OMB Number: 0690-0032
Expiration Date: 08/31/2021

DEPARTMENT OF COMMERCE
RESEARCH PERFORMANCE PROGRESS REPORT (RPPR)

For instructions, please visit
http://www.osec.doc.gov/oam/grants_management/policy/documents/RPPR%20Instructions%20and%20Privacy%20Statement.pdf

AWARD INFORMATION	
1. Federal Agency: Department of Commerce / NOAA	2. Federal Award Number: NA19OAR4320073
3. Project Title: Cooperative Institute for Research in the Atmosphere	
4. Award Period of Performance Start Date: 07/01/2019	5. Award Period of Performance End Date: 06/30/2024
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR	
6. Last Name and Suffix: Knutson , null	7. First and Middle Name: Holli ,
8. Title: Assistant to Director, CIRA	
9. Email: holli.knutson@colostate.edu	10. Phone Number: 9704918209
AUTHORIZING OFFICIAL	
11. Last Name and Suffix: Moseley , null	12. First and Middle Name: William ,
13. Title:	
14. Email: bill.moseley@colostate.edu	15. Phone Number: 9704911541
REPORTING INFORMATION	
Signature of Submitting Official: Chris Ford	
16. Submission Date and Time Stamp: 04/26/2023	17. Reporting Period End Date: 03/31/2023
18. Reporting Frequency: (●) Annual ( ) Semi-Annual ( ) Quarterly	19. Report Type: (●) Not Final ( ) Final
RECIPIENT ORGANIZATION	
20. Recipient Name: COLORADO STATE UNIVERSITY	
21. Recipient Address: 601 S HOWES ST, FORT COLLINS, CO 80521-2807 USA	
22. Recipient UEI: LT9CXX8L19G1	23. Recipient EIN: 846000545

ACCOMPLISHMENTS

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

The major goals and objectives of CIRA are encapsulated by our Research Themes:

Satellite Algorithm Development, Training and Education: develop, demonstrate, and transition cutting-edge new capabilities that leverage the latest satellite technology, and help forecasters understand and make the most of environmental satellite information.
Regional to Global Scale Modeling Systems: leverage observational (satellite and in situ) data and design tools and techniques to evaluate and improve the performance of operational and next-generation forecast models.
Climate-Weather Processes: improve short to long-term forecast models via integration of multi-sensor observational datasets, system process-oriented research.
Data Assimilation: develop tools/techniques that connect forecast models with observations to provide the best possible description of the initial environmental state.
Data Distribution: develop, demonstrate, and implement effective and efficient methods and tools for data throughput via networks, data compression, and graphical user interfaces.

These themes are enhanced by cross-cutting activities in Socio-Economics, Machine Learning, and Education/Outreach at the graduate and post-doc levels. In resonance with the spirit of CSU as a land-grant institution, we are intentionally mindful of diversity, equity, inclusion, social justice (DEIJ) and accessibility as guiding principles of our conduct and engagement with society. We help NOAA to fulfill its mission to benefit society as we endeavor to educate, engage the public, and populate the future technical workforce of NOAA and the Nation.

CIRA's Strategic Plan is as follows:
• Entrain skills beyond the traditional meteorology disciplines in support of proposals and infrastructure development.
• Diversify our funding to ensure long-term viability, complement NOAA research and enable inter-agency coordination and leveraging.
• Maintain a theme-oriented program to improve the efficiency of our research and maintain core excellence in these areas.
• Evolve research themes in coordination with NOAA priorities and in light of the long-term research trends and faculty expertise of CSU's Department of Atmospheric Science.
• Exploit cutting-edge advances in engineering and computer science to develop cost-effective methods and techniques for data collection, analysis, and distribution.
• Forge transitional pathways between basic and applied research, and develop applied research relevant to both our sponsors' missions and CSU's educational mission.
• Assist the Nation through the application of our research in public policy and economic and societal impacts of weather and climate.
• Assist national and international weather and climate managers in their selection, usage and optimization of satellite, aircraft, and ground sensors.
• Partner with Federal and State agencies and laboratories to ensure our research is both cost-efficient and non-redundant at the

25. What was accomplished under these goals?

CIRA is based at Colorado State University in Fort Collins, but also has staff at NOAA national Labs and Centers. These connections offer opportunities to address our research themes in myriad ways. CIRA's individual project reports contain technical details than what can be only summarized briefly in the RPPR; those materials are available upon request.

Our team in Ft. Collins, CO, working with on-site NOAA/NESDIS staff of the Regional and Mesoscale Meteorology Branch (RAMMB), supports our Satellite Algorithm Development, Training and Education theme. We developed new multi-sensor tools for imaging, analyzing, and predicting track and intensity of tropical storms globally; developed novel imagery applications and supported cal/val of imagery and cloud products for JPSS/GOES-R; maintained the COLMA for GPM science and validation; worked with citizen scientists in precipitation and soil moisture; prepared for future satellite sensors; designed novel optical-flow-based algorithms for motion vectors; lead national/international satellite training in coordination with the WMO; further developed 3D clouds for aviation; demonstrated new products/capabilities on CIRA's SLIDER website (https://rammb-slider.cira.colostate.edu); advanced TPW/LPW/ALPW products for weather/climate applications; demonstrated new products in the Proving Ground; spearheaded several new applications using Machine Learning; and demonstrated improved forecast skill of the RRFS by assimilating GOES-derived synthetic radar.

