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# DEPARTMENT OF COMMERCE
# RESEARCH PERFORMANCE PROGRESS REPORT (RPPR)

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## ACCOMPLISHMENTS

### 24. What were the major goals and objectives of this project?

CIRES' mission is aligned with NOAA's and focuses on science in service to society: We 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.

At CIRES, more than 800 environmental scientists, engineers, developers, students, and others work to understand the dynamic Earth system, including people's relationship with the planet, by exploring a wide variety of research areas. Among these are: weather and climate, changes at Earth's poles, air quality and atmospheric chemistry, water resources, solid Earth sciences, and more. Most of our work includes the dissemination of data and tools to professional users, the general public, and education communities.

Roughly half of our people work embedded in NOAA groups; the rest conduct their research at the University of Colorado Boulder. Our cooperative agreement work with NOAA, which is the focus of this report, is described by 73 projects that fall under two NOAA goals—Weather-Ready Nation, and Climate Adaptation & Mitigation—and two NOAA enterprise objectives—Engagement and Science & Technology. Each of these projects includes specific research activities and deliverables, and the work is conducted in NOAA laboratories or centers in close collaboration with agency scientists and leaders. Our projects are described in detail in our 2012 and 2017 proposals to NOAA, organized by nine CIRES themes.

CIRES' research efforts with OAR are centered in the NOAA Earth System Research Laboratories. CIRES also supports research conducted with other NOAA offices: SWPC and WPC in the National Weather Service; NCEI in the National Environmental Satellite, Data and Information Service; and one GSL project in the NOAA Office of Education. CIRES is also home to a NOAA RISA program, WWA. WWA is supported by NOAA's Climate Program Office, as is the National Integrated Drought Information System, which is staffed primarily with CIRES experts. The CIRES Education and Outreach program is funded by the NOAA Cooperative Agreement as well as through grants from other federal agencies including NSF, NASA, and other sources.

### 25. What was accomplished under these goals?

During the 2021-2022 reporting year, our scientists accelerated NOAA's mission work, improving scientific understanding of weather, climate, and humans' ability to adapt to a changing planet. CIRES researchers explored many aspects of the Earth system, for example: developing technology to better forecast storms and extreme weather events, from blizzards to floods; harnessing satellite, aircraft, and in-situ data to ensure we understand the future of the Arctic and Antarctic in a changing climate; air quality impacts from destructive wildfires; atmospheric constituents that drive climate change; using modeling techniques to reveal new developments in global air pollution; and much more.

In the past year, CIRES scientists published their findings in 679 peer-reviewed papers in dozens of different journals, and 450 of those directly resulted from collaborations with NOAA research teams. Our NOAA-based researchers won or were part of teams that won many prestigious awards including: six DOC Bronze Medals; a NOAA Administrator Award; and two 2021 OAR Outstanding Scientific Paper Awards. Clarivate Analytics also named five CIRES scientists "highly cited researchers" in 2021, 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.

Eight CIRES scientists joined the NOAA federal workforce in this reporting year, demonstrating, as in years past, the fact that CIRES is the foundation of a pipeline that brings exemplary candidates to the agency. CIRES supported 73 graduate students and about 40 postdoctoral researchers, including many who worked in NOAA teams. Our Visiting Fellows program brought in impressive postdoctoral and sabbatical colleagues who have not only performed outstanding collaborative research, but have also provided added visibility for CIRES and NOAA. As just one of many examples, during his time with CIRES, sabbatical Visiting Fellow Bart Croes spoke on a Climate Conversations webinar organized by the National Academies of Sciences, Engineering, and Medicine and contributed to CIRES post-fire mitigation guidance after the destructive Marshall Fire in Boulder County, Colorado.

CIRES' Education and Outreach Program runs several projects that regularly include participation from CIRES, CU Boulder, and NOAA researchers. Last year, these included RECCS, a program that serves as a model for other programs around the country to engage community college students in further STEM studies at the undergraduate and graduate levels; and the Drifting North Polar Planetarium Program at CU Boulder's Fiske Planetarium, which brought dozens of students and community members together to learn about the MOSAiC expedition. Please see Question 40 for more examples.

CIRES is committed to increasing DEI in environmental sciences and geosciences. Our 2021-22 efforts included: 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; developing resources and training for supervisors; participating in and 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;

