARC website in July 2018:

SPARC/IOC/GAW, 2018: SPARC/IOC/GAW report on Long-term Ozone Trends and Uncertainties in the Stratosphere. I. Petropavlovskikh, S. Godin-Beekmann, D. Hubert (Eds.), SPARC Report No. 9, WCRP/2018, GAW Report No. 241, doi: [tbd], available at www.sparc-climate.org/publications/sparc-reports.

Dobson

The impact of a seasonal biases in the Dobson spectrophotometer total ozone data record is related to the use of static temperature for determining the ozone absorption cross sections in the ultraviolet solar spectrum. We require this correction to post-process Dobson data to account for daily changes in stratospheric temperatures. To calculate the ozone-weighted (effective) temperatures, we use the hourly ozone profiles from the NASA GMI (Global Model initiative, https://gmao.gsfc.nasa.gov/research/modeling) model and temperature profiles from the NASA MERRA (Modern-Era Retrospective analysis for Research and Applications, https://gmao.gsfc.nasa.gov/reanalysis) re-analyses available for 1992 to 2017 for most of the NOAA Dobson stations locations. Due to the applied corrections, we observe the most significant improvements in comparisons between the Dobson and the Ozone Mapping Profiler Suite (OMPS) instrument on the JPSS-Suomi satellite over the South Pole station.

The Dobson instruments in Boulder also provided us reference for the last four years (since 2013) for the new Pandora instrument. Analyses of comparisons published by Herman et al. (2017) showed that Pandora observations were stable and compared well with the Dobson record. The realtive bias between Pandora and Dobson observations is related to the selection of spectral range of ozone absorption and its sensitivity to the stratospheric temperature variabil-

ACRONYMS IN GMD-02

OSIRIS: Canada's Optical Spectrograph and InfraRed Imaging System (OSIRIS) is the optical payload on Sweden's Odin satellite

MIPAS: The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) is a Fourier transform spectrometer, one of the ten instruments onboard the Envisat satellite

SAGE II: The Stratospheric Aerosol and Gas Experiment II (SAGE II) instrument was launched in October 1984 aboard the Earth Radiation Budget satellite.

Aura MLS: The Earth Observing System (EOS) Microwave Limb Sounder (MLS) is one of four instruments on the NASA's EOS Aura satellite, launched on July 15, 2004.

Aura OMI: The ozone monitoring instrument (OMI) is a visual and ultraviolet spectrometer aboard the NASA Aura spacecraft.

NPP OMPS: Ozone Mapping Profiler Suite (OMPS) is one of five instruments that launched aboard our Suomi National Polar-Orbiting Partnership (NPP) spacecraft in 2011.

CCMI-REF2: The joint IGAC/SPARC chemistry-climate modelling initiative (CCMI). The third simulation (REF2) is a transient run from 1960 to 2100.

SPARC: Stratosphere-troposphere Processes And their Role in Climate

IGAC: International Global Atmospheric Chemistry Project

NDACC: Network for the Detection of Atmospheric Composition Change

WOUDC: World Ozone and Ultraviolet Radiation Data Centre

ity. When the temperature artifact in the total column retrieval is corrected, Dobson and Pandora ozone column are correlated at 0.98.

We investigated the applicability of using global chemistry and transport model hourly output as compared to the monthly mean climatology to correct the Dobson historical record for stratospheric temperature variability and its impacts on long-erm trends in corrected Dobson records. We used ozonesondes and satellite profile data (i.e., Microwave Limb Sounder, MLS, Aura satellite) to validate the temporal variability in hourly outputs of the ozone and temperature vertical profiles derived from the GMI and MERRA databases. Observations strongly correlate with model output. We compared Dobson operational ozone cross-section data to other spectroscopic datasets to determine the proper selection of absorption cross-section datasets and respective temperature sensitivity for Dobson total ozone data processing (i.e., Bass and Paur 1984; Daumont et al. 1992; and Serdyuchenko et al. 2014).

Our team continued Total Ozone Column (TCO) measurements made with Dobson spectrophotometers at the 14 locations operated by NOAA's Global Monitoring Division (GMD) with the exception of our station in Perth, Australia, which malfunctioned in July 2016. Due to its outdated automation, remote location, and sparse funding, we've been unable to repair it, and all plans for servicing it have been deferred until fiscal year 2018. CIRES members at NOAA GMD have continued to process and archive data from all other stations, and have reprocessed the datasets archived with the WOUDC and NDACC using Windobson software. We will resubmit the reprocessed data from each of those datasets upon acceptance of a peer-reviewed paper describing the process.

We use Dobson spectrophotometers to measure Total Column Ozone (TCO), which is a measure of all ozone contained in a column of air between the instrument and the outer edge of the Earth's atmosphere. These instruments are operated at 14 strategic locations including the South Pole. Six Dobsons have been automated to make rough estimates of the distribution of ozone within the ozone column, which provides information on the location of ozone depletion and recovery processes. These measurements are primarily used by NASA and the satellite community to detect and correct for changes to satellite calibrations over time. Additionally, most Dobson instruments have been operated at the same locations since the early 1960s, which enables modelers to estimate longterm changes in stratospheric ozone. In addition to measuring TCO, we maintain the world standard Dobson to which all other instruments within the World Meteorological Organization are calibrated.

In 2017, we sent World Standard Dobson D083 to Melbourne, Australia, to calibrate two regional standards: D115 of Australia and D116 of Japan. We also calibrated the instrument at GMD headquarters in Boulder Colorado, and at NASA's Wallops Island facility in Virginia. Dobson spectrophotometers were invented in the early 1930s and have proven to be a reliable and accurate means of measuring TCO, but GMD is interested in understanding instrumental biases. For example, it's well documented that there is a noise component in Dobson measurements. The size of that component is instrument specific, and believed to be mostly caused by internal stray light. CIRES members at GMD are experimenting with various methods to quantify that component and improve the quality of our measurements.

NEUBrew (The NOAA Environmental UV-ozone Brewer Network).

We continued to operate the six-station NEUBrew network during 2017 and 2018. Both the total column ozone and ozone profiles are available at the NEUBrew website (esrl.noaa.gov/gmd/grad/neubrew) with one day latency.

Ozonesonde

With the recently completed ozonesonde data homogenization project finished, we reprocessed and pushed out all of the vertical ozone profiles from Boulder, Hilo, the South Pole, Summit, Fiji,

GMD-02, Fig. 2: Four ozonesondes installed in the environmental simulation chamber just prior to a simulation of an ozone sounding during a 2017 mission. Photo: Irina Petropavlovskikh/CIRES

American Samoa, Trinidad Head, and Huntsville to the NOAA ftp server replacing previous data. Our paper detailing this process and methodology was accepted for final publication in *Atmospheric Measurement Techniques*:

Sterling, C. W., Johnson, B. J., Oltmans, S. J., Smit, H. G. J., Jordan, A. F., Cullis, P. D., Hall, E. G., Thompson, A. M., and Witte, J. C. (2018). Homogenizing and Estimating the Uncertainty in NOAA's Long Term Vertical Ozone Profile Records Measured with the Electrochemical Concentration Cell Ozonesonde, *Atmos. Meas. Tech. Discuss*., doi.org/10.5194/amt-11-3661-2018.

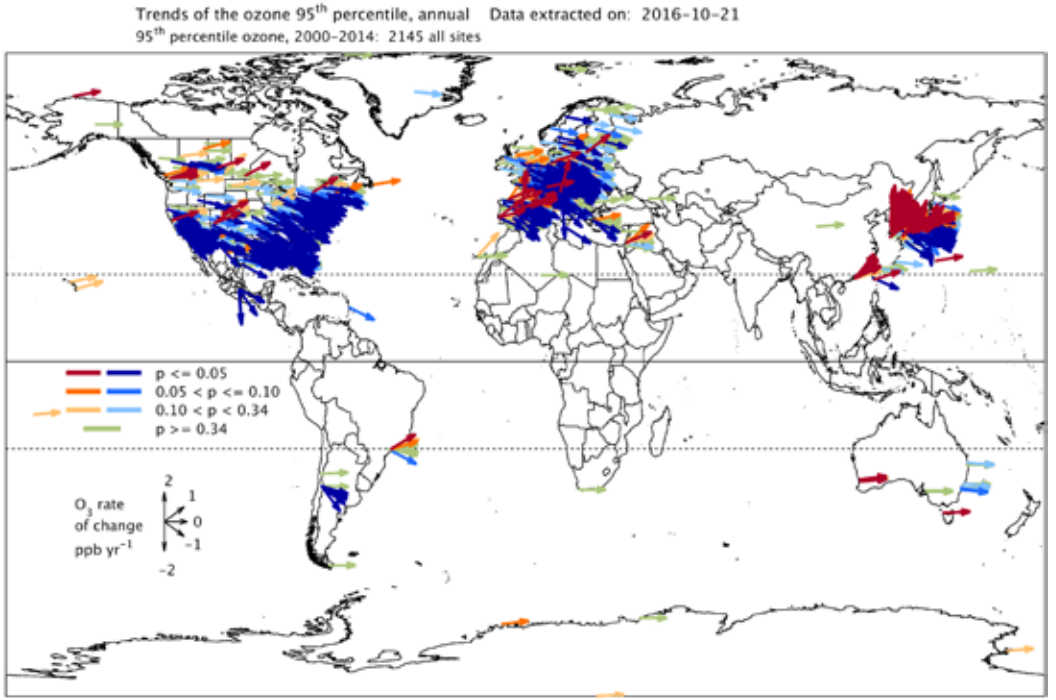
Following the completion of homogenization by NOAA and a corresponding homogenization and processing of NASA/SHADOZ ozonesonde data, JOSIE-SHADOZ (Juelich OzoneSondes Intercomparison Experiment – Southern Hemisphere Additional Ozonesondes) was held at the World Calibration Center for Ozone Sondes in Juelich, Germany. This experiment brought together operators from several collaboration sites from around the world, gave them hands-on instruction of WMO guideline procedures, finalized transfer functions for solution corrections, and moved sites forward using proper preparation and launch procedures (Fig. 2, previous page).

Surface Ozone

CIRES members in NOAA's Global Monitoring Division have monitored surface ozone since 1973, with measurements expanding spatially and temporally. There are currently 17 active measurement locations. Ozone at the surface is a critical species which impacts concentrations of other trace gases, the photochemical oxidation capacity, and radiative forcing properties of the atmosphere. In addition, at high levels, ozone can have negative impacts on human health and ecosystem functioning.

Mt. Bachelor Observatory is located in central Oregon and often measures free tropospheric air masses. However, the station is also subject to episodes of long-range transport of pollutants from Asia as well as regional pollutant influence. We collaborated with the University of Washington to install a Thermo-49i ozone monitor, and measurements began in May 2018 at this location. The measurements will be used to validate previous measurements at the stations and further investigate observed trends from the Northwest region of the United States.

Stratospheric intrusions are spring and early summer high-ozone episodes which are a result of the sub-tropical jets located near 40°N influencing the vertical transport of stratospheric air (relatively high in ozone) to the ground level. We have designed three stations along the Colorado's Front Range to capture the elevation gradient of the influence of these events to study the frequency and impact to high ozone in the region. These studies are further investigated by the Stratospheric Ozone Working Group, lead by EPA Region 8.



GMD-02, Fig. 3: Trends (2000–2014) of summertime (April–September) daytime average ozone at available ozone monitoring stations. Vector colors indicate the p-values on the linear trend for each site: blues indicate negative trends, oranges indicate positive trends and green indicates weak or no trend; lower p-values have greater color saturation. This and other Tropospheric Ozone Assessment Report (TOAR) trend figures can be downloaded from: https://doi.pangaea.de/10.1594/PANGAEA.876108. DOI: https://doi.org/10.1525/elementa.243.f1. Image: TOAR/CIRES

There are four GMD surface ozone measurement locations: Barrow, Alaska; Eureka, Canada; Summit, Greenland; and Tiksi, Russia. These Arctic locations have been an integral part of the International Arctic Systems for Observing the Atmosphere Ozone and Trace Gases working group. We have analyzed these data, in addition to four other measurement stations' data, to develop a seasonal climatology of expected conditions. This data analysis is complete for all eight stations for the entire measurement record. In addition, we have produced longterm variation and trend analysis. We have also used the coastal locations (Barrow, Eureka, and Tiksi) to help understand the seasonal ozone depletion events and associated active halogen chemistry.

The Tropospheric Ozone Assessment Report was a community effort to develop ozone metrics necessary for quantifying the impact on climate, human health, and ecosystem productivity (Schultz et al. 2017 and Gaudel et al. 2018). We used 15 NOAA GMD surface ozone station data in the development of the TOAR database and provided data for the longterm trend analysis (Chang et al. 2017).

Gaudel, A, et al. 2018. Tropospheric Ozone Assessment Report: Present-day distribution and trends of tropospheric ozone relevant to climate and global atmospheric chemistry model evaluation. *Elementa*, 6: 39. DOI: https://www.elementascience.org/articles/10.1525/elementa.291

Data Archiving

The Big Earth Data Initiative (BEDI) Archival, concentrated on preparing NOAA-acquired historical records (i.e. Dobson spectrophotometer total ozone, ozonesonde profiles, and surface ozone time series) for archival at the NOAA Center for Environmental Information (NCEI) archive. The datasets incorporate records from 14 NOAA Dobson stations, 15 surface ozone stations set to be produced in a new data format known as netCDF. The netCDF is the Network Common Data File created by the University Corporation for Atmospheric Research and is "a set of software libraries and self-describing, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data."

We completed the initial production of documentation and netcdf for all four projects (Surface Ozone, Dobson, Water Vapor, and Ozonesonde). We have set up the archive system and static IP address and prepared the data for archive.

GMD-05: Understanding the Behavior of Ozone Depleting Substances

CIRES Lead: Fred Moore / NOAA Lead: James W. Elkins

NOAA Theme: Climate Adaptation and Mitigation

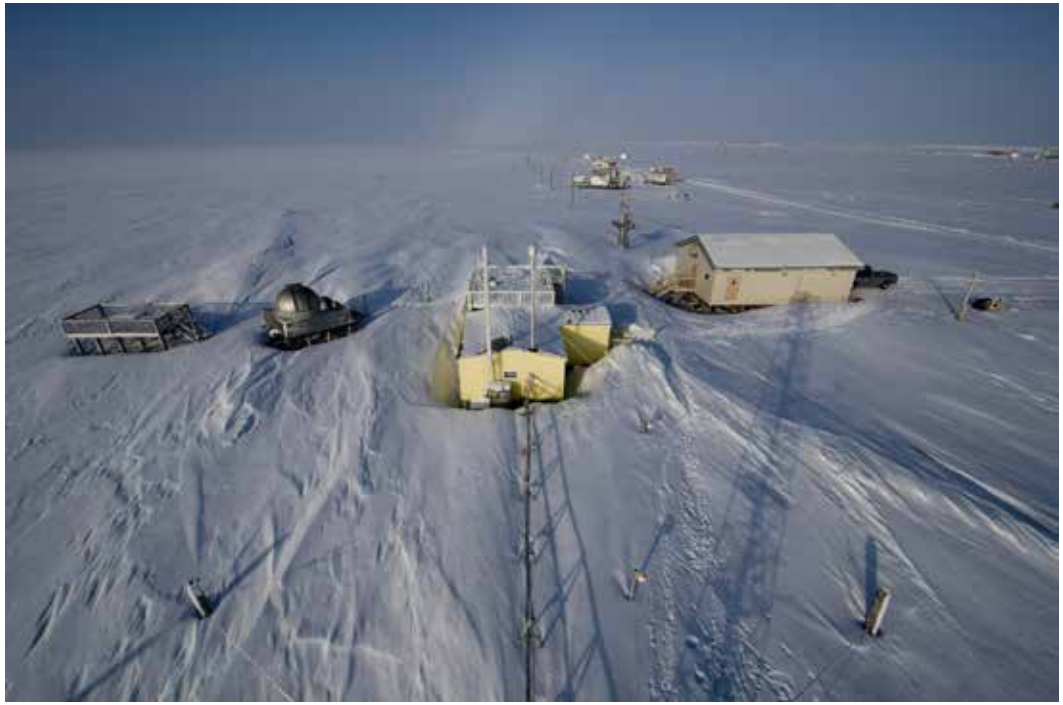
GOALS & OBJECTIVE

This project provides both long term global surface datasets and correlated vertical datasets that are used to quantify emissions, chemistry, and transport of ozone depleting and climate forcinggases. 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 two surface networks: regular, low-altitude airborne flask measurements from light aircraft profiles conducted at ~20 locations mostly over North America; and periodic higher-altitude, mission-oriented measurements. The airborne programs help define the processes that connect the surface network measurements to the atmosphere as a whole. By themselves, each set of results addresses specific aspects of atmospheric chemistry (source and sinks), transport, feedback mechanisms, etc. However, because these datasets are referenced to a common, in-house standards program, they represent a much more powerful tool when combined, and they are especially well suited to analysis by 3-dimensional models. Our highlights over this period include:

- announcing a substantial increase in global emissions of CFC-11 in recent years, despite a reported phase-out global in CFC production *(Nature)*;
- revising the atmospheric lifetime of sulfurhexafluoride (SF_6), one of the original six gases/groups for reduction of emissions under the Kyoto Protocol, from 3,200 yr. down to 850 yr. *(Journal of Geophysical Research)*;



GMD-05: The BRO observatory in Barrow Alaska is key to our surface network. Data taken from BRO was crucial for the $CHCl_3$ studies mentioned in the text. Photo: Bryan Thomas/ NOAA

- demonstrating recent declines in overall U.S. greenhouse gas emissions over the 2008-2014 period as a result of the Montreal Protocol (*Geophysical Research Letters)*;
- assessing the potential for continued large increases in the global concentration of dichloromethane, an ozone-depleting gas not controlled by the Montreal Protocol *(Nature Communications)*;
- continuing our investigation of carbonyl sulfide measurements as a means of improving our understanding of terrestrial photosynthesis *(Nature Geoscience)*; and
- examining North American emissions of chloroform ($CHCl_3$), the second largest source of natural atmospheric chlorine. Here, we used in-situ measurements at Barrow, Alaska, and flasks with whole air samples at more than 30 locations in an atmospheric inversion model to estimate seasonal $CHCl_3$ emissions. Studies show summertime high Arctic natural sources and large year-round anthropogenic emissions in the western United States (Global Monitoring Annual Conference).

We incorporated results from these programs into the 2018 WMO Scientific Assessment of Ozone Depletion Report that is almost final. Results also feed into annual updates tracking global changes in climate warming from long-lived greenhouses gases (NOAA's Annual Greenhouse Gas Index or AGGI) and global changes in ozone-depleting gases (NOAA's Ozone Depleting Gas Index or ODGI); the AGGI was updated in May 2018 and the ODGI will be updated in Summer of 2018. Furthermore, we augmented measurement capabilities in this period to enable tracking global concentrations of a number of new chemicals during ATom (see below) missions and in the ongoing network.

A major focus of our airborne programs this past year was the Atmospheric Tomography Mission (ATom) Project. This NASA-funded global survey project utilized PANTHER (PAN and other Trace Hydrohalocarbons Experiment), UCATS (UAS Chromatograph for Atmospheric Trace Species), and NOAA PFP (Programmable Flask Package) instruments. We have obtained data from the final 3rd and 4th deployment of ATom and are in the process of appropriately reviewing it. ATom generates a chemistry-oriented extension of the global-scale, tropospheric HIPPO (HIAPER Pole-to-Pole Observations), Quasi-Biennial Oscillation, ENSO (El Niño–Southern Oscillation), and the seasonal-tropical pump are imprinted onto this stratospheric air that carries north/south symmetric and asymmetric signatures into the troposphere. Together the HIPPO and ATom datasets span multiple cycles of these interacting periodic processes and should allow us to better quantify their interactions as they phase in and out. Of equal interest will be the temporal and spatially varying inter-hemispheric exchange, which occurs primarily in the upper-tropical and extra-tropical troposphere.

We also worked on the submission of two new NASA EV-3 proposals this year, each with a focus on stratospheric processes; "Middle Atmosphere Transport Timescales, Age Distribution, and Ozone Recovery (MATTADOR); and Dynamics and Chemistry Of The Summer Stratosphere (DOCTSS). MATTADOR is a large balloon-based program with a focus on quantifying Brewer-Dobson circulation. DOCTSS is an ER-2 based program with a focus on quantifying the effect of the North American Monsoon Anticyclone on Ozone concentrations over North America.

