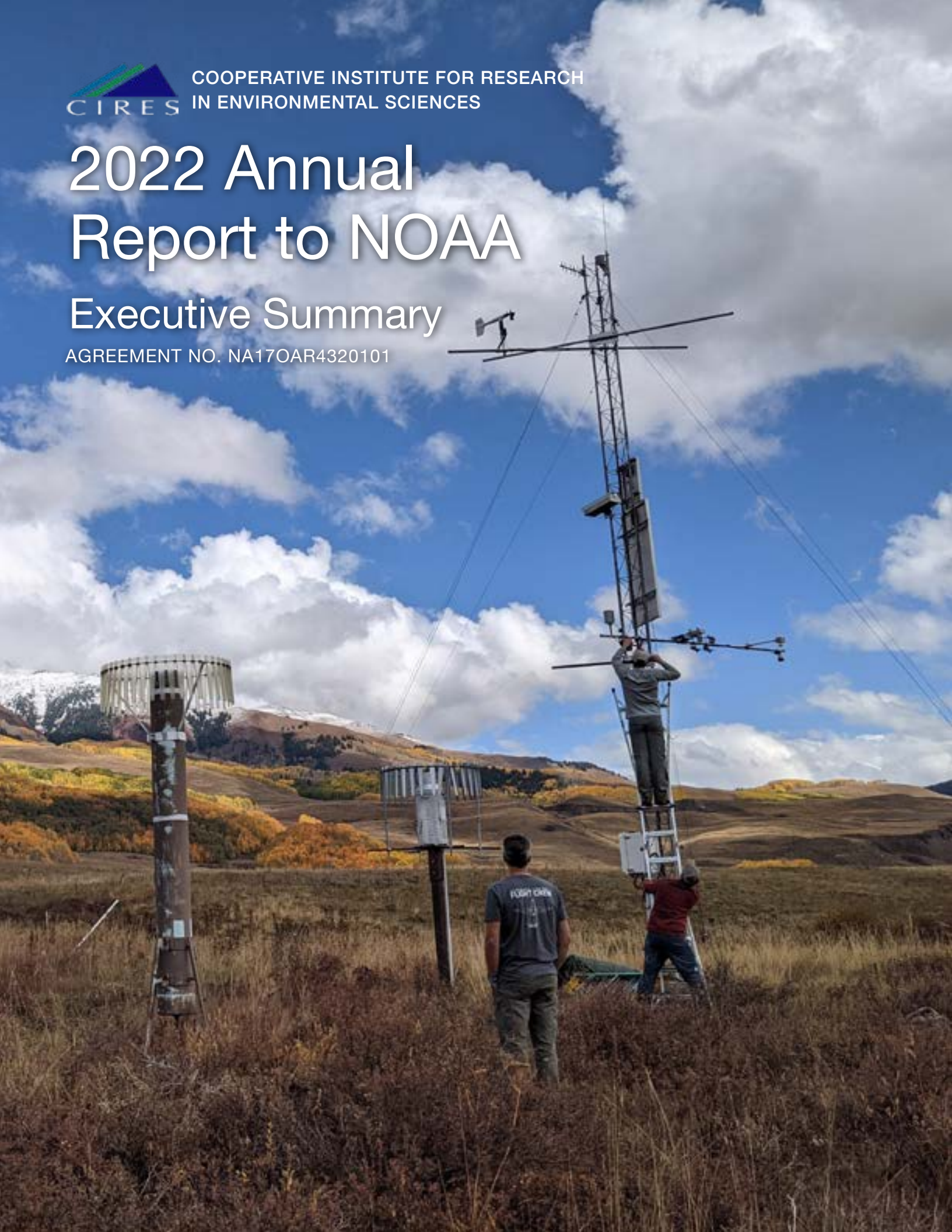


COOPERATIVE INSTITUTE FOR RESEARCH
IN ENVIRONMENTAL SCIENCES

2022 Annual Report to NOAA

Executive Summary

AGREEMENT NO. NA17OAR4320101

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 1967. CIRES brings together scientists from 10 CU Boulder departments (Atmospheric and Oceanic Sciences, Geological Sciences, Chemistry, Ecology and Environmental Biology, etc.) and several NOAA line offices (Research, Satellites, Weather) to explore all aspects of the Earth system. These partnerships encourage innovation, rapid-response capabilities and an interdisciplinary approach to complex environmental challenges. CIRES helps strengthen the scientific foundation upon which NOAA's environmental intelligence services depend, and our partnership with NOAA allows coordinated studies on a scale that could not be undertaken by university research units or NOAA alone.