**ACCOMPLISHMENTS *(cont'd)***

## 26. What opportunities for training and professional development has the project provided?

CIRES scientists engaged in professional development programs at CIRES, CU Boulder (eg, the Graduate Student Career Office, the Office of Postdoctoral Affairs, and central Human Resources), and NOAA. For CIRES scientists at NOAA, training and professional development also included lab and field work with experienced NOAA scientists, conference and workshop participation, and engagement with CIRES peers and mentors. Examples:
DEI training, focusing on justice, equity, diversity, and inclusion:
-Our D&I Director developed, led, and brought to CIRES several training programs aimed at supporting diversity and inclusion in our workforce, attracting broader participation at CIRES. Those programs include: "Conducting an Inclusive Search and Hire;" "Braiding your River," supporting personal learning and providing inclusive opportunities for CIRES researchers; and the CIRES Graduate Association Hidden Curriculum seminar series on self-direction, mentor networking, and more.
-CIRES employees participated in monthly Inter-Institute Allies meetups to deepen their anti-racism practice and knowledge.
-CIRES employees practiced inclusive mentoring as part of their work within the CIRES/GSL Summer Research Program, a program that is hosting a diverse cohort of twelve undergraduate and graduate students over Summer 2022.
-The CIRES D&I Director worked with a team to write, edit, and adopt a new vision and strategy for CIRES justice, equity, diversity, and inclusion programs, aligned with CU Boulder's and NOAA's diversity and education goals.
Technical training:
-One CIRES project lead re-certified as a drone operator for CU Boulder and a FAA Part 107 operator.
-With AI an increasingly important part of Earth system science, many CIRES staff participated in technical trainings related to AI, including machine learning, python coding, and cloud computing, as well as several project-specific training opportunities.
Mentoring: Led by the CIRES Members Council, the CIRES Mentoring Program connected CIRES staff of various career tracks and stages across the institute. The program connected 33 mentor-mentee pairs and added new training activities on career planning and goal setting. In an end-of-year survey, all respondents were satisfied with the program.
Developing leadership and other new skills, including interacting with government and industry partners:
-CIRES scientists edited the 2021 NOAA Arctic Report Card and an Arctic chapter in the BAMS State of the Climate report, gaining experience coordinating the work of international author teams.
-Several projects, including large field campaigns, allowed CIRES scientists to collaborate with colleagues in NOAA and external organizations including NCAR, universities, and private companies, to design and implement important Earth system modeling applications.
-Researchers also participated in career development workshops such as the AMS early-career leadership academy.
Collaborating internationally: Many of our projects are built on national and international collaborations, shared resources, and exchange of information—all supporting professional development.
-A CIRES scientist led an international team in the TOAR-II project, producing an authoritative update on the scientific understanding of tropospheric ozone.
-Other CIRES researchers collaborated with a WMO scientific advisory group on aerosols, contributing to the IPCC report.
HR training through CU Boulder and CIRES: CIRES staff participated in trainings offered through the university and CIRES, including

## 27. How were the results disseminated to communities of interest?

Also see Q29 and Appx 3 for publications.

CIRES is committed to communicating the institute's scientific discoveries to researchers, decision-makers, and the public. CIRES communicators collaborate closely with NOAA colleagues, CU Boulder, AGU, AMS; and other academic, professional, and government institutions.

In the past year, CIRES scientists published their findings in 679 peer-reviewed papers in dozens of different journals. CIRES scientists also presented at conferences, workshops, and meetings, including the 2021 AGU Fall meeting, the 2022 AMS annual meeting, the 2021 GSA meeting, the 2022 EGU meeting, and several more national and international meetings, inspiring collaboration and further research.

During this reporting period, communications efforts included dozens of news releases, media relations, videos, animations, social media campaigns, blogs, participation in virtual conferences, and more. CIRES scientists and research earned coverage in, for example, 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. 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) earning nearly 1.5 million "reads" in TC online.

CIRES/NSIDC researchers Twila Moon and Matt Druckenmiller helped author and edit the annual NOAA Arctic Report Card. Twila Moon participated in a press conference about the report during the 2021 AGU Fall Meeting. Their work garnered press attention from outlets including The New York Times, NPR, and Gizmodo.

Our scientists also connected with decision makers and elected officials to discuss policy-relevant charges. For example:
-CIRES director Waleed Abdalati rafted a stretch of the Colorado River in September 2021 with senators Michael Bennet (D-Colorado) and Mitt Romney (R-Utah), to talk about how Western communities can build greater resilience to climate and weather extremes.
-Matt Burgess, CIRES Fellow, moderated a Bipartisan Climate Solutions panel in April 2022 featuring U.S. representatives Joe Neguse (D-Colorado) and John Curtis (R-Utah).
-CIRES Fellow Max Boykoff joined other scientists, as well as political and religious leaders (including Italian Minister of Justice Marta Cartabia), at the Vatican in September 2021 for a workshop on "Post-truth" in which the experts explored ways to better understand misinformation on hot topics like health and climate.
-CIRES collaborated with the Colorado Local Science Engagement Network and the Institute for Science and Policy, CO-LABS (a non-profit consortium of federal laboratories, research institutions, businesses and economic development organizations supporting Colorado scientific resources), WWA, and the Colorado Climate Center to welcome scientists and decision-makers for conversations focused on rural broadband in Colorado, climate-informed decision-making, and carbon markets as a policy tool.