GMD-06: Monitor Water Vapor in the Upper Troposphere and Lower Stratosphere

CIRES Lead: Dale Hurst / NOAA Lead: Russell Schnell

NOAA Theme: Climate Adaptation and Mitigation

GOALS & OBJECTIVE

This project will make use of long-term UTLS water vapor measurements by balloon-borne frost point hygrometers to measure inter-annual changes and longer-term trends at three monitoring sites.

ACCOMPLISHMENTS

We launched balloon-borne NOAA frost point hygrometers (FPH) every 3-4 weeks from Boulder, Colorado; Hilo, Hawaii; and Lauder, New Zealand, to measure water vapor in the upper troposphere and stratosphere (UT/S). Our measurements extended the long data records at these sites to lenghts of 38, 8, and 14 years, respectively. Each sounding produces a vertical profile of water vapor, ozone, temperature, pressure, and horizontal winds from the surface to approximately 28 km altitude. We used the data to examine inter-annual variability and longer-term trends in these essential climate variables, as critical checks of climate model output, and for the calibration and validation of satellite-based water vapor and ozone sensors.

Starting in July 2017, we coordinated some of the balloon-based soundings at Boulder and Lauder with overpasses of the 3rd generation Stratospheric Aerosol and Gas Experiment (SAGE III) spectrometer on the International Space Station. We are comparing SAGE III retrievals of water vapor and ozone to the vertical profile data obtained from these coincident balloon flights. This collaboration is ongoing and the results are forthcoming with the first release of SAGE III ISS data products, expected in late 2018.

We collaborated on a paper (Lossow et al., recently accepted in *Atmospheric Chemistry and Physics*) that explores the claim (in a previous paper)

GMD-06: Emrys Hall (CIRES) prepares to launch a balloon-borne NOAA Frost Point Hygrometer, ozonesonde and radiosonde at the Marshall Field Site near Boulder, Colorado. Photo: Diane Perry/NOAA Corps

that the stratospheric water vapor mixing ratios over Boulder are not representative of zonal mean values for the Northern Hemisphere middle latitudes. The claim was made to explain why stratospheric water vapor mixing ratios measured over Boulder by the NOAA FPH during 1980-1989 are different from those output by a chemistry-climate model for that same period. The paper compares stratospheric water vapor retrievals from the Aura Microwave Limb Sounder (MLS) satellite sensor over Boulder to zonal mean retrievals for the Northern Hemisphere middle latitudes and finds only small differences. The paper also exposes large discrepancies in the results from several models using various reanalysis datasets as input.

We also collaborated on a paper (Weatherhead et al. 2017) that evaluates the spatial representativeness of each measurement site within the Global Climate Observing System Reference Upper Air Network. The analysis uses satellite-based temperature data to examine correlations in measurements as a function of distance from each site. The intention of such an evaluation is to assist in designing a measurement network capable of capturing the variability and longer-term trends in essential climate variables on regional to global spatial scales.

We have seen the recent divergences in stratospheric water vapor measurements by the MLS and FPHs over five different sites continue through 2017. Drifts in MLS retrievals in the lower stratosphere have propagated full-record wet biases of up to 0.4 ppm (10 percent) relative to the FPHs. We continue to monitor this drift as the MLS approaches its 15th year of near-global operation.

PUBLICATION

Lossow, S., Hurst, D.F., Rosenlof, K.H., Stiller, G.P., von Clarmann, T., Brinkop, S., Dameris, M., Jöckel, P., Kinnison, D.E., Plieninger, J., Plummer, D.A., Ploeger, F., Read, W.G., Remsberg, E.E., Russell, J.M., and Tao, M. (2018): Trend differences in lower stratospheric water vapour between Boulder and the zonal mean and their role in understanding fundamental observational discrepancies, *Atmos. Chem. Phys.*, doi.org/10.5194/acp-2017-1120.

An ozonesonde rises above the Utah landscape. Photo: Patrick Cullis/CIRES

Project Reports: Systems and Prediction Models Development

GMD-01: Two Vaisala Model CL51 Ceilometers installed on the NOAA David Skaggs Research Center roof in Boulder, Colorado. Units are being tested before permanent field deployment. In order to test side-by-side, one unit is tilted slightly so the retrieved signals do not interfere with each other. Photo: Gary Hodges/CIRES

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

CIRES Lead: Gary Hodges / NOAA Lead: Allison McComiskey

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 will indicate the mitigation strategies that might be necessary to maintain acceptable UV exposure and total irradiation exposure that is not excessively perturbed by human activity.

ACCOMPLISHMENTS

There are still a few small issues our team will address, but after two years of proactive updating and refurbishing Surface Radiation (SURFRAD) network infrastructure, all remote sites are structurally well positioned moving forward. While not as glamorous as science reporting, careful design and maintenance of site infrastructure is foundational to any successful long-term measurement program. We are excited to report about two new instruments currently being prepared for installation across the SURFRAD network.

The first is the Vaisala CL51 Ceilometer, which provides cloud base information up to 15 km and as many as three layers. Additionally, it can also be used for analysis of the atmospheric boundary layer. The addition of vertical cloud distribution and boundary layer height data afforded by this instrument will significantly expand the usefulness of the SURFRAD sites for satellite and model diagnosis and development, as well as add the vertical dimension to analyses of trends in cloudiness properties and their relationship to the observed cloud radiative forcing. These field-proven, autonomously operating ceilometers are ideal for the SURFRAD operational paradigm, with a longstanding record of reliability and longevity that fits well with the yearly technical maintenance and local on-site daily cleaning assistance that SURFRAD operates under. At this time, we have delivered three, with four more to be purchased mid-year. Our first field installation will be at the Table Mountain, Colorado, site.

The second instrument we are preparing for installation across the SURFRAD network is a web camera mounted on a 10-meter tower to monitor surface conditions of each site. Knowledge of changing surface conditions is valuable when analyzing broadband and spectral surface albedo. Monitoring surface conditions is a natural extension of the detailed surface albedo measurements we are making at all SURFRAD sites, allowing us to better understand the nature of broadband and spectral albedo across the seasons. Along with direct applications to core SURFRAD measurements, the cameras will also become part of the extensive PhenoCam network operated by Northern Arizona University. This network archives and analyzes vegetation images, characterizing vegetation phenology of ecosystems across North America. Using the relatively high frequency imagery, typically 30-minute, derived time series characterizing vegetation color are processed to one- and three-day intervals. For ecosystems with a single annual cycle of vegetation activity, the PhenoCam group provides date estimates, with uncertainties, for the start, middle, and end of spring green-up and autumn green-down (senescent) phases. Our SURFRAD team is eager to team with PhenoCam network researchers, and are hopeful SURFRAD data will prove valuable to them as well.

GSD-01: MADIS (Meteorological Assimilation Data Ingest System)

CIRES Lead: Leon Benjamin / NOAA Lead: Gregory Pratt

NOAA Theme: NOAA Engagement Enterprise

GOALS & OBJECTIVE

Extend NOAA's operational infrastructure to help improve numerical weather prediction and forecasting services.

ACCOMPLISHMENTS

The Meteorological Assimilation Data Ingest System (MADIS) provides a framework for easily extending NOAA's observational data capabilities. MADIS does this by leveraging partnerships with international agencies, federal, state, and local agencies (e.g., state Departments of Transportation), universities, volunteer networks, and the private sector (e.g., airlines, railroads) and integrating observations from their stations with those of NOAA to provide a finer density, higher frequency observational database. Through these partnerships, our MADIS team provides NOAA with an additional 70 million quality-controlled (QC) observations a day from just over 85,000 stations received from over 200 providers. We make these observations available to the greater meteorological community in standardized formats. MADIS observations are used throughout the weather research and operational communities in the data assimilation phase and verification of weather forecast models. MADIS was declared operational at the NWS' National Centers for Environmental Prediction (NCEP) Central Operations (NCO) as part of the Integrated Dissemination Program in December of 2015.

Below are some of our MADIS accomplishments. Last year we:

- Completed the (Airlines for America) data feed transition so all data is routed directly from ARINC (Aeronautical Radio, Incorporated) to MADIS instead of non-NOAA hoops
- Completed the SNOTEL (Snow Telemetry) hardening and transition
- Completed the WVSS-11 (Water Vapor Sensing System version two) transition
- Completed the TAMDAR (Tropospheric Airborne Meteorological Data Reporting) data transition
- Added frame work for RWIS (Road Weather Information System) and mobile data processing
- Added the Esri Aircraft Display
- Completed the EDR (event data recorder) data transition
- Reduced processing CPU (central processing unit) footprint by more than 50 percent while improving throughput and processing more data
- Added the AWIPSII (Advanced Weather Interactive Processing System version two) data provider agent data feed by LDM (Local Data Manager) service
- Restored providers:
  - Binary ASOS (Automated Surface Observing System) data feed
  - AK-Meso
  - Mobile data feed
  - GPS precipitable water
- Added providers:
  - New York State Mesonet
  - Nebraska Mesonet

GSD-03: Improving Numerical Weather Prediction

CIRES Lead: Ming Hu / 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

We handed off code for the next versions of the Rapid Refresh model RAP (version 4, RAPv4) and High-Resolution Rapid Refresh HRRR (version 3, HRRRv3) to the Environmental Modeling Center of the National Centers for Environmental Prediction (NCEP) in June 2017, on schedule. Meanwhile, we continued to run the current operational version of the RAP/HRRR reliably as the primary source of short range guidance for critical weather forecasts, such as convection, aviation, and renewbale energy.

The RAPv4 and HRRRv3 received approval for implementation based on forecaster evaluation in February 2018. They are under NCEP Central Operations reliablilty testing, with plans for operational implementation at NCEP in July 2018. This implementation includes a new HRRR-Alaska, covering all of Alaska and running every 3h and a longer forecast length for the RAP and HRRR at certain times of the day. In particular, the HRRR-CONUS and HRRR-Alaska will run out to 36h every 6 h.

We have begun work on the next version of the RAP and HRRR (RAPv5/HRRRv4) for a planned operation upgrade in 2020. This version will continue to use the WRF-ARW model (Weather Research and Forecasting model-Advanced Research) and gridpoint statistical interpolation (GSI) analysis with many new and upgraded features. We have already incorporated a few of these upgrades into the Global Systems Division's real-time experimental RAPv5/HRRRv4 including: the updated GSI synced with April 2018 GSI master branch; the use of rawinsonde moisture data at levels above the 300mb level in the analysis; new parameterization of the drag effects of unresolved and partially resolved terrain; and the updated version of the Grell-Freitas scale-aware convection scheme (RAP only).

Other potentially important upgrades we are considering or testing are: replacing the current non-variational cloud analysis with variational analysis of hydrometeors; improving the representation of subgrid (unresolved) cloudiness and its impact on the surface radiation budget; possible domain expansion of the CONUS-HRRR; possible increase in the number of computational layers in the forecast model; a new version of the aerosol-aware Thompson microphysics from our colleagues at the National Center for Atmospheric Research (NCAR).

We developed and completed daily real-time runs of the High-Resolution Rapid Refresh Ensemble (HRRRE) throughout the period from summer 2017 through spring 2018. The reflectivity and precipitation forecast skill of individual HRRRE members now exceeds that of the HRRR during the first ~six hours of the forecast. HRRRE members and HRRR have

comparable forecast skill at longer lead times. HRRRE forecasts were evaluated by researchers and forecasters during the following testbeds: FFaIR Experiment, Aviation testbed, Winter Weather Experiment, and Spring Experiment.

We built a new, three-dimensional real-time mesoscale analysis (3D RTMA) based on the HRRRv3, but with sepecial parameter settings, and this has been running in real time since early 2018. The 3D RTMA analyses provide improved depictions of clouds, visibility, PBL, and surface fields. We updated the GSD real-time 2D RTMA to match the new operation upgrade; this is running as benchmark.

Our team has tested the RAP-HRRR physics suite in the global FIM atmospheric model in preparation for implementing this suite in the FV3 (Finite Volume on the cubed sphere) model, which will become the NOAA operational global model (FIM is the Flow-Following, Finite-volume Icosahedral Model). CIRES scientists in collaboration with scientists at NCAR are also developing a Community Collaborative Physics Package to be used as an aid to developers who wish to contribute physics development for the major upgrade currently underway to NCEP's Global Forecast System (GFS) using FV3 dynamic cores (GFSFV3).

The weekly real-time forecast of the global coupled FIM-iHYCOM model started in July 2017, as a part of NOAA's multi-model ensemble for subseasonal forecast. We have also carried out a set of hindcast experiments, which are documented in the peer-reviewed papers.

We have migrated all of the existing java applet-based verification tools to the new Model Analysis Tool Suite (MATS). This was critical, as current-generation web browsers are no longer supporting java applets. MATS makes the implementation of new applications and capabilities much faster and more robust. Several new capabilities, including spatial maps of verification scores, have been included in MATS. Our verification group has also implemented an automated testing process for MATS to make the MATS release process more robust.

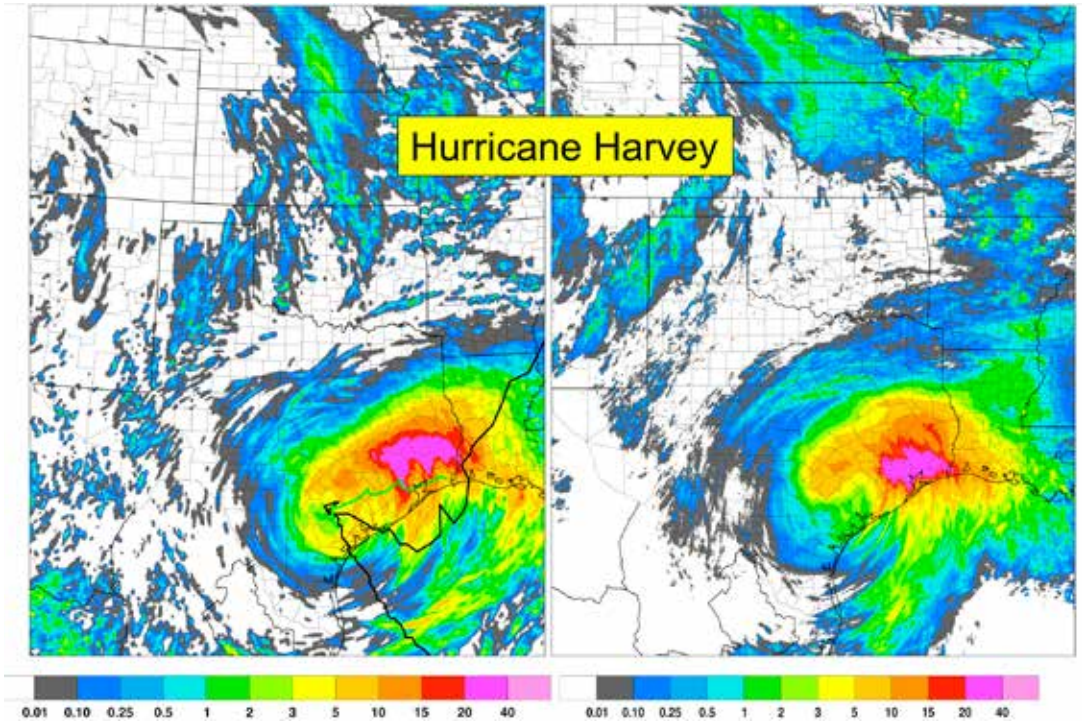
GSD-05: Development of High-Performance Computing Systems (HPCS)

CIRES Lead: Eric Schnepp / 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.

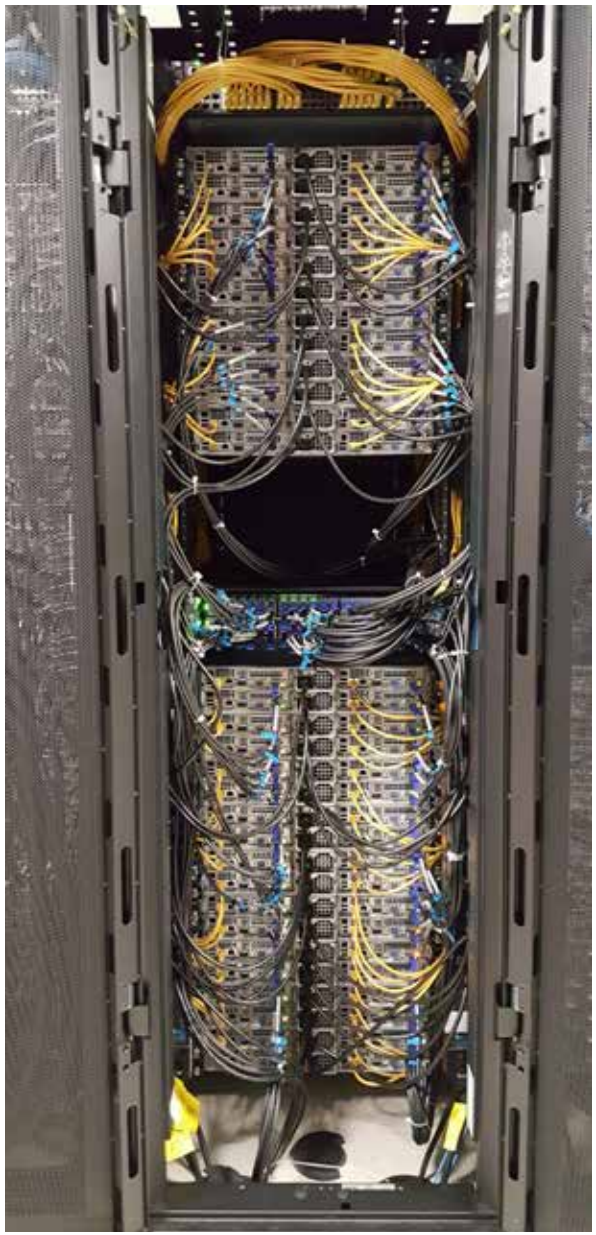


GSD-03: Experimental HRRRv3 48-hour quantitative precipitation forecast for Hurricane Harvey (left) and MRMS radar-only observed 48-hr precipation for Hurricane Harvey (right). Image: RAP/HRRR development group

ACCOMPLISHMENTS

Over the past year, our researchers have helped support NOAA's High Performance Computing (HPC) team in the Global Systems Division (GSD) and NOAA's High Performance Computing and Communications (HPCC) Program. Work spanned several areas, including new system acquisition and planning, application optimization, software development, user management and support, and cross-site IT infrastructure leadership and management.

Our researchers, working as technical advisors to the government, provided detailed requirements for use in NOAA's Request for Proposal (RFP), in support of a solicitation for a nine-year integrator contract to support systems integration services for NOAA's Research and Development High Performance Computing and Communications (R&D HPCC) infrastructure. Specific responsibilities included: providing expertise to NOAA in developing requirements for High Performance File



Systems, High Performance Compute systems, High Speed Interconnects, software stacks, and IT infrastructure. Our researchers also assisted in industry briefings, guiding site tours, and answering solicitation-related industry questions.

One of the more important experiments that our researchers support on the HPC systems at GSD is the annual, real-time hurricane season experiments for HFIP, the Hurricane Forecast Improvement Project. The goal of this experiment is to demonstrate the ability to deliver improved hurricane forecasts, with the goal of transitioning next-generation severe weather models from Research to Operations (R2O). Our responsibility is to develop the tools and techniques for HFIP scientists to use so that their experiments can run reliably and on time. The development and support of the Rocoto work-flow management tool is a big part of this process. Well before the peak of hurricane season, we implemented a complex system, based on reservations, which guaranteed system resources to HFIP projects when needed. We closely monitored system utilization and reservation usage in real-time during the hurricane season. During periods of low storm activity, we provided tools to HFIP projects to allow them to release unneeded resources, letting the rest of the research and development community execute as resources became available.

Our researchers assisted NOAA in the acquisition of a new High Performance File System (HPFS), used to replace two of Jet's aging legacy file systems. This new file system was installed in order to meet the growing needs for increased input/output (I/O) performance and capacity of both the HFIP and Global Systems Division. Our role in this acquisition included defining requirements, performing trade-off studies, system validation, and performance testing. The replacement of the legacy file systems (pan2 and lfs2) with a new file system (lfs1) left Jet with two production HPFS file system, brought Jet's total storage capacity up to 5.5 Petabytes with 62.5 Gigabytes per second of I/O performance.