Our team in Boulder, CO, working with NOAA/OAR Global Systems Laboratory (GSL), supports our Data Distribution, Data Assimilation, and Regional to Global Scale Modeling Systems theme. We supported development of the UFS and RRFS, staging of data (MADIS), analysis/verification tools for precipitation, physics upgrades, code optimization, benchmarking, the assimilation of satellite-retrieved aerosol optical depth (for wildfires), lightning, and synthetic radar, as well as high performance computing (HPC), and managing the massive database feeding the model. We also transitioned code to EPIC, transitioned SoS to NOAA OE, tools for tracking/visualizing weather hazards in AWIPS, and customized tools for aviation.

At the Aviation Weather Center in Kansas City, MO, our team supports NOAA's Aviation Support Branch (ASB), including information technology, web management, science functions, and the entire research to operations (R2O) process. We supported the NWS Operations Proving Ground (OPG) in experiment-based and testbed evaluation of new tools for watch/warnings, data sets, threats in motion, and forecaster decision aids with advanced, mobile-friendly visualization tools. We overhauled the AWC's website (https://www.AviationWeather.gov) and upgraded the AWS infrastructure.

Our team at the NOAA Center for Weather and Climate Prediction (NCWCP) in College Park, MC, focuses on developing, demonstrating, and transition cutting-edge capabilities to convert satellite data into actionable information related to ocean, land, and atmospheric parameters, and improve the representation of current environmental state in forecast models. We introduced new/improved algorithms to generate global gap-free high-resolution ocean color data, and extended the CRTM to METImage, MTG/FCI, JPSS2/VIIRS, and GeoXO/GXI.

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

ACCOMPLISHMENTS *(cont'd)*

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

CIRA is an umbrella award comprised of various NOAA technical projects. Our diversity of research makes it difficult to provide unified training and professional development opportunities applicable to all CIRA staff, but we do offer high-level training and professional development opportunities to all our employees in various core-competency areas of programming.

1. Through CSU, CIRA offers training in both Diversity, Equity and Inclusion, Social Justice and Accessibility, Sexual Harassment, and well as supervision/management fundamental courses. All CIRA supervisors are required to complete a core series of courses.
2. CIRA continues to support Machine Learning training for both CIRA and NOAA partners, via introductory courses, discipline-targeted training. These efforts have resulted in several new experts and advances to various applications.
3. CIRA's software support group connects across all CIRA locations to share best practices in software development and maintenance.
4. Several projects offer natural gateways to professional develop as required to address the work, including proficiency in Git/GitHub, Amazon Web Services, Python, HPC, GPU systems, MODTRAN, CRTM, and NOAA's Commerce Learning Center.

Through funded projects such as the SoS, the Virtual Laboratory, and UFS developments, the GOES-R Satellite Proving Ground, CIRA also offers a host of training opportunities to the NOAA community. All new satellite sensors and applications require user training, providing opportunities for dedicated modules guided by the technical reports of product construct and performance. These come in the way of Quick Guides, Quick Briefs, Blogs, and teletraining.

CIRA engages, educates, and trains the operational user community on the best use of new products and applications. We provided leadership through the VISIT and SHyMet programs to merge NWS and NESDIS training efforts focused on transferring the results of research into NWS operations and gathering feedback. Materials include quick guides, satellite blogs, social media platforms, teletraining, and other modes.

CIRA continues to partner with the Cooperative Center for Earth System Sciences & Remote Sensing Technologies (CREST) to recruit undergraduate students from minority backgrounds to participate in the Research Experience for Undergraduate (REU) program hosted at CSU, and will sponsor an ATS grad student from this program. CIRA continues its MSI projects with Texas Tech and CUNY, and will build on this program. We hosted the 2022 CoRP Symposium, emphasizing connections with MSI universities with NOAA's Cooperative Science Program.

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

The results of CIRA research are disseminated to many communities of interest:
- NOAA and the discipline-focused community via workshops and professional development opportunities
- The broader scientific community via peer-reviewed publications and presentations at scientific conferences
- The general public via media engagement on scientific results and/or for real-time events (e.g. hurricanes, fire weather, SoS, etc.)
- K-12 education via educator professional development, citizen science engagement, and public affairs activities.

Pathways of CIRA research results dissemination include external methods via publications and presentations, and through internal methods including workshops, professional development courses, and collaborative research. Box #29 addresses the major emphasis of this form of dissemination – via a wide range of presentations, publications, and conference papers covering the scope of CIRA research. CIRA continues its leadership in publications and presentations on our research, especially with regard to new satellite product retrievals.

Specific means of dissemination include: near-real-time demonstrations on dedicated websites (e.g., SLIDER, CoastWatch, PolarWatch) and interfaces (e.g., AWIPS-2, VLab), liaison/stakeholder meetings, informal and official e-mail correspondences, internal team and NOAA management meetings (in-person, virtual, and hybrid), science meetings/webinars, discipline-specific working groups, technical interchanges, training sessions, NWS testbed participation, scientific conferences, operational partner coordination, code repository/delivery coordination, release/change notes and help desk functions, and technical progress reports on various cadences from monthly to semi-annually.

CIRA's efforts to expand research results and knowledge for synchronous and asynchronous training, workshops, and professional development were articulated in Box #26. Learning materials were disseminated via in-person CIRA-led workshops, via the training VLab and VISIT programs, webinars, online modules, blogs, and short videos. Notably, a number of reference guides on CIRA-derived products were promulgated; these products have seen widespread use among the professional community as well as through media use and interaction with CIRA products.

Via its cutting edge imagery and products, CIRA has afforded NOAA significant media exposure during severe weather events, notably tropical storms. Through articles in major newspapers (New York Times, Washington Post, etc.) and through in-person interviews with subject matter experts at CIRA, a wider audience has been exposed to the NOAA mission. CIRA's GeoColor imagery of GOES data continues to be the flagship imagery of the GOES-R program.