## ACCOMPLISHMENTS *(cont'd)*

### 28. What do you plan to do during the next reporting period to accomplish the goals and objectives?

During the next reporting period, CIRES scientists will continue collaborating with NOAA colleagues to address the mission-critical science of each partner group in the agency. Our work will continue to push the boundaries of research in Earth and environmental sciences, foster climate literacy, improve life-saving forecasts and technologies, and deliver critical information to decision makers.

CIRES will also keep training next-generation Earth and climate scientists, developing and improving innovative techniques and products, and disseminating scientific findings. Through all of these efforts, we will adjust to changes in NOAA's strategic priorities, goals, and objectives, aligning our work and workforce with the agency's needs. This priority will include a continuing emphasis on increasing the diversity of our workforce.

Please see Appx 2 for a complete list of current projects. A few highlights follow.

CIRES scientists will continue to participate in the second year of the SPLASH field campaign, deploying and maintaining instruments at six sites in central Colorado to measure energy budget and snow levels (PSL-23). Researchers will also begin processing SPLASH data, evaluating how large-scale weather patterns impact the distribution of surface precipitation over Colorado's East River basin (PSL-22).

In CSL, CIRES scientists will participate in the first deployment in the Arctic of the SABRE campaign, measuring aerosols in the stratosphere aboard the NASA WB-57 high-altitude research aircraft to assess the potential impacts of injection of reactive material from sources such as fires, volcanoes, and strategies to mitigate climate change (CSL-04, -06).

CIRES scientists in GML will install PurpleAir sensors at all SURFRAD stations to measure real-time PM2.5 concentrations; they will also build out an instrumented mobile trailer capable of rapid deployment downwind from active wildfires (GML-01). CIRES researchers will continue measuring gases in the stratosphere with a high-altitude glider that can return scientific instruments to the ground; the researchers plan to reach a maximum altitude of 32 km and begin regular stratospheric sampling of CFCs and other trace gases (GML-04, -05).

CIRES scientists will develop real-time fire emission processing tools for the RRFS 3km resolution North American domain, and add smoke and dust modules to GSL's experimental RRFS weather forecast model (GSL-04).

CIRES scientists and educators on the NOAA SOS® team, which successfully transitioned to NOAA's Office of Education, will release new versions of SOS® and SOSx® software, based on direction provided through visioning meetings in May 2022; the researchers will also host a teacher workshop as part of their NSF grant to develop an arts-based approach for teaching data literacy (GSL-02).

## PRODUCTS

### 29. Publications, conference papers, and presentations

In June 2022, we submitted 679 peer-reviewed publications to NOAA's Institutional Repository (IR) Manager, Jennifer Fagan-Fry, who will determine those that are in the repository already or are open access. For the rest that are associated with our Cooperative Agreement, we will contact the CIRES authors and ask them to submit the relevant paper version to the IR. Please see the list of publications in Appendix 3.

Many of our 800-plus people presented during virtual seminars, workshops, and conferences last year; we did not track them.

**PRODUCTS *(cont'd)***

30. Technologies or techniques

Below are some of the many examples of technologies/techniques developed or improved by CIRES researchers during the reporting period.

CIRES scientists in CSL:
-Adapted the POPS instrument for the Stratollite, a long-duration, high-altitude balloon instrumented to measure atmospheric particles in the stratosphere, and performed two test flights (CSL-07).
-Upgraded an existing mass spectrometer to measure the chemical composition of aerosol particles and deployed it on test flights for the SABRE and ACCLIP field campaigns; built a coarse-mode aerosol size spectrometer and deployed it as a part of SABRE (CSL-06).
-Developed a new miniature cavity-enhanced spectrometer to measure nitrogen dioxide on a UAV-based platform and submitted a patent application for the instrument (CSL-04).

CIRES scientists in GML:
-Conducted successful test flights of a glider that returns air samples of near-stratosphere greenhouse gases and other constituents to a location close to the launch site, at a lower cost than other high-altitude sampling methods (GML-04).
-Worked to develop a novel frost-point hygrometer that is cooled by dry ice and ethanol instead of HFC-23; the hygrometer measures water vapor, an important greenhouse gas, in the upper atmosphere (GML-06).

CIRES scientists in PSL:
-Used global climate models to predict marine heat wave onset, intensity, and duration 1 to 12 months in advance, and characterized heat waves on the North American continental shelf using high-resolution ocean reanalyses, improving understanding of critical tipping points for marine ecosystems (PSL-25).
-Built a dual-polarization vertically-pointing radar to more precisely measure precipitation amount and type during the SPLASH field campaign (PSL-22) and adapted an existing Atmospheric Surface Energy Flux station for SPLASH, successfully deploying the instrument in an environment different than its original Arctic purpose (PSL-23).
-Developed a statistical post-processing technique to improve the skill and reliability of streamflow forecasts in hydrological models. These forecasts are displayed in real-time on a website that NWS can use for situational awareness prior to precipitation events (PSL-28).