In 2021-2022...

Total funding for CIRES was more than $86 million in FY 2022, thanks in part to proposal writing by CIRES scientists who achieved a 51 percent success rate the previous fiscal year—for grants from NOAA, the National Science Foundation, NASA, the U.S. Geological Survey and other sponsors. Our current NOAA Cooperative Agreement funds almost half of the CIRES research enterprise, and the achievements highlighted in the following pages derive primarily from that work in support of NOAA's mission.

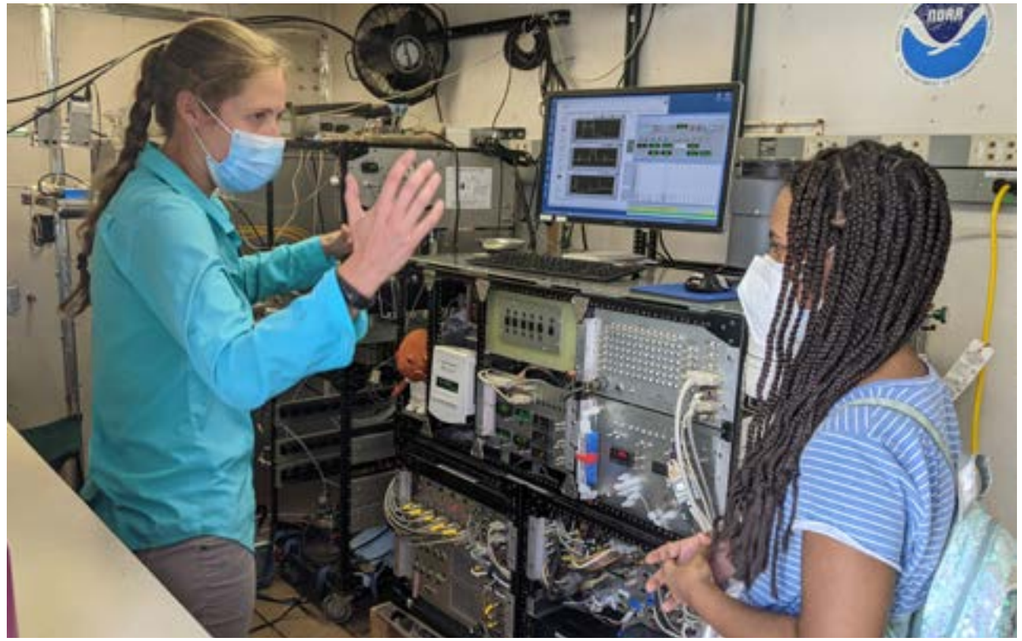
NOAA PARTNERS

CSL: NOAA Chemical Sciences Laboratory
GML: NOAA Global Monitoring Laboratory
GSL: NOAA Global Systems Laboratory
NCEI: NOAA National Centers for Environmental Information
PSL: NOAA Physical Sciences Laboratory
SWPC: NOAA Space Weather Prediction Center
WPC: NOAA Weather Prediction Center

COVER IMAGE: Researchers install a flux tower as part of an observation network to measure conditions such as wind speed and direction, moisture and temperature. The goal of this project is improved prediction of weather and water in the Colorado mountains and beyond to inform societal preparedness and response. Photo: Janet Intrieri/NOAA

IMAGE ABOVE: Researchers pause for the camera while they perform repairs and maintenance on an Atmospheric Surface Flux Station during the MOSAiC expedition in the central Arctic in 2021. Photo: Dave Costa/CIRES

Science in Service to Society, 2021-2022



CIRES and NOAA scientist Chelsea Stockwell explains the workings of instruments in the CSL Mobile Laboratory to a visitor during the 2021 SUNVEx field campaign. Photo: Chelsea Thompson/ NOAA

WEATHER-READY NATION

CIRES science helps society better respond to weather-related events, reducing loss of life and property, and improving transportation safety and understanding of human health and air quality.