Direct dissemination of select CIRA research results is made possible through education and outreach efforts. CIRA images and videos are featured in regular "This Week in Weather" videos produced by NESDIS, which are now a regular feature of NESDIS public relations, satellite blogs, Twitter, and Facebook postings. Our imagery is used by the national and international media on daily basis, and was recognized by Nature in its Best Science Imagery of 2022.

ACCOMPLISHMENTS *(cont'd)*

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

Our RAMMB-affiliated CIRA team will support NESDIS in near real-time product demonstrations (via the Proving Ground and SLIDER) to forecasters and the public, conduct cal/val of new satellite sensors, and continue to prepare for the next-generation satellite observing system. Our work with GOES-R ABI imagery, JPSS Cloud Imagery and 3D clouds developed for the entire GeoRing will include coordination with the Office of Naval Research. Real-time demonstration products (e.g., GeoColor) will include new satellite observations and other data sets. Our machine learning (ML) initiative will design novel solution architectures, enable new ways to assimilate satellite data into NWP, improve soundings, improve TC track and intensity forecasts and synthesize new observations like synthetic high-resolution microwave data and synthetic radar data. Our successful Optical Flow research will continue. Satellite training will continue to engage national and international communities. Social science activities to assist forecasters in communicating forecasts and to improve products usability for the public will expand.

CIRA's GSL-affiliated team will continue its efforts to prepare NOAA for UFS, via advances to both long and shortwave radiative transfer emulation, code stewardship and deliveries, improved prototyping, testing and verification of the RRFS in coordination with EMC, and serve as subject matter experts to our transition partners. Preparatory assessment work for the FAA will continue with many core research projects (including ceiling and visibility climatology and JPSS satellites data), upgrades/additions to the Continuous Improvement through Verification as a Service site, and continued development work for IDSS Engine (with a generic data manager to support the deployment of the tool to AWS). Algorithm and software development for the global and regional model development activities in the laboratory and will continue. We will further expand our DEIJ activities at GSL under the leadership of our DEIJ committee.

Our ASB-affiliated team at AWC in Kansas City, MO will support a variety of Operations Proving Ground experiments and provide satellite expertise within them. We will work with Master Instructors with focus on developing a distance learning program for the new ASOS (Automatic Surface Observation System) to be deployed 2023-2024. We will support the ASB mission through existing and new aviation research projects.

CIRA's NESDIS/STAR staff in College Park, MD will conduct calibration, processing, and algorithm development. We will further improve our models/algorithms, and strengthen user support and services, with an additional focus on coasts. We will grow our collaborations with the CIRA RAMMB team in the space of sea surface temperature and ocean biomass as related to marine bioluminescence and cloud masks.

The CIRA-MDL Team (Silver Springs, MD) will lead code development for Common Alerting Protocol (CAP) and Threats In Motion (TIM), National Blend of Models (NBM; in collaboration with CIRA/RAMMB and the NHC) tools for feature matching of tropical cyclones, participating in the Operations Proving Ground (OPG) and Hazardous Weather Testbed (HWT) experiments. In addition, we will run prototypes of 15-minute station-based LAMP and G-LAMP ceiling height and visibility guidance with code transitioned and delivered to NCEP Central Operations (NCO) in early 2024 and coordinate with NOAA's Aviation Weather Center (AWC) and the

PRODUCTS

29. Publications, conference papers, and presentations

As a research arm to NOAA, CIRA is engaged in scientific pursuits that often lead to publications in peer-reviewed journals and participation in national and international community scientific conferences.

During this RPPR reporting period, CIRA scientists gave 137 presentations and published 44 manuscripts in peer-reviewed journals, 28 of those publications have a CIRA scientists as first author. A comprehensive list of presentations and publications can be found as an attachment to this report.

PRODUCTS *(cont'd)*

30. Technologies or techniques

New applications developed by CIRA's NESDIS team via its Proving Ground and Risk Reduction projects are displayed in SLIDER and AWISP2. Tropical cyclone satellite products for objective guidance on probability of storm formation are run operationally at NESDIS and demonstrated at operational centers. CIRA's night-time ProxyVis imagery is being demonstrated to multiple National and Regional NWS operational centers, including NHC, OPC, and WPC, and is being expanded to additional centers, including CPHC and JTWC. CIRA's Hurricane Intensity and Structure Algorithm (HISA) is being adapted to work with TROPICS data. Lightning RII is being demonstrated to NHC. VIIRS 3D cloud cross-sections based on 3D gridded data processing are available on CIRA's aviation website. They have been provided for NTSB's aircraft accident investigations. CIRA reported evaluation results for the official DAPs, and delivered the updated algorithm document (ATBD) to the NOAA algorithm team with input for the JPSS VIIRS cal/val documents. CIRA's GeoColor imagery is used at WFOs, OPC, NHC, AWC, and the Center Weather Service Units (CWSUs). GeoColor is now available with newly blended layers like ProxyVis night-time clouds, SST, Dust, Fire Temperature. CIRA's Machine learning (ML) focus has led to new technologies and techniques, like a Python post-processing routine for CLAVR-x that runs an ML model and outputs low cloud predictions on the CLAVR-x grid. We demonstrated the use of linear regression, fully-connected neural networks, convolutional neural networks, and deep residual U-nets in modifying RAP temperature and moisture profiles using GOES and RTMA data. We demonstrated the value of ML technologies for assimilating satellite observations into NWP models and the GREMLIN (GOES Radar Estimation via Machine Learning to Inform NWP) convolutional neural network model for producing synthetic radar reflectivity fields from GOES ABI and GLM.

