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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 including: 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 67 projects that fall under two NOAA goals—Weather-Ready Nation, and Climate Adaptation and Mitigation—and two NOAA enterprise objectives—Engagement, and Science and Technology. Each of these projects includes specific research activities and deliverables, and the work is conducted in NOAA laboratories 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 line offices: SWPC and WPC in the National Weather Service, and NCEI in the National Environmental Satellite, Data and Information Service. CIRES' Western Water Assessment is supported by NOAA's Climate Program Office, as is the National Integrated Drought Information System, which is staffed primarily with CIRES experts. Our Education and Outreach team is funded primarily through grants from federal agencies including NOAA, NSF, NASA, and others.

25. What was accomplished under these goals?

During the 2020-2021 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 all aspects of the Earth system: developing technology to better forecast storms, from blizzards to hurricanes; harnessing satellite, aircraft, and in-situ data to ensure we understand the future of the Arctic in a changing climate; understanding air quality impacts from biomass burning; assessing atmospheric constituents that drive climate change, using innovative instruments and modeling techniques to reveal new developments in global air pollution; and much more.

In the past year, CIRES' scientists published their findings in 806 peer-reviewed papers in dozens of different journals, and 454 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: five Department of Commerce Gold Medals, a DOC Silver Medal, and three DOC Bronze Medals; three NOAA Administrator Awards; and a NOAA Technology Transfer Award. This year, Clarivate Analytics also named four CIRES scientists "highly cited researchers," among the one percent most cited in their fields: Doug Day, Noah Fierer, Jose Jimenez, and Julienne Stroeve. CIRES Fellow Joost deGouw was named an AGU Fellow in December 2020.

Fifteen CIRES scientists joined the NOAA federal workforce in this reporting year, forming the foundation of a pipeline that brings exemplary candidates to the agency. CIRES supported 90 graduate students and about 40 postdoctoral researchers, including several who worked in NOAA teams. Our Visiting Fellows program brought in impressive postdoctoral and sabbatical colleagues: Dillon Amaya, for example, was lead author on a marine heatwave study published this year in NOAA and the Bulletin of the American Meteorological Society's "Explaining Extreme Events in 2019 from a Climate Perspective." NOAA's PSL has just hired Amaya as a federal employee.

In this year of maximum telework, our researchers found creative ways to share their science remotely with students and the public. For example, CIRES scientists: connected with middle and high school classrooms in Science@Home, a weekly webinar series, and the monthly Serie La Ciencia-en-Casa; developed educational tours for GSL's Science On a Sphere® free mobile app, SOS Explorer™; helped create PSL's Funtastic Science Talks, an online educational program for kids learning at home; and participated in NOAA's first-ever Virtual 8th Grade Science Days, reaching school districts across Colorado and beyond.

CIRES' Education and Outreach Program runs several projects that regularly include participation from CIRES, CU Boulder, and NOAA researchers. Last year, these included Research Experience for Community College Students, 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; please see Question 40 for more examples.

CIRES is committed to increasing diversity and inclusion in science, and plays a key leadership role in the university's D&I initiative.

ACCOMPLISHMENTS *(cont'd)*

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

CIRES scientists have—and take—the opportunity to engage in all professional development programs that are part of CIRES or the University of Colorado Boulder (e.g., the Graduate Student Career Office, the Office of Postdoctoral Affairs, and central Human Resources), and some of NOAA's. For CIRES scientists who work at NOAA, training and professional development also include lab and field work with experienced NOAA scientists, conference and workshop participation, and engagement with CIRES peers and mentors.

Selected examples of professional development in 2020-2021:

Focusing on justice, equity, diversity, and inclusion: Much of our institute's professional development this year focused on equity and inclusion. Examples are below.
Our Diversity & Inclusion director developed, led, and brought to CIRES a number of training programs aimed at supporting diversity and inclusion in our workforce, attracting broader participation in our organization, and improving inclusivity in the sciences.
About 65 CIRES scientists and other staff (many based at NOAA) signed up for a 15-hour Coursera online course called Anti-Racism, offered by the University of Colorado Boulder, and participated in four weekly discussion sessions around the topic, with other researchers from diverse departments around campus.
CIRES supervisors participated in CIRES training sessions about "Conducting an Inclusive Search and Hire."
CIRES Diversity & Inclusion Director Susan Sullivan engaged with a group of employees to define a new vision and strategy for justice, equity, diversity, and inclusion programs at our institute.
CIRES offered a new, monthly professional development series called "Braiding your River," supporting personal learning and providing inclusive opportunities for CIRES researchers to connect and grow together.