CIRES scientists in GSL:
-Developed products for aircraft guidance around weather hazards, to help aviation managers assess weather-related threats to aviation safety and comfort (GSL-06).
-Contributed to several public releases of software packages, including the UFS Short-Range Weather application for regional weather forecasts; updated the CCPP for NOAA's operational weather prediction models; the CCPP allows the research community

31. Inventions, patent applications, and/or licenses

No inventions, patent applications, and/or licenses to report.

**PRODUCTS *(cont'd)***

32. Other products

No additional products to report.

**PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS**

33. What individuals have worked on this project?

CIRES Director Waleed Abdalati and Christine Wiedinmyer (CIRES Associate Director for Science) are the PIs on the CIRES-NOAA Cooperative Agreement. They are supported by CIRES Associate Director Margaret Tolbert, a senior management team of four other managers, and the CIRES Council of Fellows, which includes an executive committee.

In 2021-2022, 484 CIRES people worked on NOAA projects at least some of the time.

About 55 administrative staff members support the director's agenda, serving the finance, human resources, information technology, communications, and other needs of CIRES' 800-plus scientists, engineers, developers, students, postdoctoral researchers, and others.

More information is listed in Appendix 5, CI Employee Support Table. Please note that in that table, only 33 people are listed as "Administrative." This lower number is based on job titles: some people who work on the CIRES Administration Team are research scientists or associate scientists because of their degrees or job tasks.

**PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS *(cont'd)***

34. Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?

There have been no changes since the last reporting period.

35. What other organizations have been involved as partners?

Please see Appendix 4, Partners and Collaborators.

*Attach a separate document if more space is needed for #6-10, or #24-50.*

**PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS *(cont'd)***

36. Have other collaborators or contacts been involved?

Yes, CIRES scientists collaborate nationally and internationally. Please see Appendix 4, Partners and Collaborators.

**IMPACT**

37. What was the impact on the development of the principal discipline(s) of the project?

CIRES scientists are world leaders in Earth and environmental sciences, including atmospheric chemistry and physics, space weather, cryospheric change, weather and climate forecasting, and others. Examples of impacts on these disciplines include:

CIRES scientists made groundbreaking findings that influenced the direction of research within their fields:
-CIRES scientists in SWPC continued to develop and analyze the coupled WAM-IPE, helping forecasters identify ionospheric impacts on satellite communications and navigation, high-frequency radio wave propagation, and satellite drag (SWPC-03).
-After the Hunga Tonga volcano erupted in early 2022, CIRES scientists in CSL participated in a rapid response field campaign in La Réunion. They launched balloons equipped with the POPS instrument to characterize how the volcano's plume evolved, to better understand how volcanic eruptions contribute to stratospheric aerosols (CSL-07).
-In GSL, CIRES scientists contribute to the EPIC, which is coordinating advances from academic, private, and federal research communities into NOAA's operational forecast systems. The researchers improved UFS' global 7-10 day weather forecasts and began transferring UFS Short Range Weather and Medium Range Weather releases to EPIC (GSL-18).
-CIRES scientists in GML analyzed tropospheric ozone over Antarctica using more than 25 years of measurements, finding that ozone increased at the surface and in the lower and mid-troposphere; this increase in Antarctic ozone could have a profound impact on the region's future climate, as tropospheric ozone has a warming effect (GML-02).
-The CIRES-led TOAR project has facilitated new research, evident from the highly cited TOAR-I papers and dozens of published studies utilizing the TOAR Surface Ozone Database (CSL-03).

CIRES scientists improved models and data assimilation to advance global scientific understanding of Earth systems, including life-threatening storms, air quality, and more:
-CIRES scientists in WPC developed innovative tools, now operational, to better understand and predict hazardous winter weather and extreme rainfall events (WPC-01, -02, -03, -06).
-In WPC, CIRES scientists planned and executed the Hydrometeorological Testbed Winter Weather Experiment and the Flash Flood and Intense Rainfall experiment; both resulted in improved precipitation forecasting skill (WPC-06).
-CIRES researchers in CSL tested a mobile Doppler lidar system in overland and offshore flights, finding that the instrument allowed them to characterize boundary layer dynamics, improving air quality and transport models (CSL-08).
-In CSL, CIRES scientists improved how fire emissions and smoke plume movement are represented in the community-developed WRF-Chem model (CSL-02).
-CIRES scientists in CSL conducted the SUNVEx field campaign in Las Vegas and Los Angeles to examine changing emissions and their impact on summertime ozone in these urban areas. Researchers used these observations to evaluate air quality predictions from NOAA forecast models, improving how those models predict the impact of emissions on air quality (CSL-04).
-In GSL, CIRES scientists working on the RAP-Chem Experimental Air Quality Forecast Model made several model improvements

**IMPACT *(cont'd)***

## 38. What was the impact on other disciplines?

CIRES' research in the past year significantly impacted other disciplines. For example:

-NSIDC, part of CIRES, produces short-term sea ice forecasts, indices, and other products used by diverse entities, including many in non-academic sectors: commercial shippers, energy companies, and the U.S. Navy. (NSIDC-01, 1557480)
-The U.S. Extended Continental Shelf project determines and documents the geophysical extent of the seafloor. The U.S. State Department relies on these data for defining where the United States sovereign has rights to explore, manage, conserve or exploit the natural resources of the seabed and subsoil. (NCEI-13)
-CIRES scientists in GML collect and analyze data that support international reports that are used for decision making and policy development. In this reporting period, they continued measurements of long-lived greenhouse and ozone-depleting gases that fed into the IPCC Sixth Assessment Report (Working Group 1), and NOAA's Annual Greenhouse Gas and Ozone Depleting Gas indices. (GML-05, -04)
-CIRES scientists in GSL design and evaluate tools to help aviation managers assess weather-related threats to aviation safety and comfort, supporting these products as they transition to operations. In this reporting period, the researchers assessed the performance of the updated Graphical Turbulence Guidance tool for the Federal Aviation Administration, finding that the GTG version 3 outperformed version 4 due to its ability to detect more moderate-or-greater turbulence events. (GSL-06)
-In GSL, CIRES scientists supported the second phase of deployment of a new architecture for NOAA's RDHPCS program. This architecture will provide a common framework for efficiently moving large data sets between NOAA's HPC data centers, non-NOAA HPC centers, and commercial cloud providers, supporting severe weather and climate research as well as piloting government-industry collaborations in cloud computing (GSL-05).
-CIRES scientists in SWPC improved space weather forecast services supporting the ICAO, providing important alarms for aviation forecasters when space weather thresholds are exceeded (SWPC-07). With federal colleagues, the researchers planned the September 2022 space weather testbed experiment to help airlines incorporate the new ICAO space weather advisories into their operating procedures; planning activities included providing modeling results for a tabletop exercise and communicating with airline industry representatives about the experiment (SWPC-06).
-CIRES scientists in PSL working on the MOSAiC Arctic expedition made appearances in U.S.- and U.K.-based documentaries on the mission, and their datasets fuel K-12 education, continuing education, and general science literacy, through their outreach efforts (PSL-23).
-In NCEI, CIRES scientists collaborated with the U.S. Federal Reserve Bank to quantify future economic impacts of the coastal housing market due to uncertainties in sea-level rise projections (NCEI-04) and delivered archived nighttime files spanning 2020-2022 to the World Bank for its "Lights Every Night" project (NCEI-14).
-CIRES scientists in CSL studied two perfluoroolefin compounds being considered as replacements for ozone-depleting chemicals, to understand how they affect climate, air quality, and stratospheric ozone. These studies help environmental policymakers assess the compounds' potential climate impact (CSL-05).

## 39. What was the impact on the development of human resources?

As of May 2022, CIRES remains more than 800 people strong. In this reporting period, eight CIRES employees transitioned to NOAA employment.

Highlights of CIRES hires in NOAA labs follow:
-We hired several additional scientists in CSL to work on instrument development for upcoming airborne field campaigns and to co-lead SABRE mission planning (CSL-07); to design and develop new lidar technologies (CSL-08); and to assist in the development and maintenance of custom-built scientific instrumentation (CSL-06).
-In GML, we hired several new scientists, including postdocs and graduate students, to work on projects involving the collection, archival and analysis of surface radiation network data (GML-01); to analyze ozone data and archive projects, and to support Dobson and surface ozone monitoring (GML-02); to study greenhouse gas trends (GML-04); and to investigate the behavior of ozone-depleting substances (GML-05).
-In PSL, we hired scientists to work on improving wind forecasting (PSL-19); linking weather, climate, and environmental tipping points (PSL-25); and developing a next-generation global prediction system (PSL-26).
-In GSL, we hired several new research scientists with expertise in data assimilation, modeling, and software development (GSL-03) and worked with the CU Boulder colleagues to create a new internship opportunity to work on the EPIC Unified Workflow Team with a CIRES mentor (GSL-18).
-In NCEI, we hired additional staff to complete data management and software development requirements for the marine geophysical data stewardship project (NCEI-01); to reprocess and document NOAA's multi-decadal space weather datasets, develop products, and make those data available to the public (NCEI-05); and to compile and make available new paleoclimatic data and research results (NCEI-11).
-In SWPC, the Space Weather Information Technology and Development project hired an unprecedented eight new CIRES employees (SWPC-01).

Examples of other key HR impacts include:
-We have continued to build our support for current CIRES scientists with many kinds of professional development and trainings, other support such as visa support, a compensation project, and work to comply with the Colorado Equal Pay Act.
-We updated the CIRES merit-based promotion program to better reflect the roles and responsibilities of the CIRES scientists working at NOAA. This year, about 68 CIRES people advanced to the next level in their "career track."
-We have developed new supervisory training and resources for our CIRES Supervisors.