CIRA-GSL Team's work on the IDSS Engine led to continuous improvement through Verification as a Service web application. Lake, soil, and vegetation information generation software package for UFS. A customized interpolation package that changes the resolutions of UFS initial conditions and a Pytho- based visualization package that allows for Python-related modules to be used, including MetPy and Basemap. CIRA's GeoFLOW software framework continues to be advanced for use as a high-order research dynamical core for weather/climate applications, and for research into stochastic behavior of moist convective regional and global flows.
CIRA at AWC/ASB develops, tests, and evaluates nascent scientific techniques, products and services, including tools to decrease weather impacts to the National Airspace System and the FAA Command Center, Traffic Flow Management (TFM), and public aviation. They worked closely with Microsoft on the testing and implementation of beta.aviationweather.gov on the cloud computing platform. They used cloud platforms to test and evaluate AWC forecast generation technologies (Hazard Services and PGEN) into AWIPS-2.

The CIRA NEAT Team generated a suite of 2 km gap-free experimental ocean color products, chlorophyll-a, Kd(490), and suspended particulate matter by merging four sensors (2 VIIRS, 2 OLCI). They also performed initial groundwork for active (Synthetic Aperture Radar) sensor simulation with CRTM and improved a machine learning algorithm for snowfall.
Our MDL support team provides the IT framework that enables NOAA and its partners to share ideas, collaborate, engage in software development, and conduct applied research from anywhere. They developed an AWIPS Hazard Services TIM software and

31. Inventions, patent applications, and/or licenses

CSU STRATA is an on-campus service who handles interfaces with industry, licenses and patents. Based on the number of requests for its distribution we are still considering a licensed software arrangement for CIRA's GeoColor application. CIRA's lunar irradiance model continues to undergo improvements for better handling of near full-Moon behavior (opposition surge). Once the work has been completed, we may pursue licensing for this software. The CIRA software system, DPEAS, is a previously declared CSU invention that is under NOAA ownership for use in NOAA operations.

The pursuit of patents remains a challenging process. In 2017, CIRA employee Kevin Micke filed a patent application for a web application called "The Satellite Loop Interactive Data Explorer in Real-time" (SLIDER). SLIDER provides satellite data information to the general public by making it available on a public webpage in an easily accessible and user-friendly manner via a thoughtfully designed application interface. The patent application has gone back and forth through three rounds of office actions between the Patent Office and the Polsinelli law firm representing CIRA. If the process languishes, we will instead pursue a license (easier to set up).

Several of the tools developed by CIRA (particularly those related to satellite algorithms, decision support system, visualization tools, and data analysis techniques developed by the RAMMB, GSL, MDL team members) may be candidates for licensing and patents, but this has not been an expressed priority of the Cooperative Institute managers. That said, the process can indeed by arduous (as exemplified by SLIDER), so the reward for patents must be commensurate with time and effort spent in pursuit of them.

PRODUCTS *(cont'd)*

32. Other products

CIRA develops several other products related to our research:

• The new RAMMB-CIRA Satellite Library with a link directly from CIRA's homepage to https://satlib.cira.colostate.edu/daily/ has a substantial audience with frequent requests by news outlets as well as book and magazine publishers to use the imagery for supplement their stories.
• A real-time ground-based precipitation product for local water agencies in Northern California.
• A validation winds dataset along with benchmark comparison
• The statistical TC intensity models being improved as part of this project are used as input to NHC's operational consensus models, so there is potential for downstream product improvements.
the Blended TPW and Blended RR are official NOAA operational near real-time products.
• Multiple VIIRS cloud products on CIRA's SLIDER website for general users
• We are updating the tropical cyclone dataset following the revised AI-ready guidelines and creating supplemental training materials that will be shared with the community online.
• An analysis of the impact of lightning observation operators in the HWRF DA system
• Real-time GREMLIN running over CONUS using GOES-16. Soon we will be running GREMLIN on Full Disk for GOES-16/18. We have submitted the GREMLIN "CONUS2" dataset to a public repository with a DOI. We are preparing to submit the GREMLIN "CONUS3" dataset to a public repository with a DOI.
• Through the VISIT program, we have generated numerous two-page 'quick guides' on products developed by CIRA were made available to the public. These guides are available online at: http://rammb.cira.colostate.edu/training/visit/quick_guides/ and cover each satellite product in sufficient detail that a forecaster, media user, or interested citizen will have a good understanding of the products developed by CIRA and can effectively use those products for their own particular applications. Originally intended as a product for forecasters (who still are the primary audience for the quick guides) the material has seen wider adoption for educational efforts and for media who seek additional information on products they have encountered online, either through CIRA social media or through use of such online tools as SLIDER.
• CIRA continues to improve its branding, including an augmented online presence. It has done so through a dramatically updated homepage with improved navigation and product delivery and increased social media activity, where CIRA has a presence on Facebook and Twitter.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

33. What individuals have worked on this project?

Please see "BOX 33 attachment." The individuals in that attachment worked on CIRA projects during this year. We list their names, project roles, time commitment and job classification, along with any foreign duty stations if appropriate.

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?