- Following the 2021 Marshall Fire, CIRES scientists in CSL sampled outdoor air and worked with the Colorado Department of Public Health and the Environment to quantify possible risk to residents. Preliminary results showed pollutant concentrations around the burned neighborhoods were similar to levels seen in urban areas.
- CIRES scientists in PSL used machine learning to improve fire weather forecasting and provide skillful 8-14 day guidance. Other researchers in PSL developed statistical techniques to improve precipitation forecasts, so forecasters can help water managers decide whether to retain or release water from reservoirs when heavy rain threatens life or property.
- In WPC, CIRES scientists improved forecasts and developed situational awareness tools for extreme weather events. They updated the Extreme Precipitation Monitor, which puts forecasted precipitation into a historical context—for example, relative to a 100-year storm. Researchers also updated the Excessive Rainfall Outlook, which forecasts the probability that rainfall will exceed flash flood guidance within 25 miles of a location.
- In GSL, CIRES scientists provided decision-support services for users evaluating weather forecasts and observations. The team created a new system and integrated it into NWS services supporting emergency personnel and public safety officials when weather impacts lives and livelihoods.
- CIRES scientists in SWPC completed a NOAA-NASA critical design review for the Space Weather Follow-On (SWFO) Program. Scheduled to launch in 2025, SWFO will replace observations from the U.S.'s and Europe's aging fleets of space weather satellites.

CLIMATE ADAPTATION AND MITIGATION

CIRES research improves critical understanding of Earth's changing climate, informing society and allowing decision makers to anticipate and respond.

- In GML, CIRES scientists published a follow-up investigation into the 2010-2018 increase in emissions of CFC-11, a banned ozone-destroying chemical, finding that three Asian regions were responsible for the rising emissions. Researchers also collected global stratospheric ozone data to track ozone layer recovery and to support international assessments including the WMO/UNEP *Scientific Assessment of Ozone Depletion: 2022.*
- CIRES scientists in GML provided atmospheric emissions estimates of four major hydrofluorocarbons, important greenhouse gases, to the U.S. EPA for inclusion in the U.S. Inventory of

Chris Guiterman, now with CIRES, extracts a tree-ring sample from a fire-scarred pine stump in Navajo Nation in Arizona. Photo: Rebecca Brice/USGS

Greenhouse Gas Emissions and Sinks, and they produced key radiation datasets that improve weather models for forecasting solar and wind energy.

- In GML, CIRES scientists supported the modernization of NOAA's Barrow Atmospheric Baseline Observatory, moving all instruments to a new facility in 2021, and they evaluated overlapping measurements at the sites in Utqiaġvik (formerly Barrow) to determine that the observatory move would not impact the long-term time series.
- In CSL, CIRES scientists projected impacts of future space traffic on the stratosphere, finding that black carbon pollution due to increased rocket launches would likely warm the stratosphere, disrupt the jet stream and increase ozone depletion. CIRES researchers also developed near real-time vehicle emissions inventories of carbon dioxide and other pollutants under business-as-usual and COVID-19 scenarios and made the inventory available to scientists and regulators.
- CIRES scientists in NCEI's World Data Service for Paleoclimatology provided data supporting several key conclusions in the 2021 IPCC Working Group I report, including the finding that atmospheric carbon dioxide concentrations are higher now than at any time in the past 2 million years.
- In PSL, CIRES scientists developed ocean models that produce high-resolution hindcasts and predictions of marine heat waves, critical information for NOAA Fisheries managers. Researchers also used modeling to predict summer habitat loss in 2100 for blue sharks along the U.S. East Coast, from Florida to Cape Cod.

SCIENCE AND TECHNOLOGY ENTERPRISE

CIRES develops innovative research approaches to understand the connection between human prosperity and Earth system changes.

