



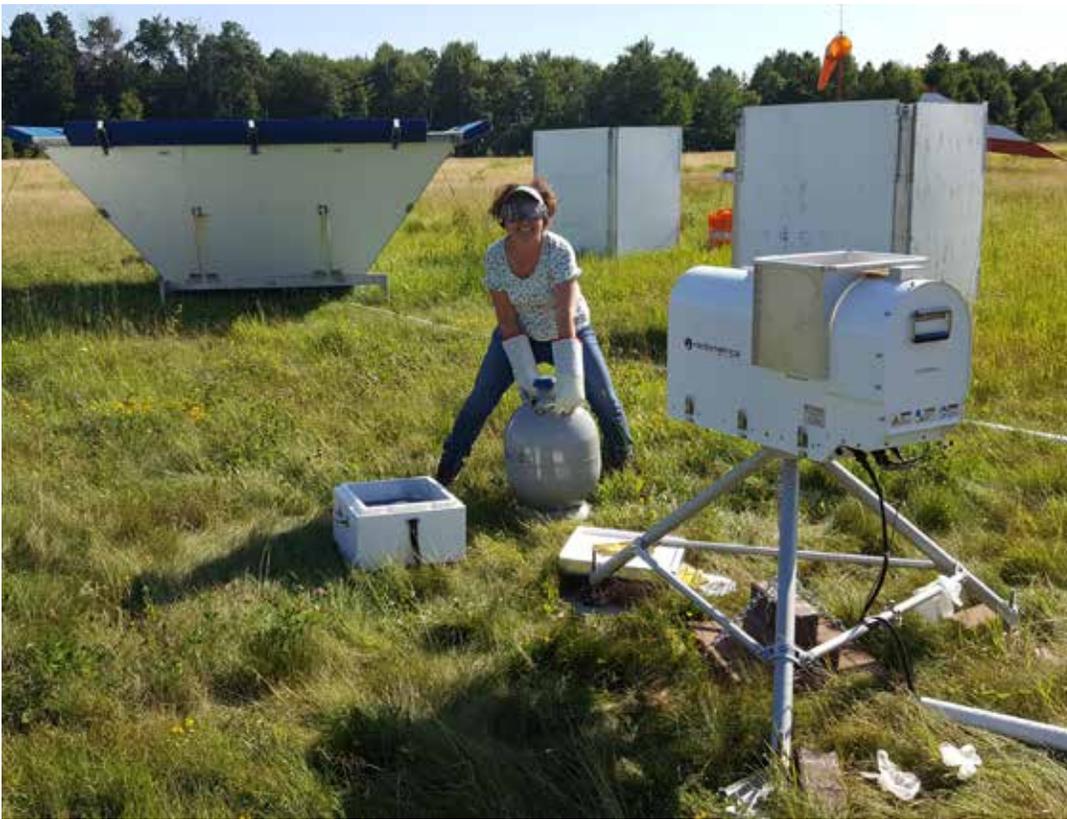
COOPERATIVE INSTITUTE FOR RESEARCH
IN ENVIRONMENTAL SCIENCES

2021 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. Our purpose is to support NOAA’s mission by furthering research that crosscuts traditional scientific fields. CIRES brings together scientists from 10 CU Boulder departments (Atmospheric and Oceanic Sciences, Geological Sciences, Chemistry, Economics, 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 2020-2021...

CIRES total funding was more than \$92 million in FY21, thanks in part to proposal writing by CIRES scientists who achieved a 44 percent success rate the previous fiscal year. Our current NOAA Cooperative Agreement, a competitive award re-bid every 10 years, funds about half of the CIRES research enterprise; most of the rest is from the National Science Foundation, NASA, and other federal science sponsors. In the following pages, we highlight some of the many accomplishments achieved in support of NOAA’s mission through Cooperative Agreement funding.