Mentoring: Led by the CIRES Members Council, the CIRES Mentoring Program connects scientists and administrators of various career stages across the entire institute. In its second year, with 26 mentor-mentee pairs, the program is proving very successful. Participants describe it as "...a great first step and culture change," and "a great experience—just connecting people and providing the opportunity is huge." Another participant said: "I've gained much experience through the training series and mentoring that have prepared me for supervising others in a diverse and inclusive way."

Leading field safety training: CIRES Fellow Kristy Tiampo and Education & Outreach director Anne Gold led an NSF-funded field safety training series—including a focus on harassment—for the second time in 2020, at CU Boulder. There were 13 participants, including 6 from CIRES and 1 NOAA federal employee.

Developing leadership and other new skills, including interacting with government and industry partners: CIRES scientists led projects such as editing the 2020 NOAA Arctic Report Card and an Arctic chapter in the BAMS State of the Climate report, earning professional experience as editors coordinating the work of international author teams. Some of our project work gave CIRES

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

Also see Q. 29 and Appendix 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; the American Geophysical Union (AGU); the American Meteorological Society (AMS); and other academic, professional, and government institutions.

During this reporting period, communications efforts included dozens of news releases, media relations, videos, animations, social media, 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, The Washington Post, The Guardian, Forbes, Space.com, 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 (four featuring or including NOAA science) earning nearly 285,000 "reads" in TC online, plus syndication in more than 40 other outlets.

During the 2020-2021 coronavirus shutdown and mandatory telework period, CIRES researchers presented virtually at conferences, workshops, and meetings in the United States and around the world, inspiring collaboration and further research. CIRES scientists presented at the 2020 AGU Fall meeting, the 2021 AMS annual meeting, the 2020 Geological Society of America, the 2021 European Geosciences Union, and several more national and international meetings.

CIRES/NOAA scientist Matthew Shupe, who co-led the MOSAiC polar expedition, participated in two press events during the 2020 AGU Fall Meeting, one related to the end of MOSAiC and the second supporting the NOAA 2020 Arctic Report Card. He also led several AGU sessions related to the mission.

Our scientists also spoke with decision makers and elected officials, and served on national committees with policy-relevant charges. For example:
CIRES Fellow Lisa Dilling served on a National Academy of Sciences panel that produced the report "Recommendations for Solar Geoengineering Research and Research Governance (2021)." The study's study sponsors included NASA, NOAA and the Department of Energy.
The editors of the 2020 NOAA Arctic Report Card, including CIRES' Matthew Druckenmiller, briefed three Congressional offices on the report in December, 2020.
CIRES Associate Director Margaret Tolbert represented CIRES during a conference call with U.S. Rep. Joe Neguse in February 2021, providing an overview of CIRES work on climate change, severe weather research, and forecasting—much of it done in service to NOAA.
CIRES Fellow Jennifer Balch presented some of her research on wildfire during a "Science Flash Update" with Neguse, also in February, and Balch and CIRES Associate Director for Science Christine Wiedinmyer headlined at Neguse's 2021 Wildfire Summit in February.

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 to build on past successes by collaborating with NOAA colleagues to address the mission-critical science of each of our partner groups 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 new innovative techniques and products, and disseminating scientific findings to the public. Through all of these efforts, we will continue to keep up with 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 Appendix 2 for a complete list of current projects and amendments. A few highlights follow.