GSD-05: One of 50 racks that make up the Jet High Performance Compute System, located at NOAA ESRL/GSD. Photo: Eric Schnepp/CIRES

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

We completed the assessment of the Icing Product Alaska-Diagnosis (IPA-D) and reported to the Federal Aviation Administration (FAA). Overall, IPA-D exhibited similar skill to short-term forecasts from products already available to the Alaska Aviation Weather Unit. IPA-Ds did reduce the false-alarm rate compared to the available forecast products, but at the cost of an increase in missed events.

We completed an evaluation of the Global Graphical Turbulence Guidance (GTG-G) product. This evaluation was a focused assessment performing a comparison of GTG-G to the current World Area Forecast System (WAFS) turbulence forecast, using verification techniques and metrics aligned with those currently provided by the World Area Forecast Center, London. We found that GTG-G generally outperformed the WAFS turbulence forecast, though the forecast improvement varied by region and observation platform.

Our team evaluated the Ensemble Prediction of Oceanic Convective Hazards (EPOCH) over the Northern Hemisphere summer period. We found EPOCH outperformed the current World Area Forecast System convective forecast product in the tropics, but produced significantly less convection for higher latitudes. In the fall, we will deliver a report on the performance of EPOCH during the Southern Hemisphere summer.

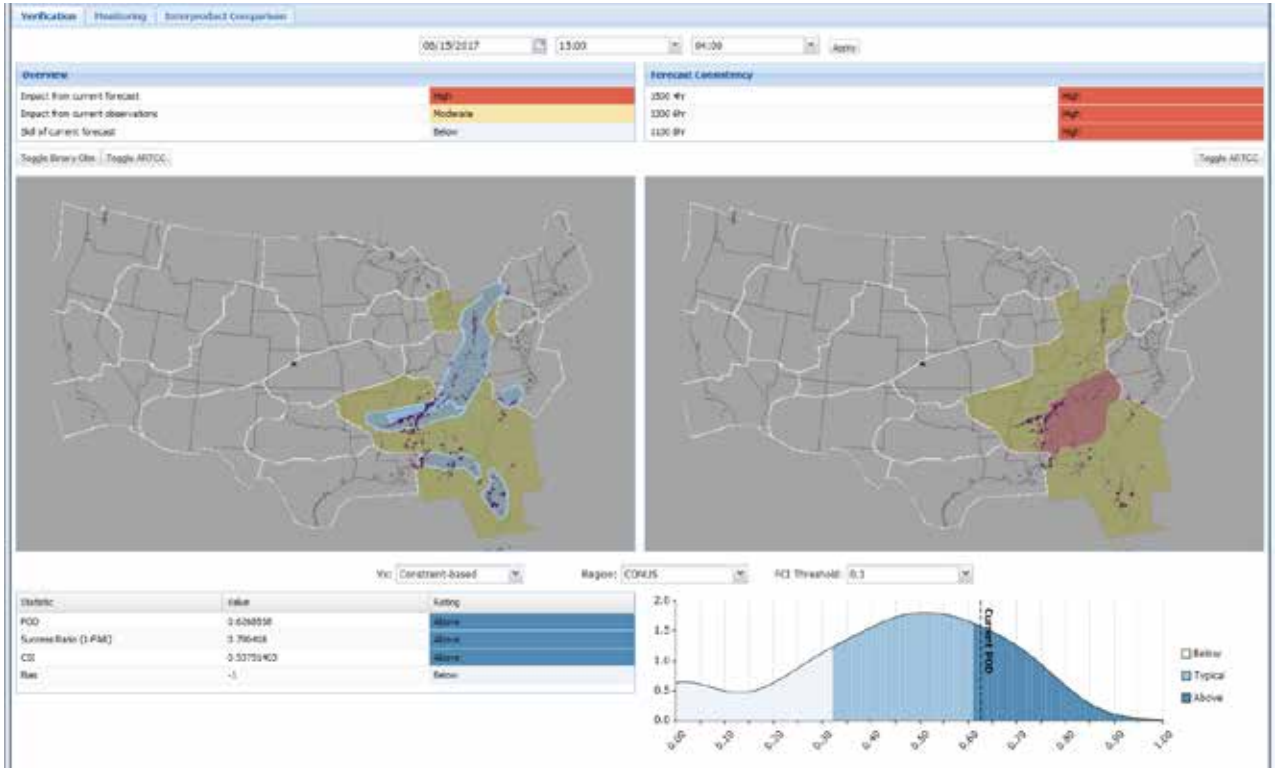
We have begun evaluation of the Ceiling and Visibility (C&V) Analysis Products for Helicopter Emergency Medical Services Tool, involving a comparison of multiple C&V analyses. Later this summer, we will deliver a report in the performance over the cool season (winter 2018) and in November, will report warm season results. Preparatory work

for this project by CIRES and collaborators led to the inclusion of over 300 additional surface stations by C&V analysis product producers.

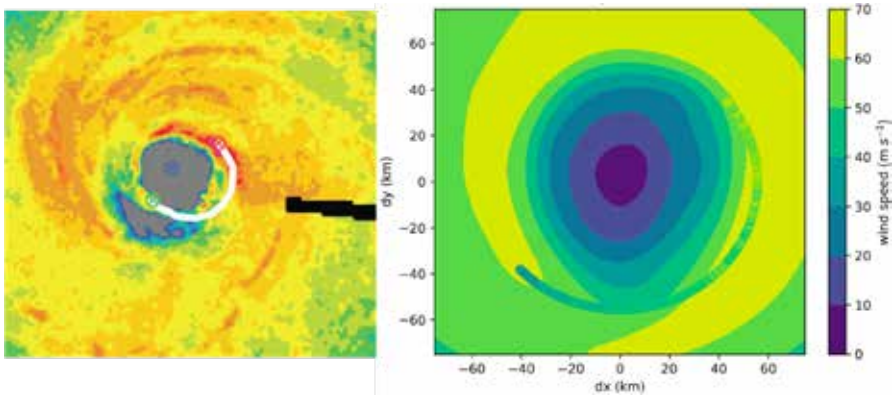
In collaboration with Idaho National Laboratory (INL), we completed an assessment of the High Resolution Rapid Refresh (HRRR) in the context of dynamic line ratings (DLR) for electric grid transmission lines. Our main findings were that the transmission capacity could be potentially increased by up to eight percent by leveraging short-term weather forecasts, without changes to existing infrastructure. We presented results at a DLR workshop hosted by INL, which included participants from a variety of organizations in the power transmission sector.

Our team completed enhancements to two web-based verification tools, the Center Weather Service Unit (CWSU) Briefing and Verification Tool (CBVT) and the Terminal Radar Approach Control Facilities (TRACON) Gate Forecast Verification Tool (TFVT). These tools evaluate forecasts of wind shifts and convection, respectively, provided by the National Weather Service to the FAA. We developed a third web tool, the Convective Weather Verification Service (CWVS), to track the performance of the Aviation Weather Center's Traffic Flow Management (TFM) Convective Forecast (TCF). This tool is used by the National Weather Service to provide regular reports on TCF performance to stakeholders. We also continued work in support of the plans to transition the Integrated Support for Impacted Air-Traffic Environments (INSITE) tool to National Weather Service operations.

We completed core research projects exploring possible data-denial approaches for evaluating analysis products and possible future uses of GOES-16 satellite products, along with an investigation preparing for future evaluations of convectively induced turbulence. In another project, we developed a method for modeling the flow of air traffic in the presence of weather hazards. We will complete a project investigating probabilistic turbulence forecasts this summer.



GSD-06: Screen capture of the Convective Weather Verification System (CWVS) website. The tool provides an overview of the performance of the Traffic Flow Management Convective Forecast (TCF) product for the selected forecast issuance and lead (upper left) and with a view of the consistency of the forecast air-traffic constraint over the last three issuances (upper right). The maps provide a view of the selected forecast (blue polygons) and radar observations (purple shading) along with the forecast (left) and observed (right) constraint aggregated over Air Route Traffic Control Center areas (yellow and red shading). The bottom of the page shows a set of performance metrics along with a categorization of those metrics relative to historical forecast performance. (https://esrl.noaa.gov/fiqas/tech/convective/monitor/). Image: CIRES/NOAA



GSD-07: A Coyote Uncrewed Aircraft System was flown by NOAA around the eyewall of Hurricane Maria on 23 September 2017 (left image). CIRES researcher Evan Kalina devised a method to "fly" the Coyote around the eyewall of a Hurricane Weather Research and Forecasting (HWRF) simulation. This capability allowed a comparison of the observed and forecast temperature and moisture characteristics within the lowest 2 km of the storm, providing diagnostics to inform future model enhancements. Image: CIRES/NOAA

GSD-07: Numerical Prediction Developmental Testbed Center

CIRES Lead: Ligia Bernardet / NOAA Lead: Georg Grell

NOAA Theme: Weather-Ready Nation

GOALS & OBJECTIVE

This project aims broadly at improving operational numerical weather prediction by connecting the research community to the National Weather Service and accelerating the rate of transition of innovations to operations.

ACCOMPLISHMENTS

Our CIRES team and collaborators continued to act as a bridge between research and NOAA (National Oceanic and Atmospheric Administration) National Weather Service (NWS) operations in the field of NWP (Numerical Weather Prediction). Our activities focused on two fronts: O2R, or transition of operational capabilities to the research community; and R2O, the testing, evaluation, and transition of new research and developments to operations.

The past year, our accomplishments included:

- Development of the CCPP (Common Community Physics Package), a library of physical parameterizations for use in NWP systems and its associated CCPP Framework, which allows connecting the library to a host model. Activities involved updating requirements, improving design, developing the framework, adapting physical parameterizations for inclusion in the library, and connecting the CCPP with the Finite-Volume Cubed-Sphere (FV3) dynamical core.
- Public release and support of the HWRF (Hurricane Weather Research and Forecasting) model, the GSI (Gridpoint Statistical Interpolation) data assimilation system and the Common Community Physics Package (CCPP). This involved testing code, creating and updating documentation and instructional materials, conducting tutorials, and answering questions from users.
- Support to the developers of the HWRF, GSI and CCPP codes, by chairing developers' committees, conducting code management, and providing assistance in adding new capabilities to the software.
- Maintenance of a hierarchical test harness for assessment of global models. This included capability to run the experimental GFS (Global Forecast System) that employs the FV3 dynamical core in cycled data assimilation mode and produce diagnostics to inform model development.
- Diagnostic study of the HWRF planetary boundary layer temperature and moisture structure using observations from the Coyote Uncrewed Aircraft System (UAS).
- Assessment of new capabilities for R2O, including:
  - -- Use of radial velocity data in data assimilation for improved model initialization and forecast.
  - -- Alternate weighting of the ensemble versus static background error covariances with the HWRF data assimilation system.
  - -- Use of Stepped Frequency Microwave Radiometer (SFMR) and inner-core dropsonde data to improve the operational HWRF forecast (transitioned to NWS operations).
  - -- Alternate cumulus parameterization for HWRF.
  - -- Updates to cloud-radiation interaction in HWRF (transitioned to NWS operations).
- Establishment of the Model Evaluation for Research Innovation Transition (MERIT) capability, a testing framework to assess and improve upon shortcomings in operational models. This testing framework allows for community contributions to be readily tested and includes running the FV3-GFS system, post-processing model output, verifying model simulation, and plotting model output.
- Publication of a quarterly newsletter to inform the community of the activities undertaken by DTC.

GSD-09: Improve the AWIPS Weather Information System

CIRES Lead: Sylvia Murphy / NOAA Lead: Mike Kraus

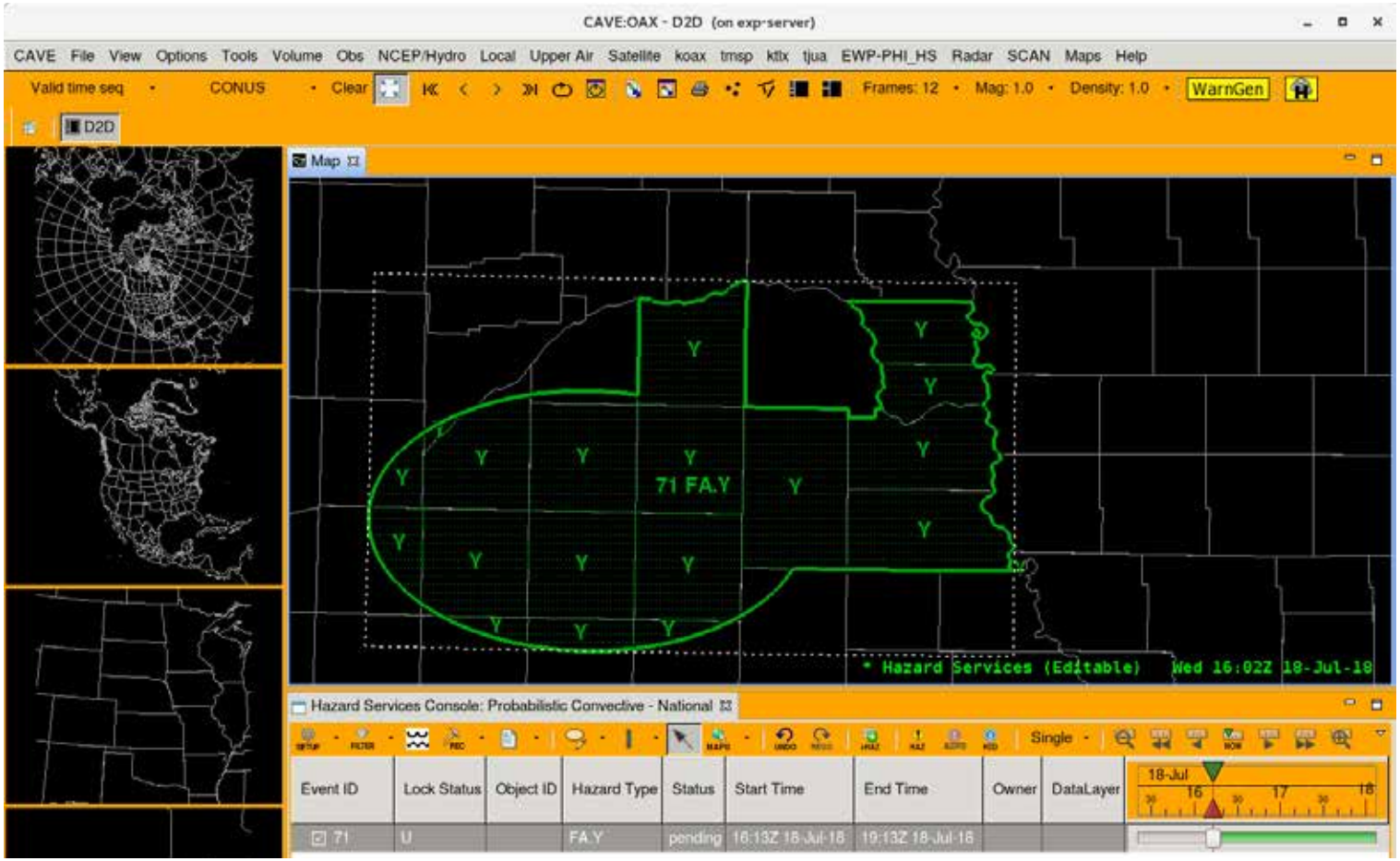
NOAA Theme: NOAA Engagement Enterprise

GOALS & OBJECTIVE

This project focuses on developing forecast tools for NWS forecasters using the AWIPS-2 system.

ACCOMPLISHMENTS

We have been actively developing the Forecasting a Continuum of Environmental Threats



Hazard Services-Experimental (HS-E) software geometry-based editing tools allow arbitrary shapes to be created on the geographic display, forming hazard regions. Image: CIRES and NOAA

(FACETS) software for several years and it is now reaching stable maturity. Probabilistic hazard events can now be automatically generated, updated, and removed as time progresses. We also updated the core software upon which FACETS sits, Hazard Services-Experimental (HS-E). For example, we added geometry-based editing tools, allowing arbitrary shapes to be created on the geographic display. These shapes can be combined in various ways to form additional hazard regions. Finally, we have placed considerable effort on importing features from the Hazard Serviced-Initial Operating Capability (HS-IOC) into HS-E. We will need to merge these two code base before FACETS can become an operational product for the National Weather Service, and expect this integration to take another year. Our team will also continue FACETS development for the next few years under Joint Technology Transfer Initiative (JTTI) funding.

For Hazard Services, we dedicated this past year to the development of winter weather and marine workflows and to expanding the output capabilities to include newly emerging formats such as "Hazard Simplification." We developed winter weather in FY17 and tested at National Weather Service Functional Assessment Tests (FAT) in November 2017 and June 2018. The software was well received and is on the fast track to operations. Our development of marine workflows began in the second quarter of 2018 and will continue through the remainder of the fiscal year. FAT testing for marine is scheduled for FY19. We support-

ed HS-IOC through the addition of Impacts Based Warnings (IBW) for the hydrological workflows, and expect HS-IOC to become operational by the beginning of FY19.

Our team checked the latest version of the Ensemble Tool into the Advanced Weather Prediction System (AWIPS) baseline at the end of FY17. This software was unfunded in FY18, but a JTTI proposal was written to continue development in FY19.

GSD did not host a visitor from Taiwan in FY17, so we focused most of the effort in support of the Chinese Weather Bureau (CWB) on ad hoc development of the Cave Annotation Tool (CAT). We will host a visitor from June to September 2018 and will work with that visitor on the adaptation of CAT to Taiwanese requirements.

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

CIRES Lead: Joe Olson / NOAA Lead: Melinda Marquis

NOAA Theme: Science and Technology Enterprise

GOALS & OBJECTIVE

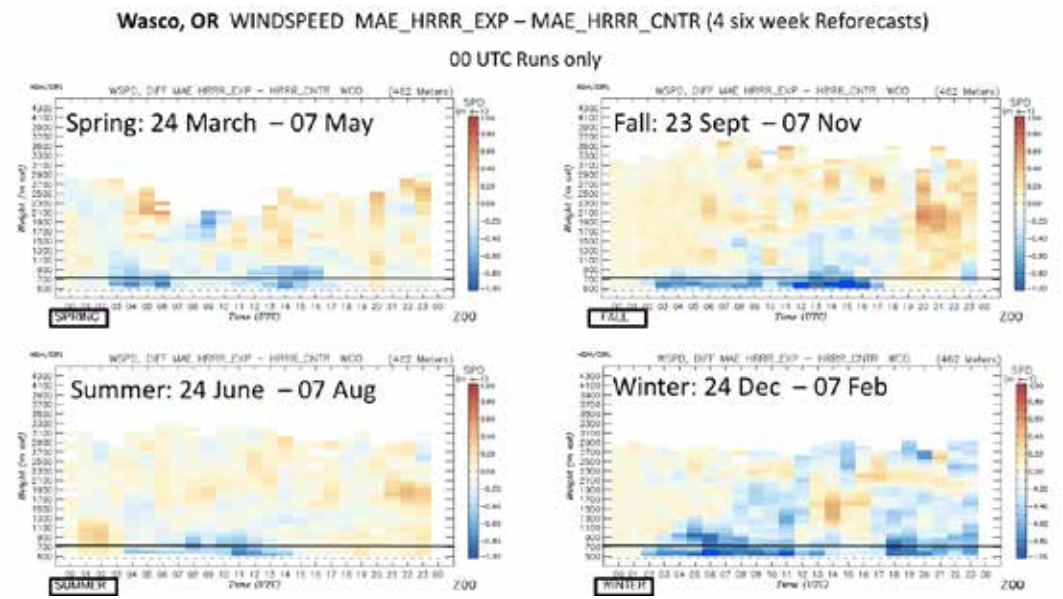
This project focuses on improving the skill of Rapid Refresh and High-Resoluation Rapid Refresh forecasts of low-level winds and downward shortwave radiation, which are both useful for the electric power system.

ACCOMPLISHMENTS

Our robust development of the boundary layer scheme used in the Rapid Refresh (RAP) and the High-Resolution Rapid Refresh (HRRR) includes improvements in both stable conditions and unstable conditions. We accomplished the former by redesigning the formulation of the mixing length scales to better control the magnitude throughout a wide range of atmospheric conditions, and the latter by the addition of a new mass-flux scheme to represent the non-local turbulent transport in convective conditions. Together, these improved and new components demonstrated superior forecast skill over the current operation version of the RAP and HRRR. We included these modifications in the code transfer to the National Center for Environmental Prediction for the next generation operational versions of the RAP and HRRR, planned for implementation in July 2018.