CIRES DIVISIONS

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

CIRES CENTERS AND PROGRAMS

- Center for Microbial Exploration
- Earth Lab
- Earth Science and Observation Center
- Education & Outreach
- International Global Atmospheric Chemistry Project
- National Snow and Ice Data Center
- North Central Climate Adaptation and Science Center
- Western Water Assessment

OTHER INSTITUTIONAL PROGRAMS

- Diversity and Inclusion
- Graduate Student Research Awards
- Innovative Research Program
- Integrated Instrument Development Facility
- Undergraduate Research Opportunities Program
- Visiting Fellows Program

COVER IMAGE: Photographic time series captures an ozonesonde balloon launch from Boulder’s Marshall Mesa Field Site. The balloon rises to more than 30 km (100,000 feet) above the surface while sending measurements of atmospheric ozone and meteorological data back to a ground station. Photo: Patrick Cullis/CIRES

THIS PAGE: Preparing to calibrate a microwave radiometer deployed for the 2019 CHEESEHEAD field campaign in Wisconsin. Photo: Laura Bianco/CIRES

Science in Service to Society, 2020-2021



Smoke rises from the Calwood Fire as it nears homes in Boulder County, Colorado, in October 2020. Photo: Malachi Brooks/unsplash

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.

- CIRES scientists in GSL design and evaluate tools to help aviation managers assess weather-related threats to aviation. This year, the team provided critical support for several products to become operational within the Federal Aviation Administration, with the overall goal of producing better aviation forecasts, more comfortable and shorter flights, and lower costs and emissions.
- In WPC, CIRES scientists updated two tools that improve how forecasters get information about heavy precipitation; one, the Extreme Precipitation Monitor, transitioned into operations in June, 2021. CIRES scientists also developed web pages to help forecasters and emergency managers better anticipate the threat of extreme or record-breaking weather events, and to put those events into context.
- CIRES scientists in WPC also worked to improve forecasts of hazardous weather events: Their Winter Storm Severity Index became operational for the contiguous United States in Fall, 2020, and they completed the Flash Flood and Intense Rainfall experiment.

- CIRES scientists in CSL studied the transport of smoke and its impact on air quality and climate, using NOAA-NASA FIREX-AQ data to improve NOAA's public air quality forecasts. During the COVID-19 shutdowns, a CSL team studied changes in emissions and urban air quality due to decreased traffic and economic activities; another found a temporary decline in levels of many common pollutants.
- In SWPC, CIRES scientists managed the transition of critical data processing necessary for space weather forecasts from the National Solar Observatory to NOAA Space Weather Prediction Center operations. They also continued developing ground stations and software to support a 2024 space weather satellite launch.

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 documented a decline in emissions of the ozone-depleting compound CFC-11, following their earlier discovery of an unexpected global increase in CFC-11 emissions and evidence that China was violating the Montreal Protocol. Their work was published in the journal *Nature*.

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During the year-long MOSAiC expedition, CIRES scientists in PSL collected data describing sea ice and other components of the Arctic environment. The scientific impact of MOSAiC on our understanding of the Arctic atmosphere, cryosphere, oceanography, and biology will be lasting and significant. (PSL-23) Photo: Lianna Nixon/CIRES

- CIRES scientists in GML continued greenhouse gas measurements during the COVID-19 shutdown and analyzed measurements made in 2020, finding that levels of carbon dioxide and methane continued to rise in 2020 despite the pandemic.
- During the NASA Atmospheric Tomography field campaign, CIRES scientists in CSL studied biomass burning smoke and the formation of new particles. They found that faint, old smoke that had dissipated into remote areas of the planet influences climate significantly—as much as the thick plumes produced by active fires.
- In NCEI, CIRES scientists partnered with the National Integrated Drought Information System (most staff in NIDIS are CIRES employees) to develop and archive data for the Living Blended Drought Product, which documents U.S. continental drought conditions from the last 2000 years and informs our understanding of current and future drought risk.
- CIRES scientists in GML developed an instrument that will be installed on U.S. commercial aircraft to regularly measure greenhouse gases, and installed instruments in the new Barrow Atmospheric Baseline Observatory near Utqiagvik, Alaska.
- In PSL, CIRES scientists found that marine heatwaves are becoming more extreme and frequent as the surface layer of the ocean thins, leaving waters more susceptible to warming. The researchers reported their work in the *BAMS* “Explaining Extreme Events of 2019” report.