CIRES scientists in PSL developed an instrument to collect air-ice-ocean interaction data on Arctic sea ice during the MOSAiC expedition; they'll redeploy the instrument in the upcoming SPLASH (Study of Precipitation, the Lower Atmosphere and Surface for Hydrometeorology) field program, to improve forecasts in the complex terrain of the Colorado River. (PSL-23) A CIRES team in GML will deploy mobile stations to measure surface radiation for SPLASH. (GML-01)

In CSL, CIRES scientists working on the the SUNVex (Southwest Urban NOx and VOC Experiment)
2021 field campaign will study the chemistry of air pollutants and ozone formation using an instrumented mobile van in Las Vegas, Nevada, and a ground site in Pasadena, California, and use the results to refine study objectives for the 2023 AEROMMA (Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas) campaign. (CSL-04)

CIRES scientists in GML are tracking the snow melt and snow-in date at the Barrow Atmospheric Baseline Observatory located near Utqiagvik, Alaska, after a four-year pause; they will expand their snow melt study to quantify the timing of migratory bird (black guillemot) nesting compared with historical observations, and evaluate alternative methods of tracking snow depth (such as drone flights, ultrasonic snow sensing, and measurement via snow stake) to verify their observations. (GML-01)

CIRES scientists will continue to improve key components of the detailed, hourly-updating weather models developed in GSL to support better wind and solar forecasts for the renewable-energy community. (GSL-11)

In NCEI, CIRES scientists will use satellite data to continue monitoring the performance of the World Magnetic Model 2020, and update the High Definition Geomagnetic Model and its Real-Time add-on for release in 2022 (NCEI-03). Another team will develop a new tool (the Standardized Precipitation Evapotranspiration Index) that combines observations with historical data for drought monitoring with a long-term perspective. (NCEI-11)

PRODUCTS

29. Publications, conference papers, and presentations

In June 2021, we submitted 806 peer-reviewed publications to NOAA's Jennifer Fagan-Fry, NOAA's Institutional Repository (IR) Manager, who will determine if some 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.

Most 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

We had too many developments to list. Below are examples of technologies/techniques developed or improved by CIRES researchers during the reporting period.

CIRES scientists:
Developed new techniques for forecasting Upper Colorado River Basin flows at 2- 5 year timescales, improving water resources management. (1559031)
Continued to grow the CLEANet.org resource database. (1558333)

CIRES scientists in CSL:
Designed a new version of the micro-pulse Doppler lidar to make measurements that characterize ocean and atmospheric processes, and wind flow around wildfires. (CSL-08)
Measured aerosol size distributions with an optical particle counter; modified the instrument for a high-altitude research aircraft, in support of NOAA's Earth Radiative Budget initiative to better understand Earth's stratosphere and our climate future. (CSL-06)
Used a new laser-induced fluorescence technique to build field instruments for measuring nitric oxide and sulfur dioxide; developed a new ion source for mass spectrometers that better detects some compounds, improving measurements of atmospheric constituents that affect air quality and climate. (CSL-04)

CIRES scientists in GML:
Developed 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)
Developed software for gathering, processing, and quality-controlling data to monitor water vapor in the atmosphere, where it is a powerful greenhouse gas; made the software available for a NASA high-altitude aircraft campaign. (GML-06)

CIRES scientists in PSL:
Developed a model to predict global sea-surface height and temperature on seasonal time scales, to improve understanding of critical tipping points for marine ecosystems. (PSL-25)
Improved parameterizations in the upgraded NOAA/NCEP Global Forecast System using the Finite Volume Cubed Sphere, supporting better weather forecasts. (PSL-20)

CIRES scientists in GSL:
Developed products for aircraft guidance around weather hazards. These products will be made available to the public. (GSL-06)
Contributed to software package public releases, including a Unified Forecast System medium-range application for global weather forecasts; an application for short-range, regional severe weather forecasts; and an updated Common Community Physics Package for NOAA's operational weather prediction models that allows the research community to contribute to model development. (GSL-07)

31. Inventions, patent applications, and/or licenses

The Regents of the University of Colorado, on behalf of inventors Manoj Nair and Patrick Alken, both CIRES scientists working in NOAA's National Centers for Environmental Information, filed patent application U.S. 2020/036273: "Systems And Methods To Improve Geo-Referencing Using A Combination Of Magnetic Field Models and In Situ Measurements," in December, 2020.

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 are the PIs on the CIRES-NOAA Cooperative Agreement. Abdalati is supported by Associate Director Margaret Tolbert, Associate Director for Science Christine Wiedinmyer, a senior management team of four other managers, and the CIRES Council of Fellows, which includes an executive committee of Fellows. About 41 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, and others. In 2020-2021, 476 CIRES people worked on NOAA projects at least some of the time; more information is listed in Appendix 5, CI Employee Support Table.

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?