- In GSL, researchers continued developing the Rapid Refresh Forecast System (RRFS), NOAA's next-generation data assimilation and forecast system, and improved forecasts of haz-ards to air and ground transportation, reducing damage from life-threatening weather.
- CIRES researchers in GSL improved predictions of wildfire smoke transport (HRRR-Smoke), supporting air quality forecasts provided by NOAA to the public. They also worked to integrate smoke (and eventually dust) forecasting into the RRFS.
- CIRES scientists in NCEI archived and made accessible a va-riety of atmospheric, coastal and geophysical data important to serve fisheries managers, tsunami warning centers and experts negotiating the extent of the U.S. Continental Shelf. The team also advanced the NESDIS Cloud Archive Project, a pilot effort to archive data services in the cloud.
- In NCEI, CIRES scientists provided software that SWPC uses to process GOES-R satellite data for real-time space weather monitoring, forecasting and alerts; continued developing the Space Weather Follow-On Science Center to disseminate satellite products; and transitioned space weather models to NOAA operations to support satellite communications and navigation.
- CIRES scientists in PSL extended the NOAA-CIRES-DOE 20th Century Reanalysis version 3 back to 1818, including more than 70 additional variables related to hydroclimate, renewable energy and ocean and land modeling, improving understanding and prediction of extreme weather and climate events.

NOAA ENGAGEMENT ENTERPRISE

CIRES helps NOAA meet the increasingly complex needs of its stakeholders by delivering data and knowledge and by engaging with users to better understand research needs.

- In GSL, CIRES scientists worked with forecasters to improve the Meteorological Assimilation Data Ingest System (MADIS), adding data from public and private sources to improve decision-support services. Despite reduced data during the pandemic, the team maintained MADIS' high observation count and added thousands of new mesonet sites.
- CIRES scientists in GSL also continued to develop the "Threats in Motion" tornado and thunderstorm warning system, and modernized tsunami warning systems.
- NSIDC, part of CIRES, produced short-term sea ice forecasts, indices and other products to aid in Arctic and Antarctic navigation, serving NOAA, the U.S. Navy, scientific and commercial expeditions and more. These products were featured in the *BAMS* 2020 State of the Climate report and NOAA's 2021 Arctic Report Card (ARC). At the 2021 AGU press conference on the ARC, researchers discussed how rapid human-caused warming continues to drive Arctic changes such as ice loss and warmer, wetter polar conditions.

Diversity & Inclusion

CIRES is committed to increasing diversity and inclusion in environmental sciences and geosciences and plays a key leadership role in the university's diversity and inclusion initiative. Our 2021-22 efforts include:

- recruiting at conferences for under-represented scientists, including the American Indian Science and Engineering Society, the National Association of Black Geoscientists and the NOAA EPP/MSI Forum;
- leading activities within the CU Boulder Inter-Institute DEI Working Group, which established professional development, resources and affinity groups for CU Institute members;
- hosting the Society of Latinxs/Hispanics in Earth and Space Sciences;
- leading the AGI Standing DEI Committee and the Inter-society DEI Committee;
- developing resources and training for supervisors; and
- implementing strategic initiatives for diversity, equity and inclusion across CIRES.

Aerial photo shows sea ice surrounding the *RV Polarstern* during the MOSAiC expedition in 2020. Photo: Gina Jozef/CIRES

CIRES Education & Outreach Program

The CIRES Education & Outreach Program provides programming and engagement opportunities across the spectrum of geosciences and environmental education, including professional development for teachers, digital learning resources, student programs, workforce development and program evaluation, mentoring opportunities, engagement training for scientists and support for early career scientists and more. Some highlighted projects from 2021-2022 are below.

- **Research Experiences for Community College Students (RECCS):** A cohort of 18 community college students conducted research at CIRES and NOAA, experiencing a summer of immersion into scientific research. RECCS has served nearly 100 community college students from across Colorado and just received a renewal from NSF for another five years. Students are diverse along many dimensions, including first-generation college attendees, people of color and veterans.
- **Drifting North Polar Planetarium Program at CU Boulder's Fiske Planetarium:** Dozens of students and community members visited CU Boulder's Fiske Planetarium to learn about the MOSAiC expedition through a film and hands-on activities.
- **Climate Literacy & Energy Awareness Network (CLEAN, CLEANet.org):** The award-winning CLEAN collection provided peer-reviewed climate and energy education resources to educators around the globe. The team improved and launched new materials, which are being syndicated by NOAA's Teaching Climate, the National Science Teaching Association and OER Commons. Their professional development webinars and newsletters provide ongoing and timely support for educators. The vibrant CLEAN Network serves 900+ climate literacy professionals across the country with weekly telecons and an email list.
- **Science On a Sphere® (SOS):** CIRES scientists and educators on the SOS team, now housed with CIRES Education & Outreach, launched a new website and completed over a dozen new SOS® and SOS Explorer® installations in the United States, Canada, Croatia and beyond. An estimated 66 million people visited facilities with SOS® installed, and the free SOSx® Mobile app was downloaded thousands of times.