SCIENCE AND TECHNOLOGY ENTERPRISE

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

- CIRES scientists in GSL and PSL helped develop the NOAA coupled Unified Forecast System (UFS), including the 2021 re-release of the UFS Short-Range Weather Application, new aerosol components to improve air-quality predictions, and a new tool that improves how snow data, such as snow aerial coverage and depth, are assimilated into the model.
- CIRES scientists in GSL contributed to the upgraded RAPv5/HRRRv4 weather models, which transitioned to NWS operations in 2020, improving national forecasts at storm scale and for renewable-energy applications. This upgrade also included the CIRES-developed HRRR-Smoke tool for smoke forecasts and predicting the impact of smoke on weather; the model is used widely in news reporting.
- In GSL, CIRES scientists examined whether fewer aircraft-based weather observations during the COVID-19 shutdown affected the accuracy of NOAA’s short-term weather model, finding a reduction in short-range forecast skill (temperature, winds, and relative humidity) of about 12 percent.
- CIRES scientists in NCEI archived and made accessible a variety of atmospheric, coastal, and geophysical data, including

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SCIENCE AND TECHNOLOGY ENTERPRISE

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multibeam bathymetry data, water-column sonar data, and space weather data. CIRES scientists have helped NCEI make publicly available more than 24 million files.

- In NCEI, CIRES scientists are critical members of the group helping NOAA develop data processing, calibration, validation, and archiving for the future Space Weather Follow-On satellite. CIRES scientists also support the international Aeolus space wind Doppler lidar initiative, providing data for studies of how winds affect jet streams, gravity waves, and stratospheric dynamics, and helping improve weather forecasts, including for cyclones.
- CIRES scientists in PSL are improving assessments of extreme weather and climate events with the NOAA-CIRES-DOE 20th Century Reanalysis version 3. This long-term, global atmospheric dataset of weather places current weather into a historical context. The new release includes more than 70 additional observations related to hydroclimate, renewable energy, and ocean and land modeling, going back to 1861.

NOAA ENGAGEMENT ENTERPRISE

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

- CIRES scientists in GSL worked with weather forecasters to improve decision-support products. They upgraded the Meteorological Assimilation Data Ingest System, which runs operationally at the NWS, to include new data providers and mesonet sites, and improved the “Threats in Motion” software to provide continuous warnings as hazards such as tornadoes and thunderstorms move across warning area boundaries. Their Hazard Services’ winter weather products will be operational nationwide in Fall, 2021.
- CIRES scientists and educators on the NOAA Science On a Sphere® (SOS) team developed new ways to reach audiences during the pandemic, using SOS Explorer® to deliver remote science presentations, and running an SOS Users Collaborative Network Workshop for over 200 participants, soliciting feedback and sharing ideas. The team also reached 25,000 SOS Explorer® Mobile downloads, with about 5,000 active monthly users.
- The National Snow and Ice Data Center, part of CIRES, produces short-term sea-ice forecasts, indices, and other products used in the *BAMS* 2019 *State of the Climate* report and NOAA’s 2020 *Arctic Report Card*. These products are widely covered in the media; more than 100 people attended the 2020 AGU Fall Meeting virtual press conference on NOAA’s *Arctic Report Card*, featuring a CIRES/NSIDC panelist, generating 67 news stories.

Publications and Media

PUBLICATIONS:

CIRES scientists, faculty, and students published more than 800 peer-reviewed papers during calendar year 2020, in journals such as *Nature*, *Science*, *Geophysical Research Letters*, *Bulletin of the American Meteorological Society*, *Proceedings of the National Academy of Sciences*, and many others. CIRES scientists and faculty also authored dozens of other publications in 2020, such as datasets, magazine articles, white papers, reports, and books, including *Colorado River Basin Climate and Hydrology: State of the Science*, by **Jeff Lukas** and **Elizabeth Payton**, and *Dual Frequency Comb Spectroscopy in Wildfire Combustion Processes*, by **Amanda S. Makowiecki**.

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’ work earned coverage in *Time*, *Scientific American*, *Science Daily*, *National Geographic*, *NPR*, *The Washington Post*, *Smithsonian*, *ABC News*, *BBC*, *USA Today*, *CNN*, *CBS Denver*, *The New York Times*, and many other local, national, and international media outlets.

Below are a few news stories, published between June 1, 2020 and May 31, 2021, highlighting research papers that Altmetric scored in the top five percent of all research outputs.