This reporting year, CIRES Associate Director William Lewis retired; CIRES Fellow Margaret Tolbert, a Distinguished Professor at the University of Colorado Boulder, now serves as CIRES Associate Director.

35. What other organizations have been involved as partners?

Please see Appendix 4, Partners and Collaborators.

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 several Earth science disciplines, including atmospheric chemistry and physics, space weather, cryospheric change, and weather/climate forecasting, and others. For example:

CIRES scientists made groundbreaking findings that redefined the direction of research within their fields:
The CIRES-developed WAM-IPE coupled model illustrates that space weather can be impacted by lower atmosphere variability. Whole atmosphere-ionosphere models are now an integral part of thermosphere-ionosphere science. (SWPC-03)
CIRES scientists in CSL are providing new insights into Earth's stratosphere, improving our understanding of potential future climate interventions. Our scientists published simulations that revealed unintended consequences of sulfate geoengineering over Eurasia, including warmer winters and a drier Mediterranean (CSL-09), and conducted laboratory studies of calcium carbonate, a compound being considered for potential climate intervention efforts, as well as siloxanes, human-made pollutants used mainly in consumer products. (CSL-05)
CIRES scientists in NCEI demonstrated that future World Magnetic Models can be calculated from Iridium satellite magnetometer measurements, and developed a new reference geomagnetic model, the High Definition Geomagnetic Model, to support research. (NCEI-03)
The scientific impact of the international Arctic mission MOSAiC, co-led by a CIRES scientist, will be significant and last many years. MOSAIC data describing the physical interactions in the Arctic environment (atmosphere, cryosphere, ocean, ecology) will improve understanding and modeling of the rapidly changing Arctic system. (PSL-23)
A CIRES-developed machine-learning framework that classifies cloud types/regimes is being used to understand how different cloud types influence boundary layer and surface energy budget processes. (GML-01)

CIRES scientists engaged, enabled, and empowered the global scientific community by acquiring, developing, and disseminating Terabytes of new data, software packages, and other innovations:
Thousands of scientists use NSIDC data products for research; this includes sea-ice data (sea ice is now a Vital Sign in the annual NOAA Arctic Report Card); polar region data; and lake ice products downloaded for assessments and process studies. (NSIDC-01, 03, 05)
CIRES scientists in NCEI are disseminating GOES-R-series space weather data sets to the space science community, advancing basic space science research, space weather modeling and prediction, and understanding of space weather effects. (NCEI-05)
CIRES scientists in GSL ensure the research community has free access to and support for NOAA operational models and software packages, including GSI/EnKF, HWRF, CCPP, and multiple Unified Forecast System applications, all critical for state-of-the-art weather forecasting. (GSL-07)
As part of the CIRES-led The Tropospheric Ozone Assessment Report (TOAR), a global database of surface ozone levels is freely available to scientists. (GSL-03)

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 US 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. 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), scheduled for release in 2021, and the forthcoming World Meteorological Organization report on unexpected emissions of the banned ozone-depleting CFC-11. (GML-05, -04)
CIRES scientists working on GSL's San Francisco Bay Area Advanced Quantitative Precipitation Information System project will help improve the region's management of water resources and mitigate the effects of flooding on local infrastructure. (GSL-13)
CIRES scientists in SWPC handed off the WAM-IPE—a model that couples the whole atmosphere model and the global ionosphere-plasmasphere-electrodynamic model—to the NWS for transition to operations. This transition from science to operations will help forecasters identify ionospheric impacts on satellite communications and navigation, high-frequency radio wave propagation, and satellite drag. (SWPC-03)
Data from the CIRES-led Tropospheric Ozone Assessment Report (TOAR) supported estimates of human mortality due to long-term ozone exposure for The Lancet's annual Global Burden of Disease report. (CSL-03)
CIRES scientists in GSL design tools to help aviation managers assess weather-related threats to aviation. In this reporting period, the team evaluated the Visibility Estimation through Image Analytics, Convective Weather Avoidance Model, and Offshore Precipitation Capability tools, providing critical support for these products to become operational within the Federal Aviation Administration. (GSL-06)
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 1992-2020 to the World Bank for its "Lights Every Night" project. (NCEI-14)
CIRES scientists in PSL working on the MOSAiC Arctic expedition have had significant impact on education, including K-12 education, continuing education, and general science literacy, through their outreach efforts. (PSL-23)

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

As of June 2021, CIRES remains more than 800 people strong. In this reporting period, 15 CIRES employees transitioned to NOAA employment.