No Significant changes in senior CIRA leadership have occurred over the reporting period.
Dr. Steven Miller remains as the CIRA Director.
Dr. Renate Brummer remains Acting Deputy Director.
Beth Kessler remains the Assistant Director
New Position: Dr. Matthew Rogers is now Assistant Director of Outreach & Communications

Natalie Tourville remains CIRA's Information Technology (I/T) Manager.
Heather Cronk remains CIRA Infrastructure Coordinator.
Bonny Strong is now Acting Associate Director and GSL Team Lead. A hiring process is on the way for a new CIRA Associate Director and GSL Team Lead (Boulder).
Prasanjit Dash remains the NESDIS Environmental Applications Team Lead
Amanda Terborg remains the Aviation Weather Center Team Lead
John Crockett remains the Meteorological Development Lab Team Lead

35. What other organizations have been involved as partners?

CIRA researchers engage in a wide range of collaboration; from its principal NOAA collaborators, other NOAA laboratories outside of the direct CI partnership, and other governmental and non-governmental agencies. Collaborative research with other CIs includes the CI for Research in the Environmental Sciences (CIRES), the CI for Meteorological Satellite Studies (CIMSS), the Cooperative Institute for Severe and High-Impact Weather Research and Operations (CIWRO) and the CI for Satellite Earth System Studies (CISESS) have been particularly fruitful. Considerable work is also performed with the National Hurricane Center (NHC), the National Severe Storms Laboratory (NSSL) the National Centers for Environmental Predictions (NCEP), and outside of NOAA, the Naval Research Laboratory (NRL), the Federal Aviation Administration (FAA), the United States Air Force, and the National Center for Atmospheric Research (NCAR). There are longstanding collaborations with the National Aeronautics and Space Administration (NASA), particularly through the NASA Short Term Prediction Research and Transition Center (SPoRT) and the GeoCarb, OCO-2, CloudSat, and GPM missions, among others, along with natural collaboration on joint missions such as Suomi NPP and JPSS-1, and the GOES-R series of spacecraft.

A representative list of organizations that CIRA partners follows:
NOAA Labs, Institutes, Operational Centers
• NSSL/SPC
• NHC/JTWC/HRD
• NCEP/EMC/AWC
• AOML
• OAR/NESDIS/NOS/NWS (and its numerous WFOs)
• OPC/OPG/WPC/CPHC
• STAR/ASSISTT
• TOWR-S
• NWS OIA/OCLO/OCIO/FDTD/WDTD
• OSTI/OPPA/OSPO
• SAB
• Satellite and Information Service International and Interagency Affairs Division (SIS/IIAD)
• SITWG
• MDL/AOML/ESRL (GSL,PSL)
• CIMSS/CIMMS/CIRES/CISESS/CIMAS/CIWRO
• JCSDA/JEDI/JTTI
• NOAA Performance, Risk, and Social Science Office
• NWRUP

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

36. Have other collaborators or contacts been involved?

Aside from our Federal partners, University faculty (NMINT, U. Oklahoma, U. Wisconsin-Madison, U. Akron, U. Maryland, U. Washington, U. Alaska-Fairbanks, and many others), other CIs (CIMSS, CISESS, and CSCs) and other national/internationally-based governmental agencies (including KMA, JMA, EUMETSAT), CIRA collaborates with other CSU departments to bolster skillsets available in pursuing diverse NOAA research. These include the Walter Scott Jr. College of Engineering (e.g., Computer Science, Electrical, Civil, Systems, and Mechanical), the College of Liberal Arts, Economics Department, and the College of Natural Resources. In addition, the School of Global Environmental Sustainability (SOGES) and the Geospatial Centroid (GC) at CSU provide ecosystems for multidisciplinary research. CIRA has collaborated with GC on join publications related to the COVID-19 pandemic lockdown in the US.

CIRA maintains informal and sometimes formalized relationships with private sector / industry partners when such relationships do not present a conflict of interest with our principal Federal sponsor(s). These partners (past and present) include:

Raytheon Technologies (RTX): A major aerospace contractor active in the environmental space sector. CIRA partnered with RTX on pursuit of the DoD Theater Weather Imagery and Cloud Characterization (TWICC) sensor.

Southwest Research Institute (SWRI): Major aerospace contractor active in the environmental space sector. CIRA has partnered with SWRI on NASA Earth Ventures opportunities.

Northrop Grumman Space Technology: Major aerospace contractor and builder of satellites and sensors that CIRA works with regularly, most notably JPSS. CIRA interacted closely with NGST during the early years of the Suomi satellite rollout.

L3Harris: Major aerospace contractor with a strong presence at all the major atmospheric science satellite conferences. CIRA has had discussions with them about GOE-R imagery support (they are the GOES-R Prime).

Ball Aerospace: Major aerospace contractor based in Boulder, CO, Ball has a long history of interaction with Colorado State University's Department of Atmospheric Science and CIRA. They built the CloudSat (major CSU-led NASA satellite mission) spacecraft.

The Aerospace Corporation: Major defense contractor, builder of sensors. They work closely with CIRA on some NOAA-funded projects in SmallSats right now, including this project in particular (https://aerospace.org/article/revealing-nighttime-images-cubesat.

Spire: Aerospace contractor who design/build/operate global positioning system constellations to measure vertical profiles of temperature and moisture. Some CIRA staff has transitioned to positions at Spire.