Another major accomplishment for our team was the development of a gravity wave drag suite, representing all components of drag due to subgrid-scale orography (waves, blocking, and form drag). Initially, we adopted seperate components from scientific literature or previously written schemes. We made efforts to combine these components to a single suite and modifications were made to achieve a compelentary spatial representation of momentum stress over a variety of terrain ranging from steep slopes to rolling hills. The impact of this new drag suite varies, but has the most profound improvement at coarse resolution (dx = 13 km) during the winter, where the wind speed profiles are improved throughout the depth of the troposphere. We also found improvement at higher resolution (dx = 0.75 km) in low-level winds, but the impact was typically small. This new drag suite should help generalize the RAP/HRRR physics suite for a diverse set of forecast applications at various grid spacing.

Stochastic physics is a promising approach to help improve the spread and skill of ensemble forecast systems, providing forecasters with probabilistic information along with traditional deterministic forecasts. Our implementation of stochastic parameter perturbations (SPP) into the RAP/HRRR physics, geared specifically for improving the spread of low-level winds and downward shortwave radiation, may provide valuable probabilistic information for the renewable energy industry. We made additional stochastic perturbation of parameters in MYNN PBL (Mellor-Yamada-Nakanishi-Niino planetary boundary layer), surface layer scheme, gravity wave drag, microphysics scheme, and RUC LSM (Rapid Update Cycle land surface model). Our team performed ensemble test to determine optimal pertur-



GSD-11: Time-height plots of wind speed mean absolute error differences (blue = improvements; red = degradations) between the newly developed experimental physics and the original physics used within the HRRR. Each panel shows results from 45 simulations (for each of the control and experiment simulations) beginning at 00 UTC and simulated out 24 hours for each of the four seasons. The turbine rotor layer (approximated as the lowest 200 m of the atmosphere; black line) has the largest improvements in wind speed, primarily in the nocturnal boundary layer and most pronounced in the winter. Image: CIRES/NOAA

bation magnitudes and spatial and temporal decorrelation length scales. The results from HRRR-based ensemble shows that SPP helps to improve the ensemble spread while typically maintaining higher skill in the ensemble mean relative to the deterministic HRRR. We expect the model domain used HRRR ensemble to increase from the eastern two-thirds of the United States to a full CONUS domain by the end of summer 2018. This will allow us to assess the benefit to low-level wind forecasts in complex terrain.

GSD-12: NOAA Environmental Software Infrastructure and Interoperability Project

CIRES Lead: Cecelia DeLuca / NOAA Lead: Georg Grell

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 inter-agency collaborations, and promotes resource efficiency.

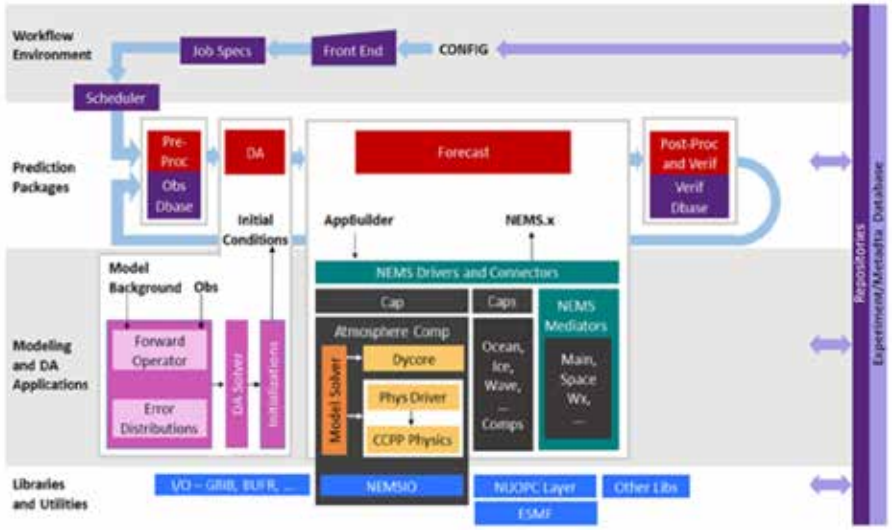
ACCOMPLISHMENTS

CIRES' Cecelia DeLuca managed the NOAA Environmental Software Infrastructure and Interoperability (NESII) project, which worked with multiple centers to develop and deploy community infrastructure software, and helped coordinate modeling activities across agencies.

For one of our primary achivements in the past year, we delivered of a new release of the Earth System Modeling Framework (ESMF) software for building and coupling models, and the National Unified Operational Prediction Capability (NUOPC) Layer, an extension to ESMF that increases the interoperability of model components across centers. The ESMF/NUOPC v7.1.0r included second order conservative grid remapping, dynamic grid masking during remapping, and many other new features and optimizations, see https://www.earthsystemcog.org/projects/esmf/download_710r.

Our NESII team collaborated with the NOAA Environmental Modeling Center (EMC), the Global Systems Division (GSD), and other partners on the integration of a new atmospheric model, called the Finite Volume 3 Global Forecast System (FV3GFS) into a set of applications at the National Weather Service. The applications are part of a Unified Forecasting System (UFS), and share components and infrastructure. The coupling infrastructure for the UFS, called NEMS (NOAA Environmental Modeling System), is based on ESMF and NUOPC layer tools. NESII contributed to application milestones that included: adding asynchronous input/output to the FV3GFS atmosphere as an optimization; ensuring the correct operation of the coupling in an atmosphere-ocean-ice subseasonal prediction application; advancing the coupling in an atmophere-ionosphere application; and completing a coupled atmosphere-chemistry application.

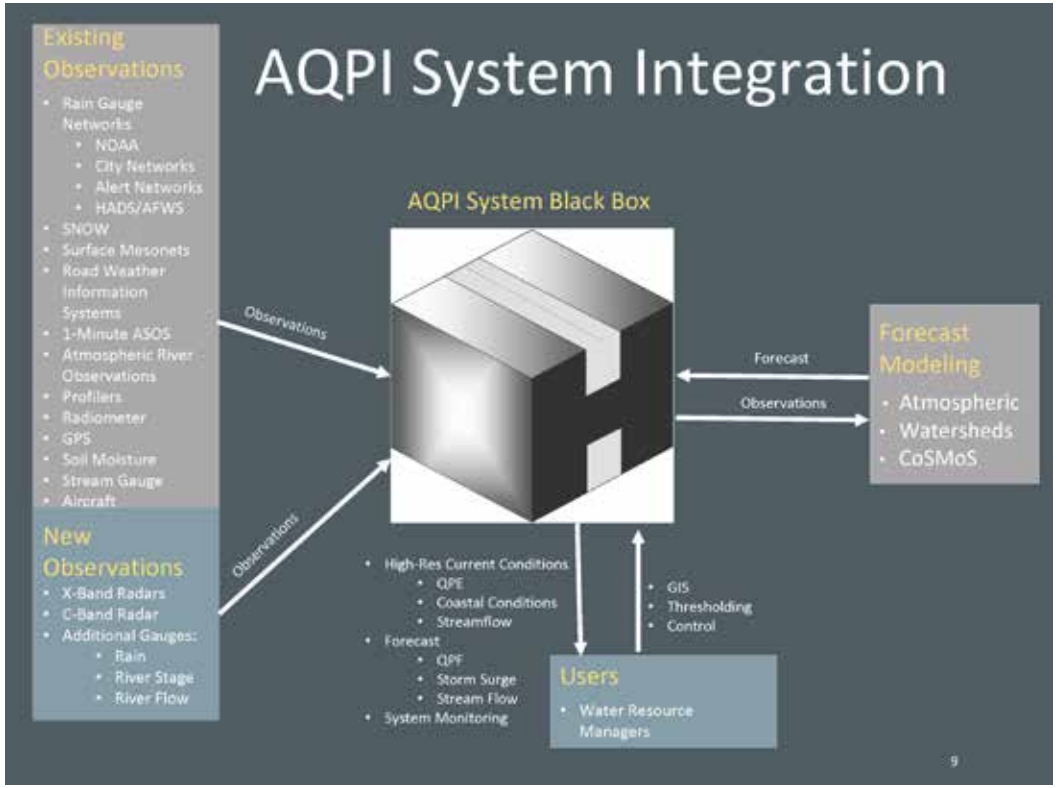
DeLuca was chosen as the lead for a NOAA Hurricane Supplemental Infrastructure project. She coordinated a draft plan and will oversee the project going forward. She also serves as co-chair of the Unified Forecasting System Architecture Working Group.



GSD-12: Diagram showing the four main layers in the NOAA Unified Forecast System architecture: Libraries and Utilities, Modeling and Data Assimilation Applications, Prediction Packages, and Workflow Environment. Purple boxes indicate parts of the Workflow Environment and databases. Red boxes indicate executables while the thin lines around them represent scripts that invoke the executables. Teal boxes show NEMS coupling infrastructure. Black boxes represent model and mediator components. Orange boxes show subcomponents of the atmosphere model component. Pink boxes show parts of the data assimilation system. Blue boxes show utilities and libraries. The Prediction Package sequence shown is typical; it may change for different applications. Image: CIRES/NOAA

Other milestones achieved by the NESII team in the past year:

- We completed a NUOPC-based version of a chemical transport model at NASA, and a coupled atmosphere-ocean application with a land and hydrology higher resolution nest for the Navy.
- We worked with the Community Earth System Model (CESM) at NCAR, EMC, and the Geophysical Fluid Dynamics Laboratory (GFDL) on a project to develop a community coupler based on ESMF/NUOPC that these centers can share, and demonstrated its use in a development version of CESM: https://github.com/ESCOMP/UFSCOMP/wiki/Milestone:-CMEPS-0.2.
- Our NESII team gained approval from its Executive Board this year to move ESMF community operations from the Global Systems Division (GSD) to NCAR. ESMF is a well



GSD-13: Transforming the capabilities of observation, models, and experts into the needs of the customers. Image: CIRES/NOAA

established community project with multi-agency sponsors and governance. The move to NCAR was motivated by the need to be better positioned for external funding. The remaining portion in GSD will focus only on NOAA projects—so our team will be significantly smaller and will have a reduced scope next year.

GSD-13: San Francisco Bay Area Advanced Quantitative Precipitation Information System

CIRES Lead: Leon Benjamin / NOAA Lead: Gregory Pratt

NOAA Theme: Science and Technology Enterprise

GOALS & OBJECTIVE

Provide improved precipitation, stream flow, and coastal inundation estimates and forecasts to water managers in the SF-Bay Area to improve operational response to adverse rain events.

ACCOMPLISHMENTS

This research effort started in FY2018 and will continue through the end of FY2021 at which time our CIRES team will be responsible for delivering the AQPI system to an operational entity identified as part of the transition process. Our CIRES research team focused on the following tasks during the last year:

Working closely with other research teams as well as water agencies, managers, and other users in the San Francisco Bay (SF-Bay) area to develop and refine requirements for the AQPI system

- Participated in kickoff meetings designed to get to know the stakeholders and researchers
- Met with various counties and agencies involved in the AQPI project to gather requirements; these meetings have continued a few times a month since October 2017 to clarify issues and requirements
- Assimilated information, notes, discussions, and requirements from meetings into AQPI knowledge database

Developing and testing a system to deliver products and services based on the requirements gathered

- Set up FXA/AWIPS (Advanced Weather Interactive Processing System) system for AQPI
- Modified processing to import MADIS data, other providers data, and models
- Worked on changes to AQPI processing system to meet stakeholder needs and requirements
- Set up automated retrievals of MADIS (Meteorological Assimilation Data Ingest System) data within the AQPI region of concern (from operational and developmental servers)
- Put together locations of interests for each county in order to to plot threat as defined by the stakeholders for their areas of concern
- Worked on geo-located data spreadsheets
- Worked on receiving and decoding of mdb files and other formats from California agencies
- Researched getting data into SFPUC's WISKI db, importing from RiverPro
- Worked on ingesting the subhourly High-Resolution Rapid Refresh data
- Set up shared source code repository and build area

Developing transition plan for moving the AQPI system from research to operations

- Designed first version of data ingest and processing system
- Refined design as requirements and needs were flushed out

GSD-14: Observing System Experiments within Rapidly-Updating NWP Systems

CIRES Lead: Eric James / NOAA Lead: Curtis Alexander

NOAA Theme: Science and Technology Enterprise

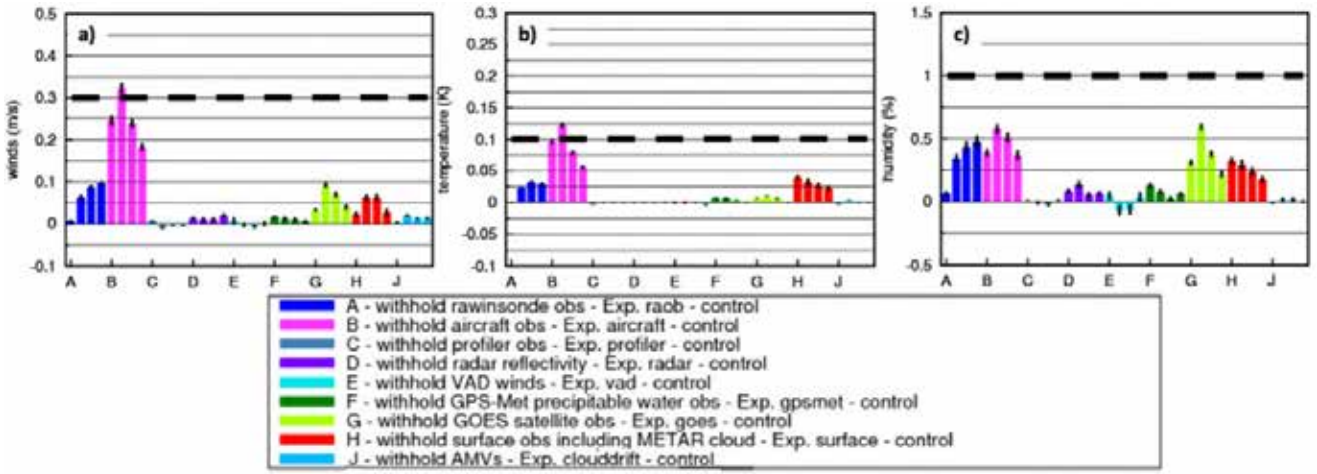
GOALS & OBJECTIVE

Observing system experiments (OSEs) serve as a way to quantify the value of the various components of the observing system for forecast skill within a numerical weather prediction (NWP) system. Within GSD, the objectives of our OSE work for FY18 are as follows: (1) Conduct a set of regional Observing System Experiments (OSEs) using the latest 13-km Rapid Refresh (RAPv4) to examine changes in relative observation impact compared to earlier versions of the RAP. For now, focus will remain on the 13-km RAP system, although tests with an FV3-based system may be conducted, depending on the availability and readiness of the FV3 code during FY18. OSE tests with the FV3 are more likely in later fiscal years. More limited testing of specific observation types may be done within the HRRR (both CONUS and Alaska domains). (2) Conduct data assimilation configuration tests using the RAPv4 code to improve the impact of observations on short-range forecast skill, with a focus on both upper-air verification against rawinsondes and surface observations (as previously) and on cloud and precipitation forecasts. These tests will be conducted as biases are noted in real-time and retrospective RAP experiments, and based upon hypotheses for the causes of these biases. 3. Continue to monitor the literature to compare observation impacts in the RAP with other regional and global systems. This will also include comparing our results with the relative impacts of observation types within other observation assessment frameworks, including the Forecast Sensitivity Observation Impact (FSOI) technique.

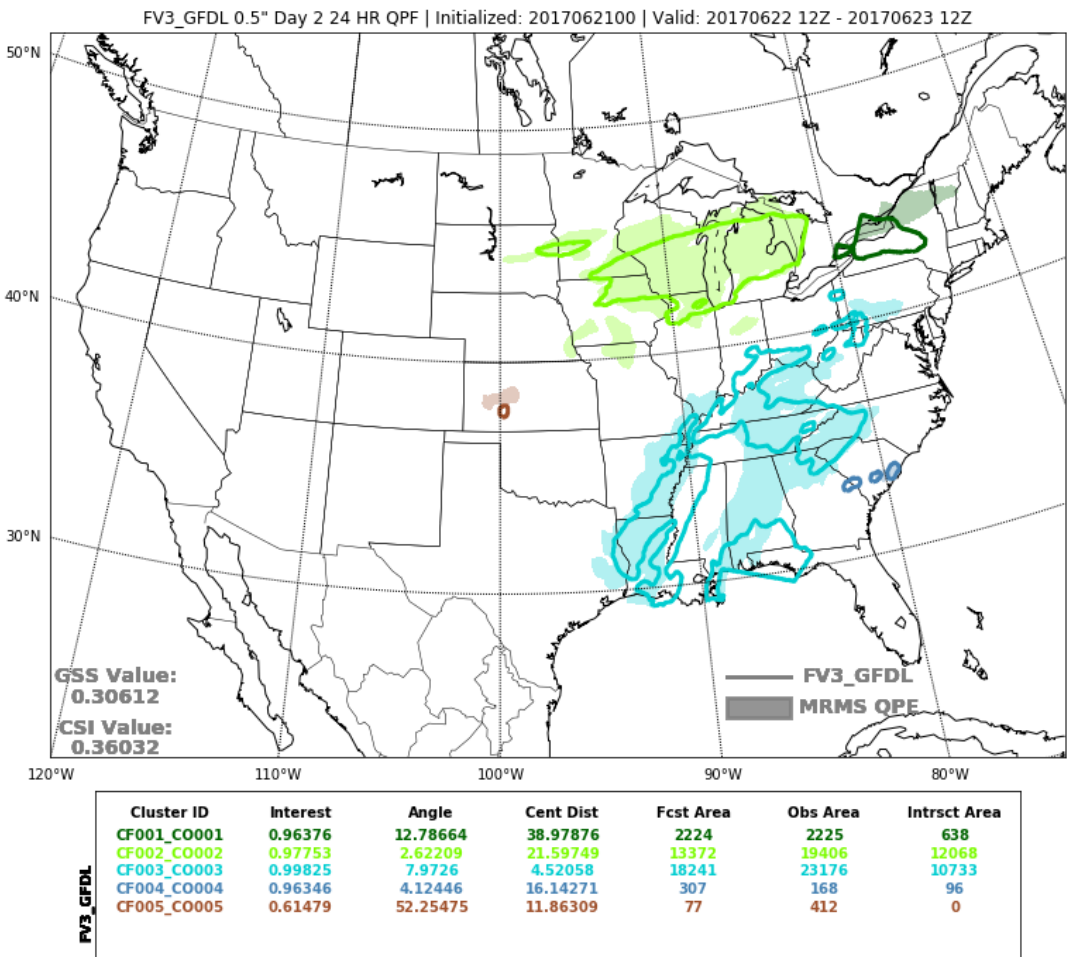
ACCOMPLISHMENTS

During this period, we continued observing system experiment (OSE) work within the GSD Assimilation Development Branch, with a developing focus particularly on various aspects of the non-variational cloud analysis employed in the 13km Rapid Refresh (RAP) and 3km High-Resolution Rapid Refresh (HRRR) numerical weather prediction systems. While much of our work leading up to this was accomplished during the previous period, we published a paper on our large set of OSEs with the RAPv3 configuration in *Monthly Weather Review* in August 2017, entitled "Observation System Experiments with the hourly updating Rapid Refresh model using GSI hybrid ensemble-variational data assimilation."

In terms of accomplishing the goals we set for this period, we did undertake a number of individual experiments focusing on various aspects of the data assimilation configuration for the RAP and HRRR. While we have not yet repeated the experiments published in our August 2017 paper with the RAPv4 code, many of the experiments were aimed at testing potential data assimilation improvements for the RAPv4 and subsequent RAPv5 implementations. These have included tests on (1) the assimilation of rawinsonde and commercial aircraft moisture observations at levels higher than 300 hPa; (2) the overall impact of the GSD cloud analysis; (3) the overall impact of the new hybrid vertical coordinate available in the Weather Research and Forecasting (WRF) model; and (4) the impact of



GSD-14: Observation impacts from different types of observations assimilated within the Rapid Refresh (RAP) version 3, for forecasts of (a) 1000-100 hPa vector wind, (b) 1000-100 hPa temperature, and (c) 1000-400 hPa relative humidity. The four bars for each experiment represent results for 3h, 6h, 9h, and 12h forecasts, from left to right, and the solid dashed horizontal line indicates a 25% forecast improvement. Verification is against rawinsondes over North America, for three 10-day tests in the winter, summer, and spring. VAD = velocity azimuth display data (derived from radar observations), GOES = geostationary operational environmental satellite, GPS-Met = global positioning system - meteorology, METAR = conventional surface observations, and AMV = atmospheric motion vector (satellite-derived wind speeds). Image: CIRES/NOAA



NWS-01: Objective verification using the Method for Object-Based Diagnostic Evaluation tool featured in the Flash Flood and Intense Rainfall (FFaIR) experiment. Image: CIRES/ NOAA

increasing the value of the specified cloud water and cloud ice number concentration in regions where the cloud analysis "builds" clouds.