Community college students from all over Colorado hike with ecology and evolutionary biology researchers near the CU Boulder Mountain Research Station during the 2022 RECCS program. Credit: Katie Weeman/CIRES

Students from the Citrus Community College Pathways to STEM program interact with Science on a Sphere® at the Fiske Planetarium in June 2022. Credit: Rebecca Batchelor/CIRES

Selected Awards 2020-2021

HIGHLY CITED

Clarivate Analytics named five CIRES scientists as 2021 "highly cited researchers," placing them among the one percent most cited in their fields: **Noah Fierer, José-Luis Jiménez, Jonathan Leff** (formerly CIRES), **Jennifer Kay** and **Julienne Stroeve**.

CIRES OUTSTANDING PERFORMANCE, SCIENCE

- **Rochelle Worsnop (PSL)** for the scientific development, demonstration and technology transfer of a one- to two-week forecast of fire weather potential—an agency first
- **Mike Hobbins (PSL)** for leadership and innovation in life- and property-saving drought research, including developing and operationalizing the Evaporative Demand Drought Index
- **Zhe Peng (CU Boulder Chemistry)** for world-class excellence in atmospheric chemistry research including the airborne transmission of COVID-19

CIRES OUTSTANDING PERFORMANCE, SERVICE

- **Kevin Beam, Michael Brandt, Daniel Crumly, Matt Fisher, Agnieszka Gautier, Jonathan Kovarik, Audrey Payne, Matt Savoie, Trey Stafford and Troy Williams (NSIDC)** for high-impact work communicating—with the scientific community and the general public—how the cryosphere is changing and why it matters
- **Veronica Martinez (NCEI)** for a pivotal role in a NOAA data rescue project saving priceless environmental data collected by the agency's research ships
- **Katie Boyd, Gina Fiorile, Alicia Christensen, Naomi Elaine Ochwat, Casey Lea Marsh and Daniela Pennycook (E&O)** for promoting scientifically accurate educational materials around climate, making CLEAN the national go-to resource for teachers and educators

CIRES BRONZE MEDALS

(recognizing CIRES people and teams whose federal counterparts earned NOAA Bronze Medals):

- **Ed Gille,** a scientist in NCEI, for implementing a repeatable process to certify scientific data services as trusted sources of information to the international community
- **A team in PSL,** for the development of a fully coupled, ocean-ice-atmosphere model that delivers daily, 0-10 day, sea ice forecast guidance to the NWS Alaska Region
- **A team in GSL,** for improving lake-effect snow and ice forecasts through a rapid transition of an innovative coupling of weather and coastal hydrodynamic models
- **A team in GSL,** for the development of the Global Ensemble Forecast System - Aerosols (GEFS-Aerosols) model to support air quality alerts and visibility forecasts
- **Eric Schnepp**, a scientist in GSL, for the successful transition and award of a $553 million High Performance Computing Integrator contract three months ahead of schedule with no protests

CIRES ADMINISTRATOR'S AWARD

- **A team in GSL**, for completion of the High-Resolution Rapid Refresh weather model project that improves forecasts and warnings for high-impact weather events

Publications & Media

In the past year, CIRES scientists published their findings in 679 peer-reviewed papers in dozens of different journals, such as *Nature, Science*, the AGU journals and many others. CIRES scientists, faculty and students also authored hundreds of other publications in 2021, including datasets, white papers, reports and books. CIRES researchers are increasingly reaching diverse audiences through The Conversation (TC), an innovative online news outlet that syndicates with other outlets around the world. This year, CIRES scientists wrote six essays (two featuring NOAA science) that collectively earned nearly 1.5 million "reads" in TC.