Although CU Boulder imposed a hiring freeze because of fiscal losses associated with COVID-19 disruptions, CIRES was exempted because of pressing science needs and because our institute continued to bring in strong funding that required new hires to get the research done.

To highlight a few key points:
We hired several additional scientists in CSL to work on instrument development for upcoming airborne field campaigns, for stratospheric measurements using radiosonde balloons to launch a portable optical particle spectrometer (CSL-07), and to design and develop new lidar technologies (CSL-08).
In GML, we hired several new scientists, including postdocs and graduate students, to work on projects including collecting, archiving, and analyzing surface radiation network data (GML-01); evaluating models using in-situ aerosol observations (GML-03); monitoring water vapor in the middle atmosphere (GML-06); and studying greenhouse gas trends (GML-04).
In PSL, we hired scientists to work on linking weather, climate, and environmental tipping points (PSL-25) and on a next-generation global prediction system (PSL-26). The CIRES Diversity & Inclusion Director assisted with some of these searches, resulting in the hire of a Native American engineer as a contractor (PSL-22).
In GSL, we hired several new research scientists in data assimilation, modeling, and software development (GSL-03).
In NCEI, we hired several full-time researchers to reprocess and document NOAA's multi-decadal space weather datasets, develop products, and make those data available to the public (NCEI-05). We are in the process of hiring a postdoc and data manager to compile and make available new paleoclimatic data and research results (NCEI-11).
We have continued to build our support for current CIRES scientists with many kinds of professional development, and with a merit-based promotion program. This year, about 60 CIRES people advanced to the next level in their "career track."

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 works hard to provide teaching and outreach experience for our researchers and for the broader community, including students of all ages. Much of this work is not directly funded through the Cooperative Agreement; rather, it consists of volunteer work by individual researchers or work that is externally funded and supported by the CIRES Education and Outreach Program. A few examples follow.

CIRES has as part of its organization 21 tenured and tenure-track faculty, plus adjunct faculty, who teach courses across CU Boulder, training the next generation of scientists who can contribute to the NOAA mission.
CIRES E&O's CLEAN network is a leading provider of peer-reviewed climate and energy education resources, which are being syndicated to NOAA's Teaching Climate, the National Science Teaching Association, and OER Commons, a public digital library of open educational resources. Our professional development webinars provide ongoing and timely support for educators. (1558333)
CIRES scientists developed and delivered product training materials (WPC-01, WPC-03, WPC-04, WPC-05), including video tutorials (GSL-07, NCEI-01), webinars (GSL-12), and usual manuals (WPC-02), for forecasters and other users.
Smartphone users around the world have become citizen scientists by using NCEI's CrowdMag app to send magnetometer data to the CIRES/NOAA geomagnetic team. (NCEI-03)
Several CIRES researchers support NOAA's Science On a Sphere® (SOS), which is rooted in teaching and education: each year, an estimated 66 million people visit facilities with SOS installed and the free SOSx™ Mobile app has been downloaded thousands of times. (GSL-02)
NCEI data products are used widely by students: In a recent survey of World Data Service-Paleoclimatology users, about 22 percent of respondents were K-12 teachers, or university educators, or students seeking data for their courses (NCEI-11). NSIDC products including the Sea Ice Index data (NSIDC-01) and NOAA@NSIDC data (NSIDC-03) also are used in classroom activities, 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 mentor high school, undergraduate, and graduate students, giving them the opportunity to conduct research in several NOAA laboratories and on the CU Boulder campus. (CSL-03, CSL-04, CSL-06, CSL-07; GML-03, GML-06; NCEI-02, NCEI-04, NCEI-08; WPC-06; 1559031)
Despite the restrictions imposed by COVID-19 shutdowns, CIRES scientists still found ways to reach different audiences during this reporting period, including: presenting a graduate-level seminar on the development of a space-based Doppler lidar (1557481); speaking at a virtual workshop for early career scientists learning techniques to collect high quality atmospheric measurements (GML-01); recording an outreach video with SWPC forecasters and scientists (SWPC-01); and reaching students with the webinar series Science@Home and La Ciencia-en-Casa, and PSL's online Funtastic Science Talks.
CIRES scientists produced educational materials including movies, handouts, and outreach activities for schools and teachers about the causes of ozone depletion (GML-02); and we provided images from a climate change web portal for a book chapter for secondary students. (PSL-25)

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 most CIRES scientists who normally work at NOAA used home offices.