10 Reasons Why the Coronavirus is Airborne: New assessment: Recognizing the virus is predominantly spread through air would save lives (<https://cires.colorado.edu/news/lancet-paper-10-reasons-why-coronavirus-airborne>)

Emissions of a Banned Ozone-Depleting Gas are Back on the Decline: 2018 discovery posed first real test of the Montreal Protocol (<https://cires.colorado.edu/news/emissions-banned-ozone-depleting-gas-are-back-decline>)

Warmer Clouds, Cooler Planet: New paper: precipitation-related “feedback” cycle means models may overestimate warming (<https://cires.colorado.edu/news/warmer-clouds-cooler-planet>)

Ozone Across Northern Hemisphere Increased Over Past 20 Years: Researchers tapped measurements from aircraft on international flights (<https://cires.colorado.edu/news/ozone-across-northern-hemisphere-increased-over-past-20-years>)

Sweat, Bleach & Gym Air Quality: CU Boulder study shows high bodily emissions during workouts, intensified by chemical reactions with cleaners (<https://cires.colorado.edu/news/sweat-bleach-gym-air-quality>)

MOSAIC’s Arctic voyage ended in October, 2020. The epic mission attracted media attention all year, and *The New York Times*, *Discover Magazine*, and others covered the *RV Polarstern*’s return to Germany after 13 months in the Arctic Ocean. In December, *Nature* selected a photo taken by CIRES’ **Lianna Nixon** as one of the best science images of 2020.

Selected Awards 2020-2021

HIGHLY CITED

This year, Clarivate Analytics named four CIRES scientists “highly cited researchers,” among the one percent most cited in their fields: **Doug Day**, **Noah Fierer**, **Jose-Luis Jimenez**, and **Julienne Stroeve**.

CIRES OUTSTANDING PERFORMANCE: SCIENCE AND ENGINEERING

- **Patrick Alken**, for successfully leading the development, validation, and release of an international reference geomagnetic model used widely in academia, government, and industry;
- **Douglas Day**, **Hongyu Guo**, **Pedro Campuzano-Jost**, **Demetrios Pagonis**, and **Donna Sueper**, for a decade developing and engineering one of the world’s most comprehensive and high-performance flight instruments for measuring aerosol chemical composition;
- **Ravan Ahmadov**, **Eric James**, and **Stuart McKeen**, for leading a multi-year effort to implement a biomass burning module into an existing hourly Numerical Weather Prediction system to predict smoke movement; and
- **Matthew Coggan**, for changing our understanding of urban and wildfire ozone formation and resulting air-quality impacts.

CIRES OUTSTANDING PERFORMANCE: SERVICE

- **Rebecca Batchelor**, **Alicia Christensen**, **Annie Fudale**, **Meghan Henderson**, **Amanda Morton**, and **Christine Okochi**, for remarkable work supporting the Research Experience for Community College Students (RECCS) program, changing the academic trajectories and lives of many;
- **Kathleen Bogan**, **Jon Griffith**, **Lynne Harden**, **Lianna Evans Nixon**, **Matthew Adam Price**, **Matthew D. Shupe**, and **Katie Weeman**, for creative, high-impact outreach, education, and communications work in support of the year-long MOSAiC Arctic research expedition;
- **John Mund**, for exceptional skill and service as a data manager, programmer, and IT specialist supporting national and international atmospheric monitoring and research; and
- **Catherine Rasco**, **Megan Melamed**, and **Chelsea Thompson**, for redesigning the Chemical Sciences Laboratory website and orchestrating excellent use of ESRI “Story Maps” in support of the 5-year laboratory review.

OTHER AWARDS

- CIRES Fellow **Joost deGouw** was named an AGU Fellow.
- CIRES Fellow and environmental economist **Matthew Burgess** received The Heterodox Academy’s 2020 Open Inquiry Award for teaching.