IMPACT

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

CIRA's vision to connect models and observations aligns with the objectives of our dual NOAA Line Office affiliations: OAR and NESDIS. Through our diversification of collaborations we enabled cross-pollination to the mutual benefit of NOAA, our domestic partner agencies, and the international community. CIRA's employ of young scientists, emphasizing graduate students and postdocs, sustains critical expertise. Some of our staff transition to Federal positions, fulfilling the objective of identifying NOAA's future workforce. CIRA's international partnerships establish close ties with future collaborators at NOAA's sister agencies worldwide.
CIRA's satellite research is germane to NOAA operations. Our suite of TC products, used widely by NOAA operational, advances forecast guidance. We showed how JPSS data can be used efficiently by forecasters, both as stand-alone products and by fusing with geostationary information to augment capabilities of high time-refresh applications. ABI and VIIRS imagery are made available to a wide variety of users in near-real-time, supporting aviation, fire weather and hydrology. Our SLIDER website is a popular resource for a wide variety of users and members of the public interested in satellite imagery. The CIRA Satellite Library extends the utility of SLIDER with pre-packaged satellite examples for broad public dissemination.
Our algorithms have made important impacts. We demonstrated that the NOAA operational algorithms can successfully produce the products for the upcoming METimage and show reasonable performance compared to NOAA satellite sensors such as VIIRS and ABI.
Our processing of GOES-R TPW data improves the quality of the operational blended TPW product and is being transitioned to operations in 2023. The validation, testing and blending algorithm development performed in this project supported this improvement. The new TPW product gives forecasters a better view of water vapor fueling destructive floods.
Our leadership in machine learning has enabled new applications, novel approaches to data-translation and assimilation, and advanced NOAA's abilities to leverage these powerful tools. To this end, we documented the information content present in ABI imagery for airmass characterization, using a three-way comparison of ML estimates, numerical weather prediction estimates, and radiosonde observations. Our AIRWOLF product is both demonstrating the viability of using machine learning to produce AMVs and setting benchmarks for future techniques to build upon.
Our satellite training continues to inform forecaster competency on the usage of basic and advanced satellite imagery and products in the forecast process.
We advanced NWP models with tangible impacts that will enable the future UFS. We demonstrated that machine learning can successfully be used to assimilate satellite observations efficiently in convection-resolving numerical models. Our real-time RRFS prototype provides the first step toward a future, operational convection-allowing ensemble model that will replace the current regional models.
Advances to AWIPS, VLab, TIM, LAMP, Hazards, and Decision Support services have enabled forecasters to quickly synthesize copious data into actionable guidance as they issue watch, warning, and advisory products to the public. Our MADIS efforts enable the assimilation of diverse data into the NOAA forecast models. GeoFLOW enables high order schemes and shows promising utility for high-resolution applications. Our verification work has provided valuable feedback on the development of new forecasting

IMPACT *(cont'd)*

38. What was the impact on other disciplines?

CIRA's cross-disciplinary theme, articulated in its CI re-competition proposal, extend to areas of social, health, and communication sciences.

CIRA research interfaces naturally with other disciplines. We impact transportation via our benefits to the FAA, NWS support of surface visibility hazards (blowing snow, dust storms), and ocean weather forecasts of fog, convection, and other hazards. Our merged vapor product used by hydrologists, including reservoir operators, to anticipate and manage major flooding events. Broadcast meteorologists use our blended vapor products to communicate the concept of atmospheric rivers to the public, and our ABI imagery to highlight weather hazards—improving literacy and awareness of NOAA's mission. As detailed in Box 36, we impact aerospace industry approaches to solving the critical observing system needs of NOAA.

To achieve societal benefit we must be very mindful of social/behavioral/economic factors, including a full awareness of the underpinning diversity, equity, inclusion, social justice and accessibility factors which determine who benefits from NOAA services and how.

CIRA collaborates with NCAR, CIRES, and GSL on NOAA-funded research to advance uncertainty communication for Integrated Decision Support Services. This work ties the new approaches to communication with an agile, web-based and cloud-ready platform called the Weather Archive and Visualization Environment (WAVE), holding the graphical capabilities to convey new types of information, with an initial focus on fire weather and winter weather. Training associated with the IDSS is tied to the National Weather Service Office of the Chief Learning Officer. This research resonates with NOAA's strategic planning to integrate these elements within the Weather Enterprise.

We continue to foster and grow its socioeconomic impact studies. An effort with the JPSS leadership team has developed a suite of collected end-user products for VIIRS, beginning with a summer workshop of VIIRS end users. Presenters from within NOAA, other federal agencies (including the Department of Agriculture and the Department of Defense), private industry, and foreign weather service agencies described the utility of VIIRS observations, including the use of Day-Night Band (DNB) data, for a wide range of applications, including (among other topics) ocean biology, flash flood forecasting and observation, fire weather monitoring and active wildfire management, economic development through city lights, operational ingest of VIIRS data for forecast models, and agricultural estimates for grain yields in Ukraine. Data from these end-user studies is being collated and processed to compute the socioeconomic value of VIIRS observations for the benefit of the NOAA mission for LEO missions.

CSU has helped CIRA make a significant strategic investment in Artificial Intelligence and Machine Learning. CIRA has fully integrated ML into the bulk of its research program, and helped the NOAA community take advantage of new/emerging tools to address a host of problems ranging from observation synthesis, to feature detection and image-to-image translation, to numerical

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

CIRA's training efforts provide continuing professional development opportunities to develop expertise in the use of satellite imagery and products. Our methods reinforce concepts of critical thinking, the cascading benefits of "training the trainer," emphasize the power of mentoring, and take advantage of peer-to-peer learning for effective and diverse exchange of information and ideas. Direct training of the NWS forecasters ensures they have the fundamental tools necessary for their positions. Certain project outcomes, such as VLab, enable staff to become more effective in their collaborations and software development.

An important element of Cooperative Institute program which further distinguishes it from the contractor arrangement is the access it provides to academic Faculty and their students. The creativity of the University environment is brought to bear on the high-risk/high-reward research challenges that NOAA must address in order to advance its models, observational capabilities, and forecaster tools serving the public.

IMPACT *(cont'd)*

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

With the 'return to normal' in a largely post-pandemic world, CIRA education and outreach activities. At the K-12 level, CIRA supports curriculum development and teacher training to support the State of Colorado Academic Standards; The CSU Little Shop of Physics (LSoP), a hands-on, physics-based education program hosted by the Department of Physics at CSU, a partnership with the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS). As part of our ML enterprise, CIRA has developed code for ethical AI support for middle- and high-school programs developed as part of CIRA's involvement in the NSF AI2ES program.