Our important findings from these experiments include: (1) assimilation of upper-level moisture observations from rawinsondes and commercial aircraft reduces the high relative humidity bias of short-range forecasts in the upper levels, at least in the summertime; (2) the GSD cloud analysis dramatically improves the performance of RAP upper-level forecast profiles (as compared against rawinsondes) for all variables, although further work is needed to understand this; (3) the impact of the new hybrid vertical coordinate upon RAP forecasts is very minimal in terms of verification against rawinsondes; and (4) specifying a higher value of cloud water and cloud ice number concentration in the cloud analysis cloud building allows for much better retention of low clouds in the first few hours of the forecast, especially in wintertime.

NWS-01: R2O at the Hydrometeorological Testbed (HMT) at the Weather Prediction Center

CIRES Lead: Joshua Kastman / NOAA Lead: James Nelson

NOAA Theme: Climate Adaptation and Mitigation

GOALS & OBJECTIVE

The National Weather Service is building the Next Generation Global Prediction System (NGGPS). The Hydrometeorological Testbed is expected to test and evaluate these components in a pseudo-operational environment to ensure quality and human-forecaster use and understanding. The project will facilitate the implementation of the results of the Testbed to NWS forecast and warning operations for hazardous weather.

ACCOMPLISHMENTS

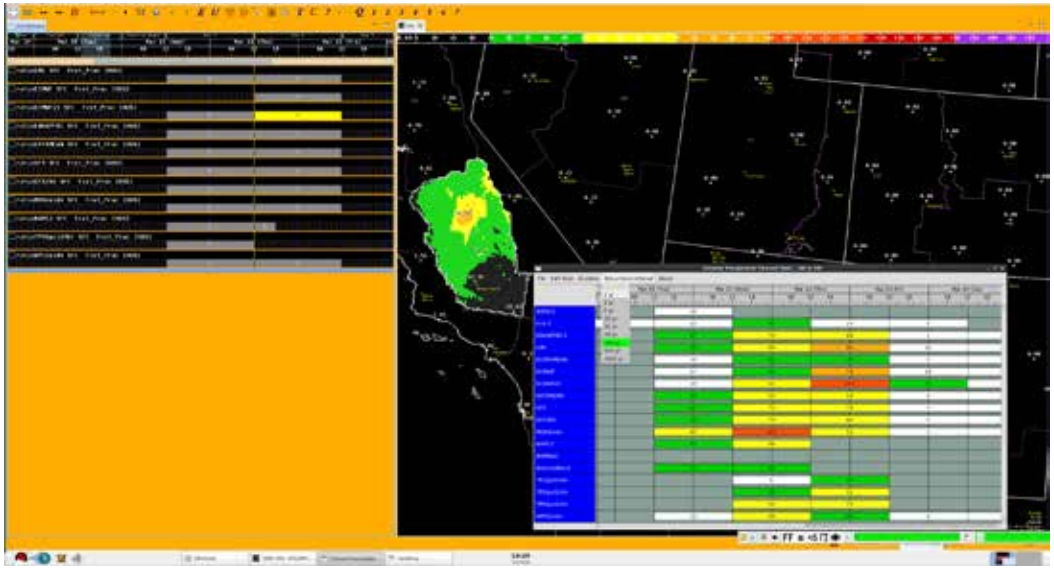
CIRES' Joshua Kastman lead the development of objective verification for the Winter Weather Experiment (WWE), Flash Flood and Intense Rainfall (FFaIR) experiment and the Day 8-10 experiments within the Hydrometeorological Testbed (HMT) using the Method for Object-Based Diagnostic Evaluation (MODE), which is a part of the Meteorological Evaluation Toolkit (MET). For the first time in the above-listed experiments' histories, participants and the science team could compare subjective evaluation and objective evaluation of experimental forecasts simultaneously. Previously, researchers could only do subjective evaluation for the experimental forecasts. This work allows the verification to be standardized across the various experiments, and is therefore easier to maintain. These new methods were well-received from the Weather Prediction Center leadership team and experiment participants. This work is now a permanent part of each experiment and is included in the final reports each season of the WWE and FFaIR experiments. Furthermore, the objective evaluation has been a part of numerous presentations at conferences over the past season and has helped influence how other testbeds are proceeding with objective evaluation.

Kastman also developed enhanced visualization of the objective and subjective verification within the WWE and FFaIR testbeds, which helped better communicate the results of the experiments. For example, the Robber Performance Diagrams were used to objectively illustrate how precipitation

forecasts were performing from a variety experimental models in comparison to one another within FFaIR. This data was then compared with subjective analysis and comments from participants to represent more fully model performance throughout the experiments.

Kastman developed a tool that communicates upper atmospheric forcing that is in juxtaposition with areas of anomalous moisture. This tool is used primarily to help identify areas where there is an increased threat for heavy precipitation, and is now being used in forecast briefings in the Day 8-10 experiment

Kastman is leading the development effort of converting experimental HMT WPC products into Geographical Information System (GIS)-enabled products. This effort allows for much higher resolution, dynamic, and interrogatable data that can be consumed by end users or internally within other GIS capable systems or GIS-based websites. This has helped WPC easily share experimental forecast data, and infuse non-meteorological data (such as population and areal coverage) into products to help better illustrate what, where and whom are being impacted. This development effort has established methodologies needed to produce operational products in this manner, and has helped test the capacity for WPC to produce these types of products in operations. This work has been long requested by WPC partners, but has not been able to be fully tested within HMT testbed until this past year. This work has allowed for a dynamic, higher resolution visualization of experimental data that reduces restrictions on how the data can be visualized as data can be viewed through an online portal rather than through a specific software.



NWS-02: This image shows the Extreme Precipitaiton Forecast Table (EPFT) graphical user interface (GUI) from an atmospheric river event in California during March 20-23, 2018. The 24-hr values in the EPFT are valid for the Hanford, CA County Warning Area (CWA). Model guidance is listed in the farthest left column of the EPFT GUI and the top row indicates the forecast time. The current time starts on the left side of the GUI and increases from left to right. The image behind the EPFT GUI depicts a spatial representation of the ratio at each pixel of rainfall forecasted by the ECMWF to the 100-yr Average Recurrence Interval precipitation estimate, expressed as a percent.

NWS-02: Improving Forecaster Anticipation of Extreme Rainfall Events

CIRES Lead: Diana Stovern / NOAA Lead: James Nelson

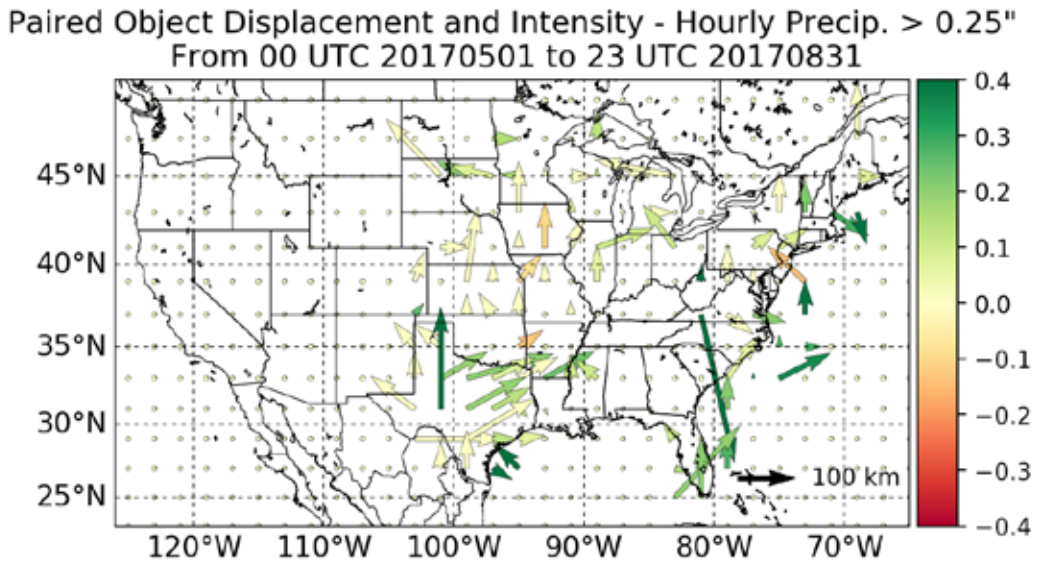
NOAA Theme: Weather-Ready Nation

GOALS & OBJECTIVE

This project will develop tools to aid forecasters' anticipation of extreme rainfall events. This project will identify key observational and model signals for extreme precipitation events; assess model skill of raw QPF output; assess model skill of key ingredients; and develop an ensemble-based situational awareness web-application based on key ingredients.

ACCOMPLISHMENTS

In an attempt to improve collaboration between the Weather Prediction Center, Weather Forecast Offices, and River Forecast Centers for extreme precipitation events, our team developed several operational tools on a common platform used across the NWS—the Advanced Weather Interactive Processing System (AWIPS). One of the tools called the Extreme Precipitation Forecast Table (EPFT) compares a user-selected set of Quantitative Precipitation Forecast (QPF) guidance to the 100-year Average Recurrence Interval (ARI) from the NOAA Atlas-14. We designed the table to help the forecaster quickly identify when a rain event has the potential to become extreme. In the image attached, each cell in the table shows the maximum ratio of QPF to the 100-year ARI, expressed as a percent, found in the area outlined in central California. A value of 100 in the table indicates that the 100-year ARI has been exceeded somewhere in the given domain. With this design, the forecaster can quickly identify the models with the most significant precipitation signal, assess the range of possibilities predicted by the guidance, and get a first-order view of model agreement. We created two more iterations of the table based on feedback from forecasters in the field. The Extreme Precipitation Assessment Table (EPAT) allows forecasters



NWS-03: We highlight the advantage of assessing object-oriented biases in this figure, which shows displacement and intensity biases for the HRRRv2. In this case, the HRRRv2 predicted heavy rain objects too far north in the Central Plains, and was too wet compared to reality east of the Mississippi River. Quantifying displacement biases such as these can be very useful to WPC forecasters in real time, allowing for on-the-fly adjustments to short-range forecasts. Image: CIRES

to view when observed precipitation, or the Quantitative Precipitation Estimate (QPE), has exceeded a 100-year event. The Average Recurrence Interval Table (ARIT), highlights the maximum ARI that has been exceeded by the QPF. Values in the ARIT range from one-year up to 100-years. This ARIT can be used by meteorologists and hydrologists who are concerned with lower-end flash-flooding in their County Warning Area.

We released the table with training materials to all operational agencies across the NWS in Summer 2016. In 2017, we enhanced all three iterations of the table to improve user interface and data sources leveraged. For the EPFT, for example, we added probabilistic QPF information from WPC to the guidance so forecasters can identify where the deterministic guidance falls within the range of the 10th, 50th, and 90th percentile QPF calculated by WPC. We enhanced the EPFT and EPAT interfaces to allow forecasters to compare QPF to additional ARIs and rainfall durations, from one to 100 years and durations from one hour to 24 hours. We sucessfully used case studies of when the EPFT, EPAT, and ARIT was used for decision support in the field, and presented the work at the 2018 American Meteorological Society annual meeting.

One challenge we had with the first iteration of each table is the lack of NOAA Atlas-14 data in Texas and the Pacific Northwest. In fall 2017, we collaborated with scientists at Colorado State University to gain additional ARI data so that WFOs and RFCs in these regions can have an EPFT and EPAT with the same functionality as regions that have complete NOAA Atlas-14 data. Furthermore, the additional ARI data has allowed WPC to create a web-based product called the Extreme Precipitation Monitor, which recasts WPC's official QPF forecast in the context of each ARI, from one to 100 years.

This web-based product is available to the public for federal and local emergency managers to use in their decision making during high-impact rain events.

NWS-03: Probabilistic Hazards Information R2O

CIRES Lead: Michael Erickson / NOAA Lead: James Nelson

NOAA Theme: Weather-Ready Nation

GOALS & OBJECTIVE

This project will develop calibrated probabilistic guidance for flash flood hazards; use feature-based, post-processing approaches to extract and present information about heavy precipitation from storm-scale ensembles; verify and evaluate post-processing approaches in an operational environment; and transition post-processing developments into NWS operations.

ACCOMPLISHMENTS

Quantitative Precipitation Forecasts (QPF) and flash flood forecasts are a critical focus of the Weather Prediction Center (WPC). One major challenge is that heavy precipitation takes the form of coherent objects, that are not considered by standard verification and analyzation techniques. For example, a model that predicts a slightly displaced precipitation object subjectively performs better than a model that predicts no precipitation at all. However, traditional grid-based verification methods would doubly penalize this forecasted object—once for missing the observation and again for producing spurious precipitation elsewhere. Using object-based verification techniques overcomes this shortcoming by treating precipitation as coherent objects and quantifying their characteristics.

Starting in June 2017, we used the Model Evaluation Tools (MET) software package to identify QPF objects and track them through space and time. This allows forecasters to quickly analyze and quantify heavy rain object attributes for a variety of models, such as object area, centroid, velocity, orientation, and intensity. To optimize tracker performance for the QPF objects of interest to WPC, we have performed sensitivity studies and evaluated for several cases. From these sensitivity studies, we selected the optimal tracker parameters for all QPF applications.

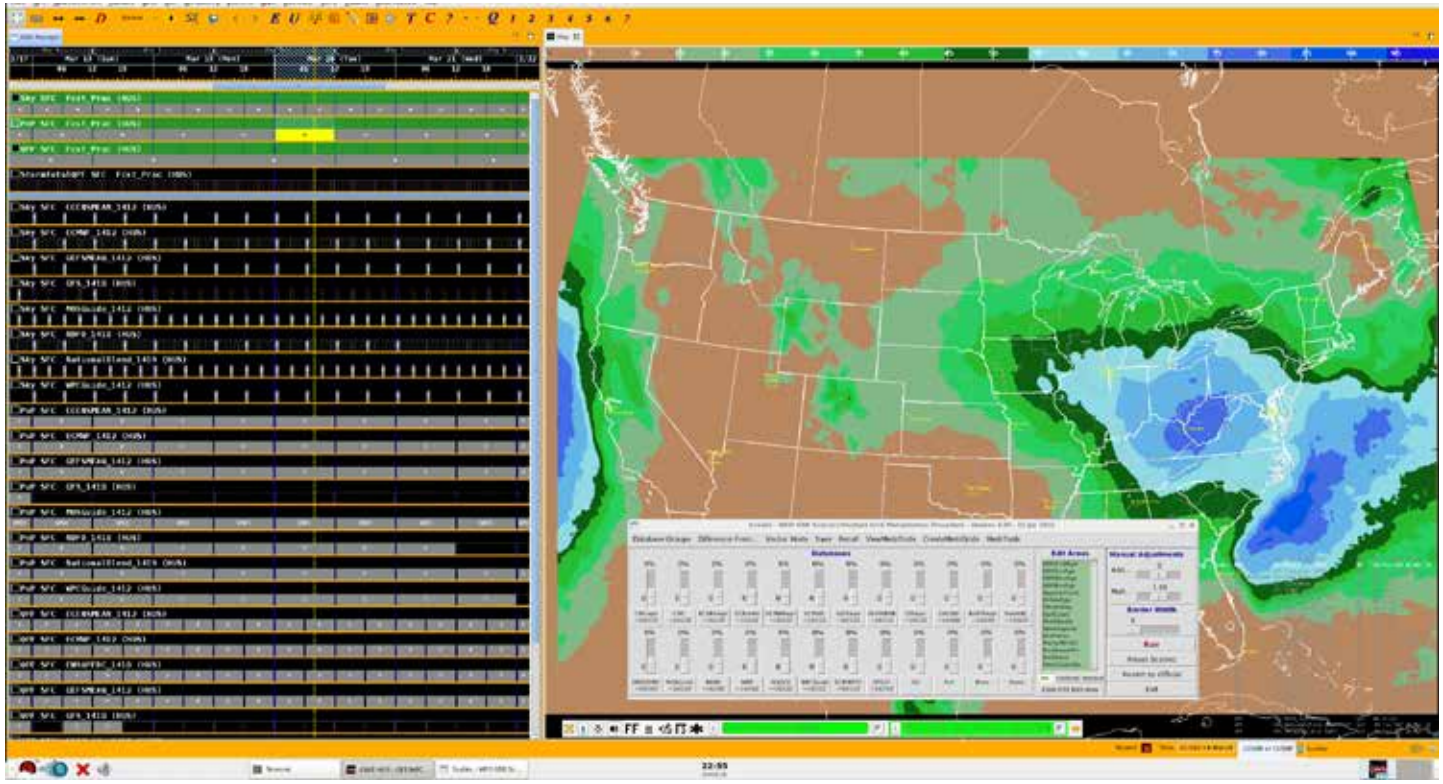
Starting in summer 2017, we have used MET to create model-derived

experimental graphics for WPC forecasters. The experimental images are displayed on an internal website and updated as new model data become available. These graphics allow forecasters to quantify ensemble uncertainty quickly by displaying select object attributes for heavy rain areas. The graphics display the probability of being in a QPF object, object centroid location, object centroid model type, and 90th percentile of object intensity for every forecast hour.

Starting in autumn 2017, we used the MET tracker to retrospectively track QPF objects and compare them to rainfall analyses. We have done this for the High-Resolution Rapid Refresh (HRRR) operational version 2 and experimental version 3. Precipitation objects for the HRRRv2 and HRRRv3 were tracked between May 2017 and August 2017 and compared to the Stage IV rainfall analysis. We highlight the advantage of assessing object-oriented biases in the figure on the facing page, which shows displacement and intensity biases for the HRRRv2.

In this case, the HRRRv2 predicted heavy rain objects too far north in the Central Plains, and east of the Mississippi River, and predicted conditions too wet compared to reality. Quantifying displacement biases such as these can be very useful to WPC forecasters in real-time, allowing for on-the-fly adjustments to short-range forecasts.

Finally, we have explicitly analyzed flooding forecasts using a hydrologic model developed at the University of Oklahoma. We have provided an ensemble of QPF for select case studies to our partners at the Hydrometeorology and Remote Sensing Laboratory, where they ran the hydrologic model to produce probabilistic flooding forecasts. Starting in January 2018, we began analyzing an ensemble of streamflow forecasts with the goal of presenting this probabilistic information to WPC forecasters



NWS-04: This image shows the ScaVec graphical user interface (GUI) within the Graphical Forecast Editor (GFE) of AWIPS. ScaVec consists of buttons containing model guidance and sliders for blending grids by weight. Dropdowns in the menu bar of the ScaVec GUI allow forecasters to view database groups specific to their forecast, create differenced grids (e.g., difference between the GFS and ECMWF forecast precipitation), save and recall blends, view grids specific to their forecast in the GFE, and initialize grids and apply tools specific to their forecast Desk.

NWS-04: Smart Tool Development to Assist the Integrated Field Structure

CIRES Lead: Diana Stovern / NOAA Lead: James Nelson

NOAA Theme: Weather-Ready Nation

GOALS & OBJECTIVE

This project aims to develop Smart Tools and Procedures within AWIPS2 to help transition specific WPC Desks from a predominant NAWIPS workflow to one within AWIPS2 using D2D and GFE.

ACCOMPLISHMENTS

Weather Forecast Offices (WFOs) within the National Weather Service (NWS) have been using AWIPS since it was rolled out by Raytheon in 2011. Since then, the National Centers for Environment Prediction (NCEP) has been working with the AWIPS Program Office (APO) to migrate NAWIPS functionality into AWIPS to allow for a more fully collaborative forecast process between the National Centers (NCs) and WFOs during high-impact weather events. As of spring 2017, we had yet to implement an NCEP-wide solution to allow the NCs to complete their transition. Recognizing the importance of migrating to a universal platform to improve collaboration with WFOs during extreme precipitation events, our leadership at WPC took it upon ourselves to complete the transition internally. With a team of WPC developers, we devised a strategy to transition each forecast desk to AWIPS by utilizing tools and capabilities that already exist within the AWIPS platform.