- CIRES Fellow **Rainer Volkamer** was one of 20 international scholars awarded the Friedrich Wilhelm Bessel Award from Germany’s Alexander von Humboldt Foundation.
- Several CIRES scientists were part of NOAA teams whose federal employees were awarded NOAA medals for their work. CIRES recognized these scientists with CIRES awards, as follows:
 - > CIRES scientists in NOAA’s GML and CSL won a CIRES Gold Medal for discovering the recent production and release of CFC-11, indicating a major violation of the Montreal Protocol;
 - > CIRES scientists in NCEI earned a CIRES Gold Medal for successful orchestration of seafloor mapping and data science initiatives imperative to fulfill U.S. Extended Continental Shelf project goals;
 - > A CIRES team in NOAA’s SWPC won a CIRES Gold Medal for the planning, development, and implementation of a new space weather forecast service to support international aviation requirements;
 - > A CIRES team in NOAA’s PSL was awarded a CIRES Silver Medal for creating a 200-year historic reanalysis dataset of global weather and extremes from only surface pressure and sea-surface temperature observations;
 - > CIRES scientists in NOAA’s GSL and CSL won a CIRES Technology Transfer award for creating a unique instrument to measure atmospheric particles and helping a small company successfully commercialize it to yield more than \$1 million in sales; and
 - > A CIRES team in NOAA’s CSL won a CIRES Administrator Award for the planning and conduct of FIREX, the largest interdisciplinary research project ever to study wildfire smoke composition, chemistry, and evolution.

Diversity & Inclusion

CIRES is committed to increasing diversity and inclusion in science, and plays a key leadership role in the university’s D&I initiative. Our 2020-21 efforts include:

- recruiting at conferences for under-represented scientists, including the American Indian Science and Engineering Society and the Inclusive Graduate Education Network;
- hosting D&I search and hire workshops for supervisors and sub-units;
- leading the CU Boulder Inter-Institute Diversity, Equity and Inclusion working group, which provides professional development, resources, and affinity groups;
- hosting the Society of Latinxs/Hispanics in Earth and Space Sciences; and
- developing a strategic plan for diversity, equity, and inclusion in 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, program evaluation, mentoring opportunities, engagement training for scientists, support for early career scientists, and more. Some projects from 2020-2021 include:

- **Climate Literacy & Energy Awareness Network (CLEAN):** The award-winning CLEAN collection (CLEANet.org) is a peer-reviewed, digital repository of climate and energy learning resources, syndicated through NOAA's Climate.gov, the National Science Teachers Association, and OER Commons, a widely used digital library. Ongoing webinars and newsletters provide training opportunities. The vibrant CLEAN Network serves more than 800 climate literacy professionals across the country with weekly telecons and an email list;
- **Research Experience 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 dozens of 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; and
- **Data Puzzles:** An innovative educational curriculum model combines classroom-friendly scientific datasets with the research-backed pedagogical practices to give students an inquiry-based learning experience as they explore CIRES and NOAA data. The new format was introduced to teachers in multiple workshops and through classroom implementation. Find out more at datapuzzles.org.

CIRES' Education & Outreach group continued to lead many efforts to support the unprecedented **MOSAiC Arctic expedition**, developing:

- two award-winning planetarium shows;
- curriculum units;
- story maps;
- virtual tours;
- teacher workshops;
- and more.



Daniel De Souza measures the pH of a soil sample while working in CIRES Fellow Noah Fierer's lab. De Souza's lab work was part of his research during the summer 2021 RECCS program. He is a student at Northeastern Junior College in Sterling, Colorado. Photo: Daniel De Souza/CIRES RECCS



A severe thunderstorm moves away shortly after producing an EF1 tornado near Keenesburg, Colorado in 2018. Photo: Jennifer Walton/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 40 Fellows below were active between June 1, 2020 and May 31, 2021.

Waleed Abdalati

CIRES Director, Professor of Geography

Richard Armstrong

CIRES Senior Research Scientist, National Snow and Ice Data Center

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

Associate 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

Director, Western Water Assessment; 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

Timothy J. Fuller-Rowell

CIRES Senior Research Scientist, NOAA Space Weather Prediction Center

R. Michael Hardesty

CIRES Senior Research Scientist

Jose-Luis Jimenez

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

William M. Lewis Jr.

Professor of Ecology and Evolutionary Biology

Ben Livneh

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

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

Associate Director, CIRES Ecosystem Science Division; Professor of Ecology and Evolutionary Biology

Michael Willis

Assistant Professor of Geological Sciences

Paul Ziemann

Professor of Chemistry