Other direct impacts to NOAA's infrastructure this year included (but are not limited to):
The CSL mobile laboratory has been substantially upgraded in preparation for extensive measurements during the SUNVex 2021 study. (CSL-04)
In September 2020, GML completed construction of a modern Barrow Atmospheric Baseline Observatory (BRW) near Utqiagvik, Alaska. CIRES scientists worked with their NOAA colleagues on a new instrument suite to be installed on the building's rooftop measurement deck. Due to travel restrictions, the team sent detailed instructions to their BRW colleagues and interacted with them using virtual support meetings during installation and testing. The new equipment includes a fully refurbished solar tracker, an updated data logging system, and newly calibrated instrumentation. (GML-01)
Projects in GSL and PSL required larger amounts of high-performance computing and storage, earning increased allocations and support from GSL, NOAA, and partner institutions. (GSL-06, GSL-07, GSL-14, PSL-20, PSL-24, PSL-25)
GSL's science education and outreach project requires IT resources for collecting and distributing the content used in Science on a Sphere® (SOS) and SOS Explorer™, including an extensive real-time dataset collection that allows users to share the most current events with their visitors. (GSL-02)
Data management software was installed and is now running on federal IT infrastructure located in Asheville, North Carolina, and in cloud environments, supporting our geophysical data. (NCEI-01)
NCEI's Information Technology Services Division provided hard disk storage for coastal data ingest and delivery, tape storage for archive, and compute options for effective management of tremendous volumes of data and database support. (NCEI-04)
A SWPC project required automated real-time transfer of data between SWPC and NCEP computers, and the computer resources to enable processing of operational products for display in the Space Weather Forecast Office. (SWPC-03)
CIRES scientists in SWPC have been working on 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 across NOAA and to other sectors, benefiting collaborating institutes, industry partners, decision makers, and the public. For example:
CIRES scientists working on improvements to the Portable Optical Particle Spectrometer met with Handix Scientific to continue tech transfer of the commercialized version of the instrument. (CSL-07)
GML's Skysonde software for predicting balloon trajectories is publicly available, with private and commercial applications, and its Python Umkehr software is used by the World Ozone Data Centre and the World Ultraviolet Radiation Data Centre to process data for the World Meteorological Organization's ozone archive. (GML-02)
Software developed by CIRES scientists for data acquisition and data review is shared with colleagues, allowing them to submit data to the World Data Centre for Aerosols (WDCA) archive in a timely fashion. (GML-03)
Science on a Sphere® (SOS) and SOS Explorer™ (SOSx) technologies are transferred to users every year 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. (GSL-02)
The global aerosol forecast model GEFS-Aerosols and three regional smoke forecast models (RAP-Smoke, HRRR-Smoke-CONUS, and HRRR-Smoke-AK) were transitioned to operations at NOAA's National Centers for Environmental Prediction in 2020. (GSL-04)
New aviation forecast evaluation tools (e.g., for icing and convection) were transferred to Federal Aviation Administration operations. (GSL-06)
Hazard Services' Winter Weather products were used operationally by the National Weather Service for the first time in January, 2021 and will be operational nationwide in Fall 2021. (GSL-09)
In GSL, CIRES scientists supported NOAA's high performance computing priorities by working with Mississippi State University to deploy the Orion computing system. (GSL-05)
Software developed for the NOAA Environmental Software Infrastructure and Interoperability Project is a key part of NWS forecasts for the public, Naval forecasts for the military, and NASA mission forecasts. (GSL-12)
Open source software developed by CIRES scientists in NCEI and related to acoustic processing is publicly hosted on Github. (NCEI-02)
Data and expertise in the Enhanced Ionosonde Data Access and Stewardship project support HamSCI, a citizen scientist group of radio amateurs interested in ionospheric science (because radio waves propagate in the ionosphere), as well as amateur radio operators with the Military Auxiliary Radio Service, who support state National Guard units in Texas, Virginia, Maryland and Pennsylvania. (NCEI-09)
Coupled Arctic model forecasts produced by CIRES and other scientists were used by the international MOSAiC campaign and are used by the NWS, the National Ice Center, the NOAA Ocean Prediction Center, Sea Ice Drift Forecast Experiment and Sea Ice Prediction Network-Phase 2, the University of Alaska Fairbanks, the Office of Naval Research, National Centers for Environmental Prediction, and many others. (PSL-21)
CIRES scientists' fire weather prediction work is currently undergoing a technology transfer to the Climate Prediction Center with a week-3 fire weather product expected to be operational in summer 2021. (PSL-26)