One of the first AWIPS tools utilized by WPC is a procedure originally developed for WFOs called the Scalar/Vector Manipulation Procedure (ScaVec). This procedure, which operates within the AWIPS-Graphical Forecast Editor (GFE), facilitates the creation of all gridded forecast products while ensuring meteorological consistency between each forecast weather element. We started ScaVec development for the Medium Range Desk in spring 2017 and continued through the end of fall 2017. While we were developing the procedure, we created extensive training modules to help the Medium Range forecasters become proficient with GFE and using ScaVec in the forecast process. By early spring 2018, the Medium Range Desk started creating and submitting gridded forecast products within AWIPS using ScaVec for the contiguous United States. With WPC and WFOs now working on same platform, we have the capability to share grids interactively and collaborate before an official forecast is messaged to the public via Inter-Site Coordination (ISC).

An evening thunderstorm moves through Boulder, Colorado. Photo: Hannah Holland-Moritz/CIRES

Appendices

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
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OAR	NOAA Office of Oceanic and Atmospheric Research
PSD	NOAA ESRL Physical Sciences Division
SWPC	Space Weather Prediction Center

CIRES scientists and faculty published at least 706 peer-reviewed papers during calendar year 2017. Below, we tabulate publications by first author affiliation, per NOAA request. CIRES scientists and faculty published additional non-refereed publications in 2017, many of them listed in the pages that follow. 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 "Research Highlights: Science in Service to Society" (page 3) and detailed throughout this report.

JOURNAL ARTICLES

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
CIRES Lead Author	141	130	110	158	137	238	186	189	141	158	194	240
NOAA Lead Author	81	73	99	79	63	41	30	44	65	64	64	41
Other Lead Author	289	264	385	342	312	293	312	370	490	496	547	425
Total	**511**	**467**	**594**	**579**	**512**	**572**	**528**	**603**	**696**	**718**	**805**	**706**

Publications

JOURNALS

Acquistapace, C; Kneifel, S; Lohnert, U; Kollias, P; Maahn, M; Bauer-Pfundstein, M. (2017). Optimizing observations of drizzle onset with millimeter-wavelength radars. *Atmos. Meas. Tech.* 10.5194/amt-10-1783-2017

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Alinia, HS; Tiampo, KF; James, TS. (2017). GPS coordinate time series measurements in Ontario and Quebec, Canada. *J. Geodesy* 10.1007/s00190-016-0987-5

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Active NOAA Awards (July 1, 2017-June 30, 2018)

Record number	Description	Start date	End date	Awarded $
NA13OAR4310074	Quantification of Fossil Fuel CO2 by Source Sector Using Multi-Species Trace Gas Measurements in the INFLUX Experiment	9/1/13	8/31/17	111,786
NA13OAR4310079	Improving Carbon Tracker by Incorporating Constraints From Atmospheric O2 Measurements and Ocean Biogeochemical Tracer Data	8/1/13	7/31/17	125,415
NA13OAR4310082	Improving CarbonTracker Flux Estimates for North America using Carbonyl Sulfide (OCS)	8/1/13	7/31/18	307,488
NA13OAR4310085	Quantifying Observational Variability and Inverse Model Biases of Planetary Boundary Layer Depths and Their Impact on the Calculation of Carbon Fluxes in CarbonTracker	8/1/13	7/31/17	79,476
NA14OAR0110120	Climate Literacy and Energy Awareness Network (CLEAN) Core Activities	6/1/14	7/31/17	280,313
NA14OAR4310140	Basin-wide Top-down Estimates for CH4 Emissions from Oil and Gas Extraction using Aircraft Observations	8/1/14	7/31/18	273,691
NA14OAR4310142	Ground-based Measurements to Study Fossil Fuels Production Operations Emissions of Methane and Non-methane Hydrocarbons and their Atmospheric Impacts	8/1/14	7/31/18	496,327
NA14OAR4310251	Balancing Severe Decision Conflicts under Climate Extremes in Water Resource Management	8/1/14	7/31/18	261,689
NA15NWS4680009	Integrating Unified Gravity Wave Physics into the Next Generation Global Prediction System	5/1/15	4/30/18	468,629
NA15OAR4310103	Modeling and Data Infrastructure in Support of NOAA's Global Models	8/1/15	7/31/19	2,519,941
NA15OAR4310144	Western Water Assessment: Building Climate Resilience by Design	9/1/15	8/31/20	2,586,426
NA15OAR4310171	Snow-Atmosphere-Ice Interactions to Advance Sea Ice Predictability	8/1/15	7/31/19	549,362
NA15OAR4590160	Validation and Improvement of Microphysical Parameterizations for Better Orographic Precipitation Forecasts	9/1/15	8/31/18	249,702
NA16NWS4680016	Critical Comparison and Evaluation of Skill Scores in Support of NGGPS	9/1/16	8/31/18	400,000
NA16NWS4680021	Data Assimilation in the Vertically Extended Global Atmosphere Models of NEMS	9/1/16	8/31/19	386,820
NA16OAR4310132	Advancing the Use of Drought Early Warning Systems in the Upper Colorado River Basin	7/1/16	6/30/19	286,367
NA17OAR4590172	Use of the Stochastic-dynamic Approach in a Single Dynamic-Core Storm-Scale Ensemble for Improved Spread and Reliability of QPF and Surface Variables	8/1/17	7/31/19	193,633
OCG6128B	Intergovernmental Personnel Act Agreement	6/1/14	8/15/18	750,715
OCG6378B	Deheza NOAA IPA Intergovernmental Personnel Agreement	8/4/16	9/30/18	401,405

Personnel Demographics

CIRES PERSONNEL BREAKDOWN 2017-2018

	Total Count of CIRES employees	≥50% NOAA[1]	Highest Degree Earned for those ≥50% NOAA			
			BS	MS	PhD	no degree info.
Faculty	21	0				
Research Scientist	257	171	0	1	169	1
Visiting Scientist	10	9	0	0	9	
Postdoctoral Researcher	27	0	0	0	1	
Associate Scientist	313	200	86	91	20	3
Administrative	34	31	23	6	2	
Hourly/Undergr	93	43	0	0	0	
Grad Students	122	6	0	0	0	
GRAND TOTAL	**877**	**461**	**109**	**98**	**201**	

[1]CIRES personnel receiving 50% of more of their pay from our NOAA Cooperative Agreement (CA)

CIRES PERSONNEL IN NOAA LABORATORIES RECEIVING ANY FUNDING FROM NOAA CA

ESRL	
CSD	88
GMD	67
GSD	70
PSD	86
NCEI (NESDIS)	64
SWPC	23
NWS	3

The remainder of those receiving any funding from NOAA work in other, non-NOAA-based groups such as the National Snow and Ice Data Center

During the period June 2017 to May 2018, five CIRES employees obtained federal employment with NOAA groups in Boulder.

Project Goals for 2018-2019

AIR QUALITY IN A CHANGING CLIMATE

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

CIRES Lead: Stu McKeen / NOAA Lead: Michael Trainer

NOAA Theme: Weather-Ready Nation; Climate Adaptation and Mitigation

- Along with the retrieval data-sets provided by NUCAPS, more detailed information used to derive the retrievals, such as averaging kernels, weighting factors, and a-priori model estimates, were also provided. By applying the averaging kernel and weighting factor information to the ATom-1 data directly, uncertainties can be quantified within the retrieval algorithm, which is very useful to NUCAPS developers.
- Address the second component of this project: examine CO retrievals during specific wildfire events to assess their utility in wildfire detection, plume height determination and long-range transport. Intercepts with several wildfire plumes took place within the ATom missions, with encounters over the Pacific from Alaskan fires and encounters over the Atlantic from west African fires during ATom-1.
- The comparisons of NUCAPS retrievals with the SENEX-2013 NOAA field campaign data accomplished in the first 2 years of this project lead to a methodology for determining a lower limit to the spatial averaging required of the retrievals to derive meaningful accuracy. This methodology was limited by the number of pixels unaffected by clouds in the data originally supplied by NUCAPS for only the continental U.S. The comprehensive global data-sets provided by NUCAPS for the 2016 ATom-1 time period allows a more detailed and robust assessment of this methodology to see if retrievals of species with significant noise (e.g. CH4) can be appropriately averaged to derive useful information.

GSD-04: Improve Air Quality Predictions on Regional and Global Scales

CIRES Lead: Ravan Ahmadov / NOAA Lead: Georg Grell

NOAA Theme: Science and Technology Enterprise

Evaluate the forecast performance of FV3-GOCART by comparing with the observation data (ATom-1 data), then improve the performance to provide more realistic results which will finally be used for operational chemical weather forecast at NWS.

For chemical data assimilation:

- Further development of Ensemble Kalman Filter and variational assimilation of AOD to FV3-GOCART model:
- Further development of AOD forward operator in JEDI assimilation framework with enhancements to radiative transfer model
- Further development of forward operator for aerosol lidar backscatter assimilation
- Development of tools and assimilation scheme for aerosol reanalysis (CPO/MAPP grant year 1)
- Development of FV3-NUOPC module for CO (JPSS grant year 1)
- Development of forward operator and assimilation scheme for CO within FV3-NUOPC (JPSS grant year)

RAP/HRRR-Smoke:

- Submit the model description paper
- Transition the smoke parameterizations to the RAP/HRRR operational system at National Weather Service.
- Test and evaluate the smoke feedback on weather prediction using RAP/HRRR-Smoke.
- Conduct smoke simulations and smoke forecast verifications for case studies
- Provide smoke forecasts to the WE-CAN-C130 and BBFLUX field campaigns during summer 2018
- Presentation of the research findings in scientific conferences (international aerosol conference, AGU Fall Meeting etc.)

CLIMATE FORCING, FEEDBACKS, AND ANALYSIS

CSD-03: Scientific Assessments for Decision Makers (IPCC, MP, U.S. Climate, U.S. AQ)

CIRES Lead: Owen Cooper / NOAA Lead: David Fahey

NOAA Theme: Weather-Ready Nation; Climate Adaptation and Mitigation

TOAR will reach completion by the end of 2018, when all TOAR papers should either be published or in-press. The TOAR chairperson, Owen Cooper (CIRES), will communicate the results of the assessment report to the IGAC (International Global Atmospheric Chemistry Project) Scientific Steering Committee (SSC) at the 2018 joint 14th iCACGP Quadrennial Symposium and 15th IGAC Science Conference, to be held in Takamatsu, Japan, September 25-29, 2018. If the SSC is satisfied with the outcome of TOAR they may request that TOAR-II be initiated to provide an update on TOAR-I using more-recent data. Planning for TOAR-II would begin in early 2019.

CSD-04: Effect of Emissions on Atmospheric Composition

CIRES Lead: Carsten Warneke / NOAA Lead: Tom Ryerson

NOAA Theme: Weather-Ready Nation; Climate Adaptation and Mitigation

Scientists from CIRES and NOAA are teaming up with scientists from NASA to lead a multi-year field campaign called NOAA/NASA FIREX-AQ—Fire Influence on Regional to Global Environments Experiment–and Air Quality. As part of a newly-announced partnership, the NASA DC-8 aircraft will carry a payload of NOAA instruments together

with other groups on flights targeting western wildfires as well as agricultural and prescribed burns across the southeast United States. In addition, one NOAA Twin Otter aircraft will fly over western wildfires and prescribed fires at night, sampling emissions along the way. Another NOAA Twin Otter will measure wind fields feeding the fires.

Atmospheric Tomography (ATom) mission data analysis will be a major focus of many CIRES researchers looking at a wide variety of gases and particles in the global background atmosphere.

Measurements of emissions of VCPs will be conducted in New York City during the NY-ICE mission (New York Investigation of Consumer Emissions) in summer 2018.

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

CIRES Lead: Dimitris Papanastasiou / NOAA Lead: Jim Burkholder

NOAA Theme: Weather-Ready Nation; Climate Adaptation and Mitigation

1. Future efforts will focus on studies of the reactivity and atmospheric degradation mechanisms of different important classes of organic compounds (for example furan, substituted furan and benzene derivatives) which are emitted from biomass burning. Understanding the atmospheric fate of those compounds can be of importance to ozone and aerosol formation. Planned activities include:
   a) UV absorption and photolytic removal compounds with aldehydic or ketone functional groups (for example 2-furfural and maleic anhydride)
   b) Measure rate coefficients for NO3 and OH radical reactions
   c) Oxidation product studies with the use of a simulation chamber or an oxidation flow reactor coupled with chemical ionization mass spectrometer detection.
2. The evaluation of the atmospheric fate and climate metrics for potential replacement compounds will continue.
3. We will continue the development and characterization of the comparative total OH reactivity method.
4. Manuscripts describing the results from completed experimental work will be prepared and submitted to peer-review journals
5. The Nr and Cy methods will be applied to the calibration of the aerosol mass spectrometer (AMS).

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

CIRES Lead: Karl Froyd / NOAA Lead: Dan Murphy

NOAA Theme: Weather-Ready Nation; Climate Adaptation and Mitigation

FIREX airborne mission: As part of the FIREX-AQ mission, CIRES scientists and collaborators will conduct measurements of aerosol composition, physical properties, and optical properties in biomass burning plumes in the western US from aircraft transects. These data will used to determine the radiative properties of the plumes and the sensitivities of those radiative properties to microphysical properties of the aerosol.

Remote sampling of mineral dust and other climate-relevant aerosol (ATom airborne mission): We will compare our measured aerosol products to predictions from different global models to investigate long range transport, aerosol removal, and potential to affect cloud formation. We are preparing publications on global distributions of mineral dust, sea salt, and biomass burning aerosol. Measurement of aerosol optical properties data will be used to assess the accuracy of aerosol extinction calculated from the measured size distribution and to assess the accuracy of aerosol absorption derived from measurements of black carbon.

Advancements of Large Eddy Simulation: Use the new LEM-LES approach to understand entrainment and mixing in stratocumulus. With the bin scheme, investigate precipitation formation in shallow cumulus clouds and its response to anthropogenic biomass burning aerosol.

Physics of Stratocumulus Clouds: Investigate the role of mesoscale organization in stratocumulus clouds for the response of the cloud radiative effect to climate change, publish findings. Publish findings on empirical relationships between stratocumulus cloud radiative cooling and cloud base updraft speeds.

Network Theory Analysis and Statistical Emulation of Stratocumulus Clouds: Publish results of statistical (Gaussian) process emulation.

LASSO: Finalize in-prep publication.

Realistic Lagrangian Large Eddy Simulations: Conduct studies of aerosol-cloud interactions using measured biomass burning aerosol properties (in collaboration with the ORACLES and CLARIFY field campaigns), publish findings.

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

CIRES Lead: Troy Thornberry / NOAA Lead: Ru-Shan Gao

NOAA Theme: Weather-Ready Nation; Climate Adaptation and Mitigation

- Complete analysis of iron oxide-like particles observed by the SP2 instrument during the NASA KORUS-AQ mission to understand their sources, transport and radiative importance.
- Use SP2 data from the four deployments of the ATom mission to investigate the seasonal variation in black carbon aerosol loadings, sources and transport in the remote atmosphere over the Pacific and Atlantic Oceans.
- Complete analysis of cirrus cloud and ozone measurement made during the POSIDON mission and prepare a manuscript describing differences between convectively detrained and in situ formed cirrus.
- Complete analysis of SO2 measurements made during the POSIDON mission and prepare a manuscript describing factors controlling the transport and distribution of SO2 in the upper troposphere and lower stratosphere over the western Pacific Ocean.

- Analyze SO2 observations from the April/May 2018 deployment of the Atmospheric Tomography mission to investigate sources and processes controlling sulfur in the marine boundary layer and its role in new particle formation in the tropical free troposphere.

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

Our primary goal is, as always, to continue to maintain high quality in-situ optical measurements at all the sites in the NOAA Federated Aerosol Network (NFAN). There may be some sites added to the network (potential locations include Finland, Slovenia and Puerto Rico). The first 15 years of NFAN have proven to be of immense value to our collaborators and to the Global Atmospheric Watch (GAW) community, and so in the past year we submitted an overview paper about the NFAN to the Bulletin of the American Meteorological Society (BAMS). The BAMS manuscript is currently in revisions. Part of the success of the network is the software we've developed for it that provides unified data acquisition, data review tools and data archiving. The software continues to be improved.

Research-wise, the primary focus will continue to be the model/measurement evaluation project. A main goal for the next year will be to investigate how well global models simulate aerosol hygroscopicity and to assess proxies for f(RH) which may help inform process parameterization in the models. There are also multiple manuscripts in the works that we hope will be submitted to peer-reviewed journals in the next reporting period. There are several manuscripts currently circulating amongst co-authors (typically the last stage before submission to a journal). These cover the following topics: aerosol climatology (for sites in California, Spain, and South Africa), aerosol hygroscopicity and the model evaluation research. Papers in progress (but not quite ready to circulate!) include a manuscript studying the relationship between aerosol optical properties and aerosol elemental chemistry at NOAA's Mauna Loa observatory in Hawaii and a manuscript on autocorrelation of aerosol optical properties across the NFAN network.

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 for 2018-2019 will focus on timely and public updates of existing products and continuation of data collection in the field and laboratory.

EARTH SYSTEM DYNAMICS, VARIABILITY, AND CHANGE

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

CIRES Lead: Prashant Sardeshmukh / NOAA Lead: Cecile Penland

NOAA Theme: Science and Technology Enterprise

Complete and extend the above and related studies and submit three papers:

Sardeshmukh, P.D., J. Wang, G.P. Compo, and C. Penland: Improving forecast models by accounting for chaotic physics.

Bengtsson, L., J.W. Bao, P.J. Pegion, S. Michaelson, C. Penland, and J.S. Whitaker: A stochastic model framework for representing uncertainties in the Next Generation Global Prediction System (NGGPS) associated with unresolved flows.

Penland, C., A. Koepke, and C. Williams: A statistical analysis of vertical velocity at Darwin.

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

CIRES Lead: Darren Jackson / NOAA Lead: George Kiladis

NOAA Theme: Science and Technology Enterprise

- Complete analysis of large scale conditions and associated atmospheric rivers that resulted in extreme precipitation events along West Coast for the 2016-17 season and submit journal article describing the results.
- Publish separate journal article on winter storm conditions leading to excessive runoff above the Oroville Dam in the winter of 2016-17.
- Complete NOAA Technical Memo on assessment of physics, predictability, and impacts on extremes for 2016-17 California precipitation.
- Conduct data denial study of ENRR data impacts on GFS forecasts for North America.

PSD-23: Observe and Understand the Coupled Behavior of the Atmosphere over Land, Ocean, Ice, and Snow

CIRES Lead: Matt Newman / NOAA Lead: Chris Fairall

NOAA Theme: Science and Technology Enterprise

Two additional projects related to monsoon intra-seasonal oscillations, Oceanic Control of Monsoon Intra-seasonal Oscillations in the Tropical Indian Ocean and the Bay of Bengal (MISO-BOB) and Propagation of Intra-Seasonal Tropical Oscillations (PISTON), will be conducted from May to Oct, 2018.

Two CAPRICORN papers (one already submitted, one in preparation) will be published.

PSD-24: Enhancing Predictability of Weather and Climate Extremes

CIRES Lead: Judith Perlwitz / NOAA Lead: Martin Hoerling

NOAA Theme: Science and Technology Enterprise

Complete and extend the above and related studies and submit the following papers:

Sardeshmukh, Compo, McColl, Penland: Unexpected impacts of global warming on extreme warm spells

Sardeshmukh, Wang: Dynamic versus thermodynamic control of changes in mean and extreme precipitation.

Compo, Whitaker, Sardeshmukh, Slivinski, McColl, Spencer, and 28 others: An improved Twentieth century Reanalysis dataset (20CRv2c)

Compo, Sardeshmukh: Changes in the global overturning circulation over the 20th century

Cheng et al.: On interrelationship between drought and heatwave in past and current climate

Research: Continue research on reconciling Front Range Colorado Extreme Rainfall Likelihoods and diagnosing the role of temperature and precipitation in driving decadal droughts/low Colorado River flow. Start new research on predictability of past extreme events on S2S time scale.