As a partner with the graduate-only Department of Atmospheric Science at CSU, CIRA's efforts towards undergraduate programs is focused primarily on developing undergraduate experiences, including taking on several new graduate students under CIRA direction. CIRA additionally supports Research Experience for Undergraduate (REU) programs, partnering with CSU's Department of Atmospheric Science, and provides 2-3 research mentors for REU student participants each summer, consisting of a ten-week focused research program on topics led and developed by CIRA staff.

CIRA continues to provide mentorship for NOAA Hollings Award scholars and NOAA William Lapenta Intern awardees, including support for student research, publication and conference presentations. Recent CIRA-supported Hollings Scholars include Marshall Baldwin (University of Oklahoma), and Angela Burke (University of Alabama-Huntsville). CIRA recently hosted Alvin Cheung (Penn State) as a William Lapenta Intern.

Of particular import is a new graduate support program to increase diversity and improve the viability of partner graduate programs for minority-serving institutes (MSIs). As further detailed in section 4e, CIRA has developed a direct-funding program to support graduate research education for MSI students at the M.S. and Ph.D. level, providing CIRA research staff as co-advisors for the graduate program, and fully funding the research and tuition for the student. The intent of the program is to erode the barriers to full inclusivity MSIs face when competing for graduate students and developing graduate programs.

CIRA participates in the NOAA Early Career Scientist Exchange Program, supporting graduate students, post-doctoral researchers, and early-career scientists to work with colleagues at NOAA institutes and CIs, including travel to the annual STAR/CoRP Science Symposium.

CIRA's corporate knowledge of the satellite enterprise extends to the beginning of the satellite era. We continue to develop the history of polar-orbiting (from TIROS to JPSS) and geostationary (from ATS-1 to GOES) operational environmental satellites. These stories are told at major science conferences, and offer "lessons learned" to guide future operational satellite missions. These materials are used in the classroom, and are provided to NOAA and the general community a way to inform and educate members of the operational satellite workforce.

Faculty are involved with NOAA research under our Cooperative Agreement, which CSU has incentivized (as a cost share) via a

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

CIRA's continued leadership of satellite algorithm development as related to the GOES-R and JPSS programs relies heavily on access to ingest of these satellite datasets in near real-time, allowing us to conduct research and development in a pseudo-operational environment. The near real-time processing of our algorithms enables their timely and relevant demonstration to operational users, ultimately facilitating in their transition to operations. It also provides a channel of feedback form the users to the developers, providing iterative improvements.

Our satellite data ingest is accomplished by CIRA's EarthStation, comprised of both direct broadcast equipment for GOES and internet-based file transfers. Our EarthStation, supported in part by NOAA/NESDIS and a critical part of CIRA's infrastructure, has evolved as new satellite sensors with higher spatial, spectral, temporal, and radiometric resolution have come online, with associated increases in data volume. To support research on retrospective case studies, CIRA stores the data it collects from GOES-R ABI (on -16 and -17, and soon -18) on disk (hot-storage). The ingest, storage, and processing infrastructure set up for existing sensors has enabled CIRA to advise NESDIS and the Direct Broadcast community of the resources required to produce and distribute METImage data products using proxy datasets in preparation for the upcoming launch of Metop-SG.

Leveraging the EarthStation and associated processing clusters is CIRA's Satellite Loop Interactive Data Explorer in Real-time (SLIDER; rammb-slider.cira.colostate.edu). Developed as a public facing demonstration tool, SLIDER continues to serve as a premier satellite imagery interface that is used regularly by researchers and the public alike. SLIDER imagery has supported flight planning for various field experiments and is used by some NWS forecasters to support their duties by leveraging imagery applications not yet in the operational pipeline. SLIDER is now regarded as a key element of CIRA's infrastructure—a critical cog in the R2O pathway—as it helps CIRA developers rapidly develop robust products.

CIRA also maintains a local AWIPS system AWIPS which enables development and demonstration of experimental satellite products being developed at CIRA to NWS forecasters for feedback and allows CIRA to provide guidance on the most efficient use of computer infrastructure to supporting AWIPS systems.

CIRA supports the GSL verification team's work, advancing the weather forecasting capabilities of NOAA. Technology is transferred in the form of weather model improvements from research at GSL to NOAA EMC, which in turn transitions it to operations at NCEP and NWS.

VLab itself is an infrastructure that enables software development best practices. Our VLab Team provides a high level of support to software developers. VLab Cloud has enabled the NWS to fully realize a cloud infrastructure. Collaboration with WMO VLab partners enhances the regional sharing of information resources that allow low-cost access and display of satellite imagery and products. For developing countries and in particular small island countries, this is an important addition to their infrastructure.

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

IMPACT *(cont'd)*

42. What was the impact on technology transfer?

As an applied research program, CIRA places an emphasis on transitioning our research products into operations (R2O) and nearly every CIRA project targets a transition path. Doing so augments NOAA's capability to analyze, predict, and respond to challenging weather scenarios, assuring a weather-ready nation and providing societal benefit.

One major technology transfer this year was the successful transition of SOS operations from GSL to the NOAA Office of Education via the OCIO in December, 2022, becoming the first official research-to-education operations transfer at NOAA.