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:

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. (SWPC-01, -05)
Improved forecasts and developed situational awareness tools for extreme weather events including winter storms and heavy rainfall. (WPC-01, -02, -03, -04, -05)
Improved wind forecasts for renewable energy, helping grid operators respond to sudden changes in power availability and increasing reliability (PSL-19). Produced key radiation datasets that also improve weather models for forecasting solar and wind energy. (GML-01)
Improved the prediction of weather and climate extremes (PSL-20) and forecasts of precipitation in the western United States. (PSL-22)
Supported work to improve forecasts of hazards to air and ground transportation, reducing damage from life-threatening weather. (GSL-03)

Supported decision making:
Provided data used by hazards assessment professionals and tsunami warning centers to understand coastal risk and prevent, mitigate, or prepare for possible loss or damages (NCEI-04).
Dissected the causes of extreme weather events such as heat waves, droughts, and floods, helping policy makers make informed decisions about infrastructure in risk-prone areas. (PSL-24) Gave policy makers and forecasters new tools to put extremes into historic context. (WPC-05)
Quantified air quality and other atmospheric changes due to coronavirus-related shutdowns, fires, and stratospheric ozone intrusions. (GML-02, GSL-03, CSL-04, -06, -08)
Edited the 2020 NOAA Arctic Report Card and the Arctic chapter in the BAMS State of the Climate in 2019 report, widely used by scientists, policymakers, and journalists. (1559245)
Continued to assess the impacts of and solutions to mitigate emissions of CFC-11, an ozone-depleter, in violation of the Montreal Protocol. (GML-05)

Improved navigation:
Completed documentation for much of the U.S. extended continental shelf and island regions to establish U.S. sovereign rights. (NCEI-13)
Developed sea-ice products (e.g., NPP VIIRS Snow, Ice EDRs and MASIE) to aid in Arctic and Antarctic navigation (1557479,

IMPACT *(cont'd)*

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

0 , --

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 coronavirus restrictions, e.g., limited or no access to labs or travel to field sites. 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). The 2020 hiring of the new specialist to fill in the vacant position for Dobson operations was delayed by seven months due to COVID-19 restrictions. (GML-02)

CSL's AEROMMA (Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas) field campaign was postponed due to COVID restrictions. Instead, CIRES researchers and their NOAA colleagues studied the global impacts of COVID-19 lockdowns on air quality and climate and published a comprehensive review (CSL-04). Also, pandemic travel restrictions prevented CIRES and NOAA scientists from updating instrumentation at NOAA's baseline atmospheric observatories; that work is planned for the next reporting period. (GML-07)

Overall, all projects are making progress despite challenges. For example, CIRES scientists successfully collected air-ice-ocean interaction data on Arctic sea ice during Legs 4 and 5 of the MOSAiC expedition, despite COVID-19 travel limitations and other challenges. (PSL-23)

Some scientists and teams reported that they grew professionally this year because of the pivots forced upon them and the need to learn different or new technologies in order to be successful. CIRES scientists continued critical work, including evaluating data already collected and writing papers. For example, the project highlighted above (GML-02) hired a part-time scientist for ozone data analyses and archiving projects, and another (NCEI-02) increased hiring to complete data management and software development requirements. Several other projects hired new team members (e.g., Climate.gov & CLEAN Curation & Education Engagement, and several CSL, GML, GSL, NCEI, and PSL projects) during this reporting period.

47. Changes that had a significant impact on expenditures

Travel restrictions related to the coronavirus pandemic meant a significant decrease in travel spending, from about $1.36M in FY20 to about $30K in FY21.

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 2020-2021 remote work period resulting from the global pandemic, many CIRES scientists who normally work at NOAA used home offices; a few dozen 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.