For more information, please see Question 26 and also Appendix 5, CI Employee Support Table.

**IMPACT *(cont'd)***

40. What was the impact on teaching and educational experiences?

CIRES provided teaching and outreach experience for our researchers and for the broader community, including students of all ages. A few examples follow.

-CIRES had as part of its organization 22 tenured and tenure-track faculty, plus adjunct and research faculty, who taught courses across CU Boulder departments (Aerospace Engineering Sciences; Atmospheric and Oceanic Sciences; Chemistry; Civil, Environmental, and Architectural Engineering; Ecology and Evolutionary Biology; Economics; Environmental Studies Program; Geography; Geological Sciences; Molecular, Cellular, and Developmental Biology) training the next generation of scientists who can contribute to the NOAA mission.
-CIRES E&O's CLEAN network 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 provided ongoing and timely support for educators (1558333).
-CIRES scientists developed and delivered product training materials on forecasting techniques (WPC-01, WPC-02, WPC-03, WPC-05), including in virtual training sessions (GSL-07).
-Several CIRES researchers develop and disseminate education tools for NOAA's SOS®, which is rooted in teaching and education: in this reporting period, an estimated 66 million people visited facilities with SOS installed, and the free SOSx™ Mobile app was downloaded thousands of times (GSL-02).
-NCEI data products are used widely by students: NSIDC products including the Sea Ice Index data (NSIDC-01) and NOAA@NSIDC data (NSIDC-03) also were used by professors and students in undergraduate classrooms to analyze and understand raw data, and NSIDC's long-term sea-ice record has long been used to educate the public about climate change (1559464).
-A CIRES scientist in NCEI served as Director of Research for the Little Thompson Observatory's radio astronomy program, which provides STEM mentoring opportunities for high school students (NCEI-09).
-Many other CIRES scientists spent time mentoring high school, undergraduate, and graduate students through a variety of programs (some of them NOAA-funded), giving those students the opportunity to conduct research in several NOAA laboratories and on the CU Boulder campus (CSL-03, CSL-04, CSL-06; GML-03, GML-06; NCEI-02, NCEI-04, WPC-06, 1559031).
-CIRES scientists produced educational materials including movies, handouts, and outreach activities for schools and teachers about the causes of ozone depletion (GML-02); and the Dutch Meteorological Institute created a climate atlas to be distributed in secondary schools using images generated from the NOAA climate change portal CMIP6 data (PSL-25).
-CIRES scientists served as mentors and consultants to programs run by CIRES E&O, NOAA, and other partner organizations, for example: RECCS, the NOAA Lapenta Student Internship Program, Significant Opportunities in Atmospheric Research, and more.

41. What was the impact on physical, institutional, and information resources that form infrastructure?

NOAA facilities were mostly closed during this reporting period, due to the global pandemic, so many CIRES scientists who normally work at NOAA used home offices.

Other direct impacts on NOAA's infrastructure this year included (but are not limited to):
-CSL field campaigns conducted this year, including SUNVEx and the Marshall Fire Air Quality Response, were made possible by institutional and IT resources at NOAA, including collaborations with several NOAA laboratories as well as external partners (CSL-04, -08).
-In GML, CIRES scientists tracking stratospheric ozone relied on NOAA IT and the agency's Atmospheric Baseline observatories, international partners operating NOAA instruments, and NWS personnel to support instrument operations and data collection (GML-02).
-In GML, CIRES scientists studying aerosol properties began installing new instruments at the Table Mountain site north of Boulder, developing an instrumented trailer to deploy downstream of wildfires, and working with the Air Force Institute of Technology to set up a new NOAA Federated Aerosol Network station in Ohio (GML-03).
-With support from NOAA's Earth Radiation Budget program, CIRES scientists in GML monitoring water vapor in the upper atmosphere increased the frequency of balloon launches in Boulder to every 3 weeks and expanded payloads to include the NOAA CSL POPS sonde to measure vertical profiles of aerosol number and size distribution in the stratosphere (GML-06).
-Projects in GML, GSL, and PSL required larger amounts of high-performance computing and storage, earning increased allocations and support from GSL, NOAA, and partner institutions, including the NOAA-funded Orion supercomputer system at Mississippi State University (GML-04, GSL-06, GSL-07, GSL-17, PSL-21, PSL-24, PSL-26).
-In GSL, MADIS is required to run within its NWS Operational Facility base resource allotment. In this reporting period, the researchers improved efficiencies, accommodating more data with the same or fewer resources. Therefore, this project increased capacity and didn't require any additional infrastructure resources (GSL-01).
-GSL's science education and outreach project required IT resources for collecting and distributing the content used in SOS® and SOSx®, including an extensive real-time dataset collection that enables users to share the most current events with their visitors. The team transitioned the project's IT needs to the NOAA OCIO (GSL-02).
-NCEI's Information Technology Services Division provided hard disk storage for data ingest and delivery, tape storage for archive, and compute options for effective management of tremendous volumes of data and database support for NCEI projects.
-NOAA provided computer resources for a SWPC project requiring automated real-time transfer of data between SWPC and NCEP computers and to enable processing of operational products for display in the Space Weather Forecast Office (SWPC-03).
-CIRES scientists in SWPC established and validated an alternate processing site at NOAA's Enterprise Data Center, enabling national critical systems to preserve continuity of operations. In addition, the team has been moving prototype application systems to the Cloud, either through Amazon's Web Service or through their relationships with NOAA's Community Coordinated Modeling Center and NASA (SWPC-01).