CIRES makes a robust effort to share the institute's research findings and implications with the scientific community, decision-makers and the public. During this reporting period, communications efforts included dozens of news releases, media relations, videos, social media campaigns, blogs, participation in virtual conferences and more. CIRES scientists and research earned coverage in *The New York Times, Associated Press, Discover,* CNN, NPR, BBC, *The Hill, USA Today, The Washington Post, The Guardian, Forbes,* Reuters and many other local, national and international media outlets. For example, CIRES/NSIDC researchers Twila Moon and Matt Druckenmiller helped author and edit the annual NOAA Arctic Report Card, and Twila Moon participated in a press conference about it. The Arctic Report Card garnered press attention from many outlets including *The New York Times*, NPR and Gizmodo.

Below are a few news stories, published between June 1, 2021 and May 31, 2022, highlighting research papers that earned so much online attention, Altmetric scored them in the top five percent of all research outputs.

- It's Not Just SARS-CoV-2: Most Respiratory Viruses Spread by Aerosols
- Majority of Climate Change News Coverage Now Accurate
- Hotter, Drier Nights Mean More Runaway Fires: CU Boulder Study
- Air Pollution from Wildfires, Rising Heat Affected Two-Thirds of U.S. West
- Risky Development
- Warmer Clouds, Cooler Planet

CIRES graduate student researchers take soil samples to test for contamination near burned homes in Louisville, CO after the Marshall Fire. Photo: Katie Weeman/CIRES

CIRES COUNCIL OF FELLOWS

The Council of Fellows is the 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. The 37 Fellows below were active between June 1, 2021 and May 31, 2022.

Waleed Abdalati
CIRES Director; Professor of Geography

Jennifer Balch
Director, Earth Lab and the North Central Climate Adaptation Science Center; Associate Professor of Geography

Stanley G. Benjamin
Senior Scientist for Advanced Modeling Systems, NOAA Global Systems Laboratory

Roger Bilham
Professor Emeritus of Geological Sciences

Maxwell Boykoff
Director, Environmental Studies Program; Professor of Environmental Studies

Eleanor C. Browne
Assistant Professor of Chemistry

Matthew Burgess
Assistant Professor of Environmental Studies

John Cassano
Professor of Atmospheric and Oceanic Sciences

Xinzhao Chu
Professor of Aerospace Engineering Sciences

Shelley D. Copley
Professor of Molecular, Cellular and Developmental Biology

Joost de Gouw
Professor of Chemistry

Lisa Dilling
Professor of Environmental Studies

G. Lang Farmer
Associate Dean for Natural Sciences; Professor of Geological Sciences

Graham Feingold
NOAA Research Scientist, Chemical Sciences Laboratory

Noah Fierer
Director, Center for Microbial Exploration; Professor of Ecology and Evolutionary Biology

R. Michael Hardesty
CIRES Senior Research Scientist

José-Luis Jiménez
Distinguished Professor of Chemistry

Craig H. Jones
Professor of Geological Sciences

Kris Karnauskas
Associate Professor of Atmospheric and Oceanic Sciences

Jennifer Kay
Associate Professor of Atmospheric and Oceanic Sciences

Ben Livneh
Director, Western Water Assessment; Assistant Professor of Civil, Environmental and Architectural Engineering

Peter Molnar
Distinguished Professor of Geological Sciences

Stephen A. Montzka Research Chemist,
NOAA Global Monitoring Laboratory

William D. Neff
CIRES Senior Research Scientist, NOAA Physical Sciences Laboratory

R. Steven Nerem
Professor of Aerospace Engineering Sciences

Balaji Rajagopalan
Professor of Civil, Environmental and Architectural Engineering

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

Anne F. Sheehan
Professor of Geological Sciences

Robert E. Sievers
Emeritus Professor of Chemistry

Kristy Tiampo
Director, Earth Science and Observation Center; Professor of Geological Sciences

Margaret A. Tolbert
CIRES Associate Director; Distinguished Professor of Chemistry

Gregory Tucker
Professor of Geological Sciences

Veronica Vaida
Professor of Chemistry

Rainer Volkamer
Professor of Chemistry

Carol A. Wessman
Professor of Ecology and Evolutionary Biology

Michael Willis
Assistant Professor of Geological Sciences

Paul Ziemann
Professor of Chemistry

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