PSD-26: Next-Generation Global Prediction System

CIRES Lead: Phil Pegion / NOAA Lead: Jeff Whitaker

NOAA Theme: Science and Technology Enterprise

- Expand the development and testing of physically based stochastic physics schemes to additional physical parameterization beyond deep convection.
- Improve the flexibility of the stochastic physics random pattern generator. Currently, the code is ported from the spectral version of the GFS, and does not scale across large number of processors.
- Process the FV3GFS reanalysis, and in conjunction with NCEP/EMC conduct the retrospective forecasts necessary for statistical post-processing. Plan to finish reanalysis processing by the summer of 2019.

MANAGEMENT AND EXPLOITATION OF GEOPHYSICAL DATA

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

CIRES Lead: David Neufeld / NOAA Lead: Drew Saunders

NOAA Theme: Science and Technology Enterprise

- Along with our collaborators, further develop an end-to-end data processing capability from ingest, to discovery, and access for NCEI data holdings by leveraging and enhancing existing software solutions such as Common Ingest and OneStop as well as adding new capabilities via Mission Science Network initiatives.
- Enhance geospatial services to improve discoverability and usability for NCEI's diverse datasets. Work towards consolidation and standardization of geospatial services across NCEI's locations, supporting migration to the Mission Science Network (MSN). Increase use of cloud-based services (e.g. NOAA GeoPlatform/ArcGIS Online, Story Maps).

NCEI-02: Enhancing Marine Geophysical Data Stewardship

CIRES Lead: Carrie Wall Bell / NOAA Lead: Jennifer Jencks

NOAA Theme: Science and Technology Enterprise

NCEI and CIRES staff will continue to search, acquire, and provide access to new and historical marine geophysical data (e.g., bathymetry, gravity, seismic, magnetics, water-column sonar and passive acoustic data) from NOAA and the global oceanographic community. Metadata content and data discovery capabilities, specifically in support of IOCM projects, will continue to be improved.

CIRES staff will continue to onboard new crowdsourced bathymetry data contributors and guide the development of a cloud based point storage technology system. The point store will lead to improvements in data discovery and enhance data extract and delivery functionality.

CIRES staff will continue to expand the passive acoustic data archive by incorporating a broader range of data sources and types. The PyEcholab water-column sonar data processing tool will be finalized and shared with the community for testing, feedback, and use.

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

CIRES Lead: Arnaud Chulliat / NOAA Lead: Rob Redmon

NOAA Theme: Science and Technology Enterprise

Our goals for next year are:

1) to develop, validate and release an out-of-cycle World Magnetic Model, the standard model for navigation, attitude and heading reference systems of the U.S. Government;

2) to perform simulations aimed at determining the impact of various data collection methods and instrument performances on the final accuracy of the World Magnetic Model;

3) to produce the 2019 update of the HDGM;

4) to develop new geomagnetic products aimed at supporting magnetic navigation, including high-resolution crustal field maps and models;

5) to continue research aimed at better separating geomagnetic signals from internal and external sources, focusing on ionospheric, magnetospheric and oceanic sources.

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

CIRES Lead: Nic Arcos / NOAA Lead: Kelly Stroker

NOAA Theme: Science and Technology Enterprise

CIRES staff at the NCEI will make improvements to the Historical Natural Hazards Events Database. This database is updated based on new references and new field studies. The database will have new tools, including a full upgrade to the web application, to enhance users' search capabilities.

In cooperation with the International Tsunami Information Center, several thousand images will be added to the online database and archive.

CIRES staff will build DEMs for new locations to support the NTHMP and the State of Alaska's tsunami modeling efforts. A new global model will be released which will upgrade the highly cited ETOPO1 to a higher resolution. The DEM group will continue development of high resolution tiled DEMs supporting hindcasting efforts for hurricane impacted U.S. coasts.

CIRES staff will work with the Center for Operational Oceanographic Products and Services to archive additional water level products. Methods to extract, display and archive tsunami amplitudes from time-series data will be explored. In cooperation with the PTWC, CIRES staff will add PTWC water level data to the NCEI archive. Improvements will also be made to the tide gauge data presentation by making them more interactive.

NCEI-05: Enhanced Stewardship of Space Weather Data

CIRES Lead: Juan Rodriguez / NOAA Lead: Rob Redmon

NOAA Theme: Science and Technology Enterprise

1. Release the rest of the GOES-16 space weather datasets to the public, at provisional maturity level.
2. Reprocess and release subsets of our space weather data holdings.
3. Perform calibration and validation on the MetOp-C SEM-2 data (after launch in Fall 2018).
4. Continue to make progress on BEDI projects.

NCEI-07: Remote Sensing of Anthropogenic Signals

CIRES Lead: Kimberly Baugh / NOAA Lead: Chris Elvidge

NOAA Theme: Science and Technology Enterprise

In the upcoming year CIRES staff will develop algorithms to work with the Day/Night Band (DNB) data from the VIIRS sensor onboard the newly launched JPSS-1/NOAA-20 satellite. This will yield two nightly global observations for the nighttime lights (VNL) and boat detection (VBD) products. Processing the historical VIIRS record, back to 2012, for VNL and VBD is continuing and is expected to be completed in 2019. The group also plans to resume work with the Defense Meteorological Satellite Program (DMSP) data to produce nighttime lights composites using recent data from the F15 satellite to investigate cross calibrating the recent VIIRS DNB nighttime lights products with the historical DMSP nighttime lights, which dates back to 1992. Finally, algorithm development to reduce false detections in the VBD and VIIRS Nightfire products in the South Atlantic Anomaly region is a priority.

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

CIRES Lead: Juan Rodriguez / NOAA Lead: Rob Redmon

NOAA Theme: Science and Technology Enterprise

1. Complete the necessary calibration and validation work to make the data from the rest of the GOES-16 space weather instruments to be ready for operational use.
2. Perform the initial calibration and validation work on the GOES-17 space weather instruments.
3. Support the NWS in the transition from research to operations of the GOES-R Level 2 processing algorithms.

NCEI-09: Enhanced Ionosonde Data Access and Stewardship

CIRES Lead: Justin Mabie / NOAA Lead: Rob Redmon

NOAA Theme: Science and Technology Enterprise

My primary goal for next year is to continue to support our customers with ingest and dissemination of ionosonde data.

My other goals for next year are:

- publish the paper that is complete
- publish my dissertation
- return to Puerto Rico to perform permanent field site repairs.
- prepare for installation of ionosonde at Tierra Del Fuego.
- attend URSI (Union of Radio Science International), CEDAR (Coupling, Energetics and Dynamics of Atmospheric Regions) and IUGG (International Union of Godesy and Geophysics) meetings.

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

- Publish variables thesaurus for harvesting and download. This will include a new web page providing history and background for the thesaurus, instructions for dataset contributors to

the WDS-Paleo, a document describing thesaurus governance, and access to the complete thesaurus in a standard format (e.g., SKOS or XML).

- Submit manuscript on quantitative model-data comparisons of hydroclimate in the western United States for the mid Holocene. This paper will be a proof-of-concept study detailing an approach to quantitatively reconstruct lake level and streamflow based on hydrologic models and global climate models. This is a first step towards finding additional funding to expand the concept to more paleoclimate sites across the Great Plains and Rocky Mountains.

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

CIRES Lead: Barry Eakins / NOAA Lead: Robin Warnken

NOAA Theme: Science and Technology Enterprise

In the coming year, CIRES team members will improve the Bering Sea and Eastern Gulf of Mexico regional Submission documents, including cartographic products and legal and scientific content, based, in part, on feedback from international experts.

The team will then focus on the Atlantic (East Coast) and Pacific (West Coast) regions. This will include conducting geospatial analyses to determine the base of the continental slope and foot of the slope points, as well as ECS formula, constraint, and outer limit lines. We will create cartographic products depicting the ECS data, and will develop draft Submission documents for these regions, in close collaboration with U.S. ECS Project colleagues at NOAA, the University of New Hampshire, the U.S. Geological Survey, and Department of State.

The team will also conduct ECS analyses and develop draft documents in other areas with ECS potential, particularly in the Central and Western Pacific Ocean.

NSIDC-03: Update, Improve, and Maintain Polar Region datasets

CIRES Lead: Florence Fetterer / NOAA Lead: Eric Kihn

NOAA Theme: Science and Technology Enterprise

1) Develop a cost effective method of creating gridded ice chart products suitable for remote sensing algorithm and sea ice forecast model validation.

2) Continue to maintain and improve all data in the NOAA@NSIDC collection. Publish new data products, after weighing the complexity of the data (and thus the cost in terms of time) against projected value to science.

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

CIRES Lead: Florence Fetterer / NOAA Lead: Eric Kihn

NOAA Theme: Science and Technology Enterprise

1) Continued contributions to the Team via teleconferences and response to requests for reviews or input as required actions arise.

2) Continued networking in order to better integrate NOAAs arctic data activates across offices.

REGIONAL SCIENCES AND APPLICATIONS

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

CIRES Lead: Yelena Pichugina / NOAA Lead: Alan Brewer

NOAA Theme: Weather-Ready Nation

In the next year, collaborating with other NOAA divisions we will:

- continue measurements and data analysis from all above-listed experiments and deploy lidars in new field campaigns including the Propagation of Intra-Seasonal Tropical Oscillations (PISTON) study.
- evaluate accuracy of operational, re-forecasts and retro runs of models using multi-instrument dataset from WFIP2 experiment to investigate where and when the models performed well and where and when they did not.
- analyze datasets from the Land Atmosphere Exchange Experiment (LAFE) for better understanding of physical processes including Low-level jets, moisture advection, structure of boundary layer and boundary layer turbulence.

PSD-19: Improving Wind and Extreme Precipitation Forecasting

CIRES Lead: Laura Bianco / NOAA Lead: Kelly Mahoney

NOAA Theme: Science and Technology Enterprise

- Detailed model-data intercomparison
- Use model experiments to understand processes that influence moisture transport and precipitation

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

CIRES Lead: Amy Solomon / NOAA Lead: Janet Intrieri

NOAA Theme: Science and Technology Enterprise

FY19 Goals:

In the nest fiscal year, the CAFS forecasting team will focus on:

1) Completing the 5 studies outlined in the accomplishments section.

2) Continue to work with NCEP and NWS to transition findings to improve operations.

3) Continue to work with the PMEL Arctic Heat program to advise on the deployment of ALAMO floats and will use the measurements from the floats to validate the forecasts.

4) Coordinate with the National Ice Center to make CAFS forecasts available to the international community.

5) Provide daily real-time forecasts until the end of the MOSAiC campaign (fall 2020).

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

CIRES Lead: James Scott / NOAA Lead: Michael Alexander

NOAA Theme: Climate Adaptation and Mitigation

We expect to publish two papers analyzing the results from Sang-Ik Shin's Regional Ocean Model (ROMS) climate change experiments. Working titles at this time are:

- Dynamical downscaling of future Gulf of Maine hydrographic changes.
- The influence of climate change on the ocean along the US east coast in a regional model forced by three global climate models.

Sang-Ik Shin is also doing model development work in trying to couple a biogeochemical ocean model (Carbon, Ocean Biogeochemistry and Lower Trophics, COBALT) to the ROMS model for use in climate change experiments.

A third experiment using ROMS is planned for the eastern Pacific California Current System. This ocean model experiment will use atmospheric forcing from a regional climate change experiment (Coordinated Regional Climate Downscaling Experiment, CORDEX) to assess how high resolution ocean modeling can better resolve climate change impacts on the west coast of the United States.

SCIENTIFIC OUTREACH AND EDUCATION

GSD-02: Science Education and Outreach (SOS)

CIRES Lead: Beth Russell / NOAA Lead: John Schneider

NOAA Theme: NOAA Engagement Enterprise

New software releases are planned for SOS and SOSx. For SOS, the release includes moving picture-in-a-pictures, closed captioning, and many behind the scenes improvements. For SOSx, the release will include features to improve the usability and stability of the software. Work will also be done to look at migrating the software to the web and mobile applications to improve visibility and accessibility of datasets for anyone with an Internet connection. For both software packages, work will be done to further expand the data catalogs to include highly-demanded datasets from across all fields of science.

A yearly goal is to grow the SOS Users Collaborative Network through new SOS installations, new content creators, and other partners. Another goal is to increase the SOSx installations. News about SOS and SOSx will be spread by attending workshops and conferences, and enhancing our online presence. Quarterly education webinars and SOS training webinars will continue in order to support users. Funds from the Global Systems Division Director's Discretionary Research Funds will be used to show proof of concept for an "SOS Web." We are also looking to bring on two new team members in web and software development to replace two who have moved on.

Collaboration with NWS on WAVE will continue. We will use our expertise in web development to help NWS modernize and scale WAVE beyond its current capabilities, making it easy for users to find and visualize data quickly. We will also be adding the capability for WAVE to display high-resolution datasets such as GOES-16.

Research into Big Data solutions for data processing and dissemination will be another key focus. Our goal is to develop a system that is capable of scaling across a computer cluster to efficiently process high-resolution datasets. We hope to support both complex calculations to quickly deliver insights, and data visualizations for fast data delivery.

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

- Promote the use of the Sea Ice Index web map services, now available through a geoserver, by geospatial applications meant to inform the public and policy makers.
- Support users that include the NSIDC Arctic Sea Ice News and Analysis team of scientists

SPACE WEATHER UNDERSTANDING AND PREDICTION

SWPC-01: Space Weather Information Technology and Development

CIRES Lead: David Stone / NOAA Lead: Steven Hill

NOAA Theme: Science and Technology Enterprise

Deploy the upgraded the Space Weather Prediction Center's (SWPC) Space Weather Data Store (SWDS) to operations and transition all operational readers and writers.

Code handoff and running the coupled Whole Atmosphere Model, Ionosphere Plasma Electrodynamics (WAM-IPE) in full operational-mode on the supercomputers at the National Weather Service (NWS).

Provide the lab with its first operational forecast verification system to evaluate the accuracy of 3-day forecasts with actual observations.

Continue to provide operational support for the following critical systems:

- SWPC's Public website (www.spaceweather.gov)

- NASA Advanced Composition Explorer (ACE) processor
- Deep Space Climate Observatory (DSCOVR) ground data system
- Geostationary Environmental Satellite (GOES) processor and preprocessor
- WSA-Enlil (Wang-Sheeley-Arge Model)
- D Region Absorption Predictions (D-RAP)
- Geospace Model processor
- North American Total Electron Content (NATEC) U.S. and North America products
- Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics (CTIPe) processor
- Air Force and Institute for Science and Engineering Simulation (ISES) Message Decoder (AIMED) processor
- SWPC's Microsoft SQL Server Space Weather Data Store (SWDS)

SWPC-03: Space Weather Modeling

CIRES Lead: Timothy Fuller-Rowell / NOAA Lead: Rodney Viereck

NOAA Theme: Science and Technology Enterprise

The current status is that the one-way coupld WAM-IPE with the WDAS lower atmosphere data assimilation system is running in real-time on WCOSS-Dev. The tasks that need to be completed in the next year for the model to be ready for transition include:

1. Complete the validation of the full two-way coupled WAM-IP system.
2. Remove the dependence on SMS for parallel processing.
3. Work with forecasters, users, and customers to develop and test output products.

STRATOSPHERIC PROCESSES AND TRENDS

CSD-09: Upper Tropospheric and Stratospheric Radiative, Dynamical, and Chemical Processes That Affect Climate

CIRES Lead: Sean Davis / NOAA Lead: Karen Rosenlof

NOAA Theme: Climate Adaptation and Mitigation

- Assess how climate change affects the frequency, strength, and location of stratospheric ozone intrusions in coupled chemistry-climate simulations.
- Examine the role of the stratosphere in subseasonal to seasonal (S2S) predictability.
- Study the interaction between the QBO, ENSO, sudden stratospheric warmings and long-term trends on the interannual variability of trace gas transport within the stratosphere, and from the stratosphere to the troposphere.
- Model the plume/aerosol evolution in the stratosphere of the 2017 Canadian pyro-cumulus event.
- Use a state of the art aerosol model (CARMA) embedded in a global climate model to examine aerosol processes and transport in the troposphere and stratosphere.
- Use satellite data, models, and reanalyses to better understand changes in the edge of the tropics and potential linkages between tropospheric and stratospheric circulation changes.
- Assess the role of stratospheric dynamical changes on recent variability and trends in stratospheric constituents such as ozone and water vapor.

GMD-02: Analysis of the Causes of Ozone Depletion

CIRES Lead: Irina Petropavlovskikh / NOAA Lead: Russ Schnell

NOAA Theme: Climate Adaptation and Mitigation

Dobson

Dobson reprocessing with seasonal correction will continue after the new GMI/MERRA2 data has been released in June 2018. With these new datasets, the correction period has been extended to the years 1985-2017 for most of the NOAA Dobson stations, with additional stations (i.e. Arosa, Arrival Heights, De Bilt, Hohenpeissenberg, Izana, Midi-Pyrenees, Paramaribo, etc.). This will be an ongoing evaluation and likely data archival for the seasonally-corrected Dobson historical record.

The plan is to continue with making Dobson observations and processing data from 14 NOAA sites. Barring funding shortages, we plan to repair the Dobson at Perth, swap instruments at the American Samoa Observatory and perform significant repairs to its shelter including total replacement of the door. The trip to Buenos Aires is planned for the fall of 2018 to provide support for calibration campaign of the instruments that are part of the WMO South American Region. The Dobson regional standard will be calibrated against the WNO travel standard.

NOAA is responsible for maintenance and calibration of the WMO GAW standard Dobson D083 instrument and provides calibration services to the Dobson regional calibration centers around the world. Dobson 083 is to be shipped to NOAA Mauna Loa observatory in June of 2017 for its biannual calibration check. Multiple Langley measurements will be made over an 8-week period and the results will be compared to station Dobson spectrophotometers and other spectrometers that measure total ozone column (TCO), including several Brewer products and Pandora instrument.

NEUBrew

Further analysis of the past data taken by Brewer network for studying the new UVC-7 solar blind filters will be performed. Additional test may also be performed to determine any longterm changes to the transmittance of the filters. It is also hoped that we can update the ozone calibration on some of the NEUBrew network Brewers in 2018. NEUBrewer instruments have not been compared to the WMO Toronto Brewer triad since 2014 and it will be of importance to track the degradation of the measurement system against the reference.

OzoneSonde

Routine observations at all NOAA ozonesonde sites will continue with regular flight schedules. Validation of the changes in homogenized ozone profiles will be accomplished through comparisons between ozonesondes and Umkehr profiles at several NOAA stations where both types of measurements have been routinely performed since the 1980s. A site visit to the NOAA/SHADOZ collaboration site of Watukosek, Indonesia, will occur in order to restart operations after they ceased during a political transition. NDACC and WOUDC datasets need to be completely refreshed with the new dataset, and version numbers need to be inserted in to the data files in order to track updates in the future.

The updated and homogenized longterm time series of ozonesondes will be assessed for trends under the SPARC Long-term Ozone Trends and Uncertainties in the Stratosphere (LOTUS) Phase 2 project. The assessment of ozone variability in the Upper Troposphere and Lower Stratosphere (UTLS) region will be performed using records from the NOAA ozonesonde stations. This is part of SPARC activity "Observed Composition Trends And Variability in the Upper Troposphere and Lower Stratosphere" (OCTAV-UTLS), which focuses on improving the quantitative understanding of the UTLS's role in climate and the impacts of stratosphere-troposphere exchange processes on air quality. Achieving this goal requires a detailed characterization of existing measurements (from aircraft, ground-based, balloon, and satellite platforms) in the UTLS, including understanding how their quality and sampling characteristics (spatial and temporal coverage, resolution) affect the representativeness of these observations.

Surface ozone

Data collection, processing, archival, and analyses of surface ozone will continue at 17 NOAA stations. Analyses of surface ozone variability and long-term trends will be performed.

Installation of 2b Technologies 205 ozone monitor at American Samoa Observatory will be completed. Given the unique station conditions, a heated and insulated inlet line will be installed to ensure no condensation of humid air occurs. Measurements will be resumed.

Publication of Arctic surface ozone climatology will be completed with collaboration from the International Arctic Systems for Observing the Atmosphere. An analysis of the conditions and variations from 8 measurement locations demonstrate the spatial variability of ozone in the Arctic region. In addition, analysis of the driving cause of detected longterm trends will be performed.