**IMPACT *(cont'd)***

42. What was the impact on technology transfer?

During the reporting period, dozens of technologies developed by CIRES scientists were transferred throughout NOAA and to other sectors, benefiting collaborating institutes, industry partners, decision makers, and the public. For example:

-CIRES scientists have continued to develop and improve instruments for measuring air quality, including advancing the precision of chemical ionization mass spectrometers (CSL-04).
-GML's Skysonde software for predicting balloon trajectories was made publicly available, with private and commercial applications, and its Python Umkehr software was used by the World Ozone Data Centre and the World Ultraviolet Radiation Data Centre to process data for the WMO's ozone archive (GML-02).
-Software developed by CIRES scientists for data acquisition and data review was shared with colleagues working on the World Data Centre for Aerosols, allowing them to submit data to the project archive in a timely fashion (GML-03).
-SOS® and SOSx® technologies were transferred to users in schools, universities, visitor centers, science museums, and directly to the general public, helping users educate themselves and others through data visualizations created by CIRES scientists. The team also successfully transitioned to NOAA's Office of Education in the last year (GSL-02).
-New aviation forecast evaluation products were transferred to FAA operations (GSL-06).
-Open-source software developed by CIRES scientists in NCEI and related to acoustic processing was posted to Github where it can be easily accessed by other researchers and the general public (NCEI-02).
-CIRES scientists developed NOAA's High Definition Geomagnetic Model (and its Real-Time add-on), which was made available (for a fee) to the directional drilling industry (NCEI-03).
-In PSL, observations made by CIRES scientists participating in the second Wind Forecast Improvement Project, to improve forecasts of turbine-height winds in the Columbia Basin in eastern Oregon and Washington, supported model improvements that transitioned into operations for NOAA's weather models, including the RAP, the HRRR, and its nested version (PSL-19).
-Coupled Arctic model forecasts produced by CIRES and other scientists were used by MOSAiC campaign participants, the National Weather Service, the National Ice Center, NOAA Ocean Prediction Center, the University of Alaska Fairbanks, the Office of Naval Research, University of Colorado, NCEP, and others (PSL-21).
-In PSL, CIRES researchers refined and improved statistical post-processing techniques and transferred them to NOAA's Model Development Laboratory for implementation in the National Blend of Models (PSL-28).
-CIRES researchers developing new physics for two NOAA Earth system models, the GFS and the UFS, updated the unified gravity wave physics from GSL to the NOAA Environmental Modeling Center for testing in the next version of the operational FV3GFS numerical weather prediction model (GSL-04).
-The TOAR Surface Ozone Database was made a permanent addition at the Forschungszentrum Juelich Supercomputing Center; the database is open access for use by scientists and policymakers worldwide (CSL-03).

43. What was the impact on society beyond science and technology?

CIRES researchers conduct science in service to society, reflecting NOAA's science, service, and stewardship missions. For example, CIRES scientists:

Supported decision making:
-Provided data that hazards assessment professionals and tsunami warning centers use to understand coastal risk and prevent, mitigate, or prepare for possible loss or damages, including to the U.S. coastal housing market due to uncertainties in future sea-level rise (NCEI-04).
-Dissected the causes of drought events, providing critical information to decision makers who manage reservoir water supply needs (PSL-24).
-Gave policymakers and forecasters new tools to put extremes into historic context (WPC-05).
-Edited the 2021 NOAA Arctic Report Card and the Arctic chapter in the BAMS State of the Climate in 2020, state-of-the-science reports used by scientists, policymakers, and journalists (1559245).
-Continued to assess the impacts of and solutions to mitigate emissions of the ozone-depleting substance CFC-11 that violate the Montreal Protocol (GML-05).

Developed and improved forecasts to protect lives and property:
-Developed GOES-R Level-2 algorithms to support SWPC's real-time space weather alerts (NCEI-08) and more accurate space weather forecasts for National Critical Infrastructure partners, decision makers, forecasting partners, and the public (SWPC-01, -05).
-Improved forecasts and developed situational awareness tools and hazard maps for extreme weather events including winter storms and heavy rain (WPC-01, -02, -03, -04, -05).
-Reduced damage, injuries, and loss of life from tornadoes in the U.S. Southeast through improvements in tornado forecasting, warning, and communications (PSL-19).
-Produced key radiation datasets that improve weather models for forecasting solar and wind energy (GML-01).
-Improved weather and climate extremes prediction (PSL-20) and forecasts of precipitation in the U.S. West (PSL-22).
-Improved forecasts of hazards to air and ground transportation, reducing damage from life-threatening weather (GSL-03), and improved precipitation, stream flow, and coastal inundation estimates to improve operational response to adverse rain events (GSL-13).

Supported management of sustainable resources and protection of natural habitats in a changing world:
-Developed ocean models that produce high-resolution hindcasts and predictions of marine heat waves, critical information for NOAA fisheries managers (PSL-25).
-Used modeling to predict summer habitat loss in 2100 for blue sharks along the U.S. East Coast, from Florida to Cape Cod (PSL-25).

**IMPACT *(cont'd)***

44. What percentage of the award's budget was spent in foreign country(ies)?

0 , Zero percent of this award was spent on sub-awards in foreign countries.

**CHANGES/PROBLEMS**

45. Changes in approach and reasons for change

Nothing to report.

*Attach a separate document if more space is needed for #6-10, or #24-50.*

**CHANGES/PROBLEMS *(cont'd)***

46. Actual or anticipated problems or delays and actions or plans to resolve them

During this reporting period, some projects experienced slowdowns or delays related to COVID restrictions, e.g., limited or no access to labs or travel to field sites. Others had no or few impacts. Overall, all projects made progress despite any challenges.

For example, the COVID-19-related quarantine prevented ozone data collection at three Dobson stations, delayed ozonesonde launches at several stations, and restricted Dobson operations at GML observatories (GML-02).

CSL's AEROMMA field campaign was postponed due to COVID restrictions. In this reporting period, CIRES and CSL scientists continued planning and preparing for the field campaign, now scheduled for summer 2023 (CSL-04).

In GML, CIRES staff continued long-term measurements at the South Pole Observatory during the pandemic, persevering when travel and science support were severely restricted (GML-07).

Travel restrictions during this reporting period led many conferences to move to a virtual venue, but CIRES team members were able to present their work remotely at several conferences, including AGU, AMS, and EGU.

The COVID pandemic prevented in-person meetings and conferences. For example, the 2022 Global Monitoring Annual Conference was held virtually, with contributions from many CIRES scientists in GML. Although a change from the traditional format, the virtual arrangement allowed participants across many time zones to contribute to and learn about the lab's work.

In September 2021, CIRES researchers in GSL led a week-long training session, held virtually because of COVID restrictions, of the UFS Short-Range Weather Application for researchers from government, academia, and private industry (GSL-07).

Within the past year, cellular companies began phasing out 3G communications technologies, so one GML group researched, identified, procured, and deployed 4G LTE cellular modems for 15 remote research stations (GML-01).

47. Changes that had a significant impact on expenditures

Total expenses on our cooperative agreement increased by $2.9M compared to the previous reporting period. This increase is primarily due to salary expenses ($2M of the $2.9M). Specifically: CIRES onboarded many new employees, accounting for some of the increase in salary expenditures; and most employees received a 3 percent base-building salary increase approved by the University of Colorado Board of Regents in 2021, following a historic year of no salary increases or travel expenditures due to the pandemic.

**CHANGES/PROBLEMS *(cont'd)***

48. Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents

Nothing to report.

49. Change of primary performance site location from that originally proposed

When NOAA facilities were mostly closed during the 2021-2022 remote work period resulting from the global pandemic, many CIRES scientists who normally work at NOAA used home offices; some were exempted and continued to work in NOAA labs.

*Attach a separate document if more space is needed for #6-10, or #24-50.*

**PROJECT OUTCOMES**

50. What were the outcomes of the award?

Please see Appendix 6: Question 50

**DEMOGRAPHIC INFORMATION FOR SIGNIFICANT CONTRIBUTORS (VOLUNTARY)**

Gender:

- ◯ Male
- ◯ Female
- ◯ Do not wish to provide

Ethnicity:

- ◯ Hispanic or Latina/o Not
- ◯ Hispanic or Latina/o Do not
- ◯ wish to provide

Race:

- ◯ American Indian or Alaska Native Asian
- ◯ Black or African American
- ◯ Native Hawaiian or other Pacific Islander
- ◯ White
- ◯ Do not wish to provide

Disability Status:

- ◯ Yes
  - [ ] Deaf or serious difficulty hearing
  - [ ] Blind or serious difficulty seeing even when wearing glasses
  - [ ] Serious difficulty walking or climbing stairs
  - [ ] Other serious disability related to a physical, mental, or emotional condition
- ◯ No
- ◯ Do not wish to provide

*Attach a separate document if more space is needed for #6-10, or #24-50.*