Global and regional model validation and assessment activities will be performed to assess the ability of models to capture ground ozone seasonal variation. In addition, data formats will be provided to ensure the ability for the modeling community to incorporate measurements for optimization of models (Community Earth Systems Model, Copernicus Atmospheric Monitoring System 84, Regional Air Quality Model Systems).

Data archiving

The Big Earth Data Initiative (BEDI) archival project for Dobson total ozone, ozonesonde profiles, and surface ozone data will continue for as long as BEDI project is active. The next step in the process is to go through the archival of the dataset. The work will involve assessment of the quality of the datasets for archival, including conformities to the required NCEI standards and policies of the data formatting.

GMD-05: Understanding the Behavior of Ozone Depleting Substances

CIRES Lead: Fred Moore / NOAA Lead: James W. Elkins

NOAA Theme: Climate Adaptation and Mitigation

This is primarily a long-term monitoring project, so the goals remain essentially unchanged, although there will be publications focused on unusual observations obtained over the past few years for important ozone-depleting gases such as methyl bromide, and follow-up studies related to the CFC-11 emission increase. The high-altitude, mission-oriented studies do evolve and as such we will be processing and submitting final data form the ATom mission, 3rd and 4th deployment. We also hope to begin work on at least one of the submitted NASA EV-3 projects.

GMD-06: Monitor Water Vapor in the Upper Troposphere and Lower Stratosphere

CIRES Lead: Dale Hurst / NOAA Lead: Russell Schnell

NOAA Theme: Climate Adaptation and Mitigation

- Continue monthly water vapor soundings with the balloon-borne NOAA Frost Point Hygrometer (FPH) at Boulder, Colorado, Hilo, Hawaii, and Lauder, New Zealand, to extend the long measurement records.
- Continue balloon launches at Boulder and Lauder in coordination with overpasses of the Stratospheric Aerosol and Gas Experiment (SAGE-III) aboard the International Space Station (ISS) to validate its measurements of stratospheric water vapor and ozone.
- Conclude the analysis and publish a peer-reviews journal paper evaluating drifts in water vapor retrievals from satellite-based sensors relative to frost point hygrometer measurements at 10 different sounding sites. The paper will become part of the Stratosphere-Troposphere Processes and their Role in Climate (SPARC) second Water Vapor Assessment (WAVAS-2).
- Publish a peer-reviewed journal paper describing the precipitous drop in tropical lower stratospheric water vapor during 2016 that was driven by the anomalous quasi-biennial oscillation (QBO) in 2015-16 and the concurrent transition of the El Niño Southern Oscillation (ENSO) from strong El Niño to La Niña conditions.

SYSTEMS AND PREDICTION MODELS DEVELOPMENT

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

CIRES Lead: Gary Hodges / NOAA Lead: Allison McComiskey

NOAA Theme: Climate Adaptation and Mitigation

Over the coming 12 month reporting period, we expect at least four ceilometers will be installed at select SURFRAD sites. Additionally, we would like to have at least three cameras installed and transmitting data to the PhenoCam network. Our local SURFRAD station, located on the southern edge of Table Mountain, will be complete refurbished this year. This site consists of much more than the SURFRAD station. It is where we conduct field calibrations, instrument testing and trials, short-term scientific studies, and hosting of guest instrumentation among many other uses.

GSD-01: MADIS (Meteorological Assimilation Data Ingest System)

CIRES Lead: Leon Benjamin / NOAA Lead: Gregory Pratt

NOAA Theme: NOAA Engagement Enterprise

Goals for next year

- Complete the MADIS 2.2 upgrade
  - Complete Clarus transition
  - 12 new providers
  - Creates ALERT providers a fast track to operations
  - SHOUT transition
  - Leverage integration of HADS into MADIS for improve efficiencies
- Transition to operations a plan to restore down providers quicker
  - Goal is less than 1 month
- Complete a plan to add new providers quicker
  - Goal is less than 3 months for existing dataset and restricted data category

GSD-03: Improving Numerical Weather Prediction

CIRES Lead: Ming Hu / NOAA Lead: Georg Grell

NOAA Theme: Science and Technology Enterprise

The code development and testing for RAPv5 / HRRRv4 will be completed, with demonstrated significant improvements in both the assimilation and forecast-model components, particularly in the analysis and forecast of clouds and a more accurate surface-energy budget in the model forecast through better representation of subgrid clouds. The new RAP/HRRR will ameliorate known issues in the RAPv4 / HRRRv3, particularly too rapid daytime clearing of low stratus at the top of surface-based cool-air layers.

An exploration will be completed, to assess the feasibility of increasing the number of vertical computational layers in RAP and HRRR, subject to the availability of NCEP computing resources. We will also examine the possibility of extending the domain of the CONUS HRRR, as well as running the HRRR-Alaska using an hourly assimilation cycle instead of 3-hourly.

Development of infrastructure needed to run the new stand-alone regional version of FV3 in cycling mode will also occur. We will then begin evaluation of the FV3 model running at cloud-allowing resolutions with RAP-HRRR physics for its suitability to replace the WRF-ARW in the HRRR. We will then implementation and conduct preliminary testing and evaluation of the RAP-HRRR physics suite in the global FV3, by evaluating performance of this suite relative to the current and advanced GFS physics suites. Work will begin to evaluate data assimilation for regional/storm-scale FV3 applications

A combined HRRR and HRRRE system is a candidate for operational implementation in 2020. HRRRE improvements and integration with HRRR in the near future will be directed toward this goal of operational implementation. Ensemble-based assimilation of satellite observations and increased ensemble spread through stochastic physics are top priorities for HRRRE development. Forecast evaluations of this system will also occur duringhydrology, aviation, winter weather, and severe weather testbeds and will help identify additional development priorities.

Will continue running 3DRTMA and including new developments to improve the analysis of cloud, visibility, PBL, and surface analysis.

The FIM-iHYCOM team has started the transition to NOAA's unified modeling. The team will collaborate with colleagues at EMC closely to help the FV3-based coupled model implementation and its application in subseasonal forecast.

The verification group will work on the development of verification tools for evaluating model ensembles and some verification tools that use satellite data. The group will begin building a MATS interface for the MET database to help the use of the MET.

GSD-05: Development of High-Performance Computing Systems (HPCS)

CIRES Lead: Eric Schnepp / NOAA Lead: Forrest Hobbs

NOAA Theme: Science and Technology Enterprise

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

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

CIRES Lead: Matthew Wandishin / NOAA Lead: Mike Kraus

NOAA Theme: Weather-Ready Nation

Goals for the year include:

- Complete Part 2 of the Global Graphical Turbulence Guidance Product assessment using an expanded study period and more extensive verification approache
- Complete Part 2 of the Ensemble Prediction of Oceanic Convective Hazards forecast evaluation for the Southern Hemisphere summer season.
- Complete the assessment of Ceiling and Visibility analyses in the context of the Helicopter Emergency Medical Services tool for both the cool season and warm seasons.
- Complete the verification plan and technique development for evaluating the Oceanic Precipitation Capability product. The actual analysis for this project will occur either near the end of next year or early the following year depending on FAA funding.
- Complete the evaluation of the High-Resolution Rapid Refresh forecasts in the context of power transmission line Dynamic Line Ratings (DLR) using Idaho National Laboratory's General Line Ampacity State Solver (GLASS) software.
- Complete the addition of forecaster-edited forecasts to the Terminal Radar Approach Control Facilities (TRACON) Gate Forecast Verification Tool (TFVT).
- Continue work on transitioning the Integrated Support for Impacted air-Traffic Environments (INSITE) Data Services to the National Centers for Environmental Prediction computer infrastructure.

Core research projects consist of investigations into neighborhood approaches for creating forecast-observation pairs or for comparing two forecast products having different native resolutions. The research will be separated into two parts: point-to-grid and grid-to-grid methods.

GSD-07: Numerical Prediction Developmental Testbed Center

CIRES Lead: Ligia Bernardet / NOAA Lead: Georg Grell

NOAA Theme: Weather-Ready Nation

1. Keep the GSI, HWRF codes used in operations and in the research and development community synchronized.
2. Assist the GSI, HWRF, and CCPP community users by providing new code releases, tutorials, updated documentation and datasets, and answering questions.
3. Support GSI, HWRF, and CCPP community developers in adding their innovations to the centralized code repository.
4. Stand up initial support for the experimental FV3-based Convective-Allowing Model.
5. Enhance the Global Model Test Bed with additional tools to diagnose the strengths and weaknesses of physical parameterizations.
6. Implement and test promising NWP developments to evaluate them for potential operational implementation.
7. Maintain and expand MERIT by upgrading the code base and adding case studies.
8. Organize a community workshop to discuss test plans and metrics for evaluation of NCEP models.
9. Publish a newsletter to inform the community of the activities undertaken by DTC.

GSD-09: Improve the AWIPS Weather Information System

CIRES Lead: Sylvia Murphy / NOAA Lead: Mike Kraus

NOAA Theme: NOAA Engagement Enterprise

The goals for each project are described in the accomplishments on page 116.

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

CIRES Lead: Joe Olson / NOAA Lead: Melinda Marquis

NOAA Theme: Science and Technology Enterprise

1) Test the potential benefit of additional higher-order tubulent moments in the MYNN-EDMF for modeling turbulence within resolved and subgrid-scale clouds. This may simply be a temporary fad within the turbulence modeling community, but if the benefits do indeed exist, we will integrate them into future operational versions of the RAP and HRRR. Primary metrics will include forecasts of ceiling, downward shortwave radiation, and precipitation.

2) Compare high-resolution simulations over complex terrain with coarse resolution simulations to assess the impact of resolved gravity waves and their associated momentum fluxes on the ambient wind profile as represented by the differences in the simulated winds at the two different resolutions. The vertical distribution of the momentum fluxes diagnosed from the high-resolution simulations, together with the differenced wind fields, will help guide the development of the gravity wave drag suite. All simulation needed for this study have already been completed. Only the analysis awaits.

3) Make improvements to the data assimilation of clouds, winds, and temperatures in complex terrain. Improved forward operators and estimated background error-covariance from the HRRR ensemble are both promising avenues of research for improving the RAP/HRRR forecast systems. As a final step, we intend to improve the dynamical balance of the initial condition in the HRRR after the data assimilation process. An improved balance helps maintain certain atmosphic features such as low-level stable layers and clouds throughout the forecast, which can otherwise be incorrectly diagnosed as model physics problems. Better data assimilation and cycling methods work hand-in-hand with better model physics to improve forecsts in a general sense.

GSD-12: NOAA Environmental Software Infrastructure and Interoperability Project

CIRES Lead: Cecelia DeLuca / NOAA Lead: Georg Grell

NOAA Theme: Science and Technology Enterprise

- Continue contributing to the development of ESMF/NUOPC community software

- Support the development of multiple applications that are part of a new Unified Forecast System (UFS) at the National Weather Service
- Advance development of a community model coupler and working with partners, deploy it within UFS
- Lead the Hurricane Supplemental Infrastructure project
- Support the migration of the community part of the ESMF/NUOPC project to NCAR

GSD-13: San Francisco Bay Area Advanced Quantitative Precipitation Information System

CIRES Lead: Leon Benjamin / NOAA Lead: Gregory Pratt

NOAA Theme: Science and Technology Enterprise

Next year we will continue to:

- Refine requirements
- Integrate data sources into the AQPI system
- Improve to the AQPI system processing
- Create an initial version of user (stakeholder) interface

GSD-14: Observing System Experiments within Rapidly-Updating NWP Systems

CIRES Lead: Eric James / NOAA Lead: Curtis Alexander

NOAA Theme: Science and Technology Enterprise

Our major goal for this period is to finally get a paper published on the non-variational cloud analysis which is used in the operational Rapid Refresh (RAP) and High-Resolution Rapid Refresh (HRRR). A draft of this paper has existed for several years, but a major effort is needed to update the results, clean up the text, and especially create new figures. This will require conducting several new cloud-analysis-related retrospective experiments (which can be considered a type of observing system experiment or OSE). We consider this a very important goal to accomplish as soon as possible, given the increasing visibility of the RAP and HRRR systems. A secondary goal is to begin investigation of setting up an adjoint-based Forecast Sensitivity Observation Impact (FSOI) capability for a regional Weather Research and Forecasting (WRF) system (i.e., applicable to the RAP and HRRR). Currently, it is largely unknown what level of effort and new coding this will require, but extensive collaborations will be required with Global Systems Division Assimilation Development Branch affiliated scientists and other external experts. We hope to at least begin making progress on this front during this period.

NWS-01: R2O at the Hydrometeorological Testbed (HMT) at the Weather Prediction Center

CIRES Lead: Joshua Kastman / NOAA Lead: James Nelson

NOAA Theme: Climate Adaptation and Mitigation

In the next year CIRES staff will continue to develop GIS visualization for Hydrometeorological Testbed (HMT) products by:

- Developing standalone, GIS webpages for the HMT experiments
- Evolving the GIS efforts by utilizing more of the analysis tools available in GIS within in the experiment in additional to the enhanced GIS displays
- Generating time enables GIS products for the testbed

Kastman also plans to work with the HMT team to publish the results of the 2018 Winter Weather Experiment in a peer-reviewed journal; the paper will feature the GIS work he has been completing

Kasman will incorporate the Winter Storm Severity Index (WSSI) into the Winter Weather Experiment and:

- Test its utility as a part of the winter weather outlook (specifically the snow amount and ice amount components)
- Explore impact based forecasting with using WSSI parameters and thresholds

NWS-02: Improving Forecaster Anticipation of Extreme Rainfall Events

CIRES Lead: Diana Stovern / NOAA Lead: James Nelson

NOAA Theme: Weather-Ready Nation

The team is currently testing a version of the EPFT that contains Flash Flood Guidance (FFG) exceedances in the short-term forecast (i.e., Day 1). The inclusion of FFG adds antecedent condition information lacking in previous versions of the EPFT. Having a table that incorporates ARIs and FFG gives the forecasters a more complete picture of the potential for flash flooding. This feature should be available Nationally in the EPFT by August 2018. There are also ongoing plans to also include ensemble-relative frequency of ARI exceedance in the EPFT and ARIT. The ensemble relative frequency will quantify model agreement by showing how likely an ARI will be exceeded in a given area based on the models selected in the table. We expect the work to be completed on this by November 2018.

Training on ARIs and use of the EPFT has been mandated by several Regions across the US (e.g., Central Region, Western Region), which helped to improve the notoriety of the EPFT. With more forecasters using it for extreme events, we have gotten excellent feedback that has prompted our team to create a survey that will eventually be used to write an arti-

cle for the Bulletin of the American Meteorological Society on the use of the EPFT in operational forecasting. We expect to submit the article by early Winter 2018.

NWS-03: Probabilistic Hazards Information R2O

CIRES Lead: Michael Erickson / NOAA Lead: James Nelson

NOAA Theme: Weather-Ready Nation

For the next year, we will continue to advance all aspects of this project towards our end goal of developing useful and calibrated probabilistic hazard information for WPC forecasters. This includes expanding both our operational and retrospective tracking to include additional experimental high-resolution models. Our goals include:

- Expand the QPF tracker internal website to include more probabilistic object attribute information with additional model data.
- Present QPF biases derived from the retrospective runs to WPC forecasters. Consider options for object-oriented bias correction of QPF and new ways to visualize model biases.
- Expand the retrospective tracking by adding more ensembles over a longer verification window and analyzing more conditional biases in the verification.
- Utilize the object-oriented bias information from the retrospective runs when ingesting QPF into the hydrologic model.

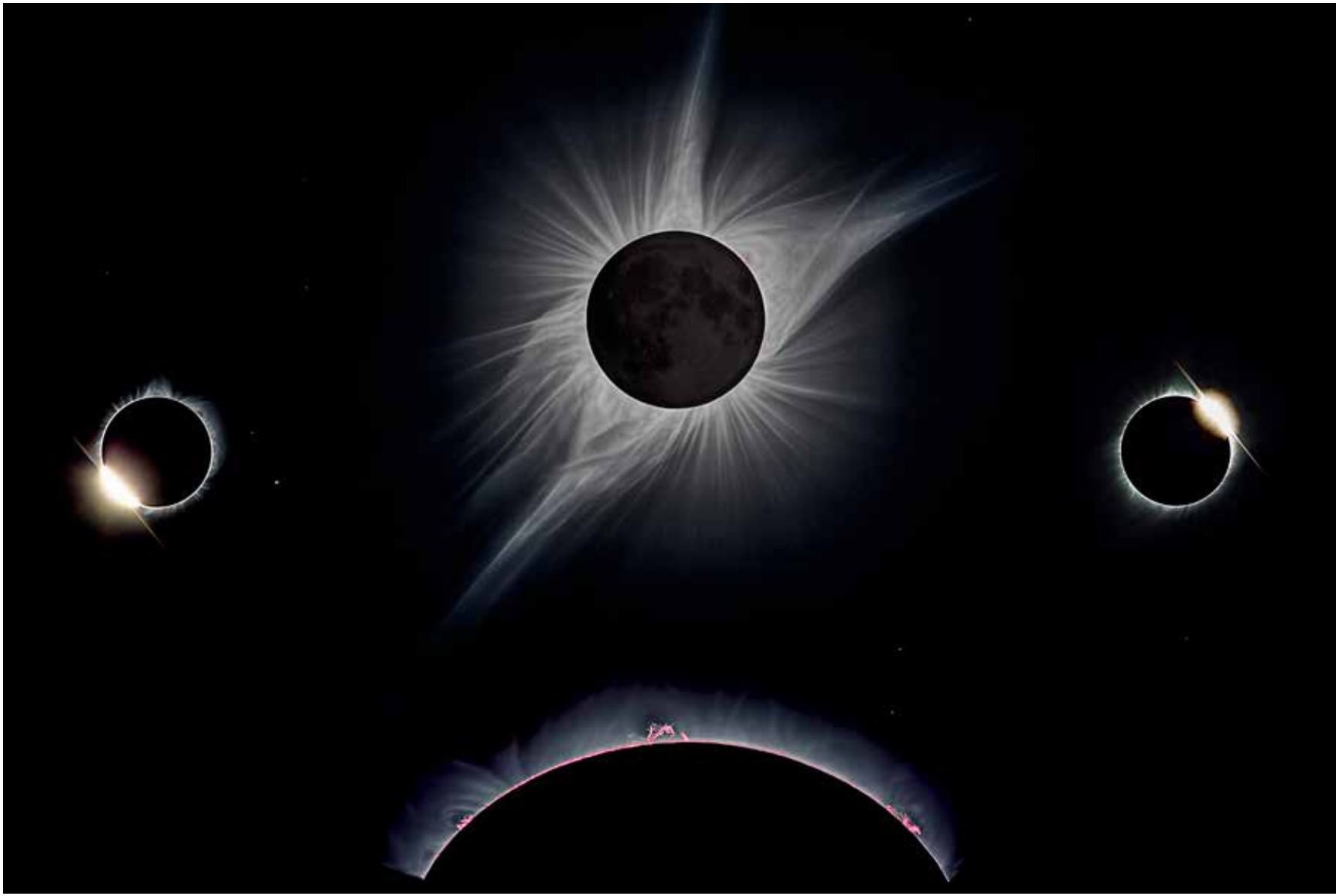
NWS-04: Smart Tool Development to Assist the Integrated Field Structure

CIRES Lead: Diana Stovern / NOAA Lead: James Nelson

NOAA Theme: Weather-Ready Nation

Our team is also actively working with the AWIPS Program Office (APO) to identify ways in which WPC can move their graphical products creation to AWIPS until a NCEP-wide solution is delivered. We are working with developers at the Global Services Division (GSD) to create WPC graphical products including the Mesoscale Precipitation Discussions, Excessive Rainfall Outlooks, and Surface Forecast Analyses. We have written use-case documents detailing ways in which AWIPS can produce these products that APO and other NCEP centers are referring to as they continue to work on an NCEP-wide solution.

Mapping the bathymetry of West Twin Lake in Rocky Mountain National Park. Photo: Victoria Arling/CIRES



Cover: Collage of the total solar eclipse as taken from Glendo, Wyoming, August 21, 2017. Images were taken with a Canon 5D Mark IV, 100-400mm lens and a 1.4x tele-extender at F11 and ISO 400. Exposures ranged from 1/500 down to 1/2 seconds. A total of 63 images were used of the totality image and 15-17 images for the outgoing and incoming diamond ring stages. Images were stacked and processed in Photoshop with the totality images slightly enhanced with a layer processed with NAFE, a solar image analysis package. Photo: Timothy Dunn/CIRES