Additional technology transfers include CIRA-produced improved near-surface temperature and dewpoint temperature profiles retrieved from NUCAPS) to individual NWS offices via LDM; updated geoTIFF formatted imagery products from VIIRS and ABI are being used by the DSRA Fire Project; ProxyVis imagery used for operational forecasting and post-season analysis at NHC; vertical cloud layer fractions for AWIPS-II and cloud layer products to AWC for evaluation; GeoColor imagery as an "On-the-Fly" product in AWIPS for NWS/WFO use; GeoColor products to NWS or NESDIS operations; the GeoColor algorithm to EUMETSAT for use on Meteosat Third Generation (MTG) Flexible Combined Imager (FCI); software for producing combined global water vapor from many satellites for forecasters to NOAA operations; Advected Layer Precipitable Water product and an upgraded blended Total Precipitable Water product algorithm to NOAA operations, along with required documentation and training; code and documentation for quantitative assessments of the Level 2 Cloud Base Height and Cloud Cover Layers Products from JPSS VIIRS sensors to the NOAA NESDIS algorithm team; integration of Metop-C sensor data into an already operational algorithm suite for two NOAA data products; weather model improvements from research at GSL to NOAA EMC, which transitions them to operations at NCEP and NWS; distance learning training courses for NOAA programs; and a Python graphics package to support assessing and verifying the model performance at GSL (pygraf) has been made available to the user community.

CIRA also participated in a number of R&D projects to inform approaches and decisions relevant to NOAA including investigating Metop-SG METImage data to inform the GeoXO Program's GXI and inform system requirements for the eventual dissemination of imagery products from METImage; providing a technical basis for transitioning the NOAA operational algorithms to the new EPS-SG METimage; providing preliminary product evaluation reports to help the NOAA GOES-R ABI team with CCL/CBH algorithm updates; and informing the upgrade of the systems to support the RRFS transition to operations.

Finally, CIRA supports others' technology transfer through development and maintenance of the VLab toolset and interface.

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

While CIRA's principal efforts revolve around science and technology, its ultimate contributions to society are far-reaching and multifold. CIRA's work in development of tropical cyclone products impact help better inform emergency management decisions, both domestically and internationally. Ongoing efforts to infuse social science into the framework of NWS communications will improve the correct and timely response to guidance.

We have demonstrated how Machine Learning (ML) provides a successful approach for leveraging observations that are otherwise not well handled by current data assimilation systems. Data assimilation benefits society by yielding more accurate forecasts.

CIRA's SLIDER website and customized imagery/videos allow the general public to engage with NOAA's state-of-the-art environmental satellite sensors, view current weather and monitor high-impact weather events, increasing awareness of weather sensors their value in every-day life. SLIDER is a go-to resource for forecasters in developing countries who rely on satellite imagery to issue weather-related warnings and advisories, yet do not have the infrastructure in place to acquire the full suite of data. The new CIRA Satellite Library has furthered this impact, especially in the realm of broadcast journalism; pre-formatted and broadcast-ready imagery and loops have been featured in the New York Times and Washington Post, including imagery from the Mauna Loa eruption and significant imagery coverage of Hurricane Ian making landfall in western Florida.

Contributions to the aviation community are increasing. NUCAPS improvements help forecasters advise commercial aviation on where to avoid hazardously cold conditions where jet fuel begins to gel. Interactions with NOAA operational users and local pilots in support of the JPSS Aviation Initiative yielded useful and improved satellite-based cloud products in support of aviation weather applications. Our algorithm for liquid-topped mixed phase clouds helps identify risk areas for aircraft icing. LAMP supports aviation planning and routing including potential use in AWC's Helicopter Emergency Medical Services (HEMS) Tool (Graphic Forecast for Aviation – Low Altitude [GFA-LA] Tool).

We are speeding up and improving the overall skill of NWP for the Unified Forecast System. The RRFS will become the flagship convection-allowing ensemble for the NWS, providing critical, life-saving forecast guidance for the public and economy. NWS forecasters and other agencies use our visualization web sites for guidance, which impacts society through public warnings and agency logistics. New forms of data assimilation (including lightning and direct-broadcast satellite radiances) improve severe weather prediction and guidance. Improved hazardous weather forecasts reduces economic losses due to transportation disruptions, and contributes to the NOAA Warn-on-Forecast and Weather-Ready Nation goals.

Our warning broadcast support helps the public learn about weather emergencies communicated to them via cellphones and NOAA Weather Radio. Improving the national blended-model guidance shared with NWS forecast offices and partners for tropical cyclones provides a direct impact on various means of transportation/shipping, emergency management, and safeguarding of the public and

IMPACT *(cont'd)*

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

0 , 0%, neglecting foreign travel expenses for U.S. researchers which were almost non-existent during this past pandemic-influenced year.

CHANGES/PROBLEMS

45. Changes in approach and reasons for change

In some cases, changes were made to take advantage of new or improved tools or to otherwise improve project outcomes. For example, many projects embraced greater utilization of cloud technology and machine learning techniques. Some of these changes also required bringing in additional expertise such as the project to create supervised machine learning algorithms to readily available GOES-R ABI L1b and L2+ products added staffing to enable expanding the original random forest technique to include both pixel-based and convolutional neural networks, which also allowed for the exploration of combining techniques. Another change to improve project outcomes was moving to a more formal reporting template and schedule to improve communication with project sponsors for the GOES-R Proving Ground for NWS Forecaster Readiness and Training project.

In other cases, changes were made in response to external issues. With the delay of the TROPICS launch, projects used proxy and Pathfinder data for development. With the lack of readiness of readiness of JEDI and RRFS+JEDI, the first version of RRFS uses GSI instead tests are being conducted in that system instead of in HRRR. For GSL model visualization, the data ingest method being used does not allow for updates of other modules, so other methods of data ingest are being investigated. Finally, with the NOAA OAR mandate that SOS operations transition from GSL to another institution, GSL will no longer do the SOS development work.

CHANGES/PROBLEMS *(cont'd)*

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

In the research and development paradigm, problems (both anticipated and unanticipated) are expected. CIRA has operated in this environment successfully for 43 years and running, and its innovative staff never fail to devise creative solutions to overcome whatever hurdles confront them.

Several projects experienced delays related resources. For many CIRA projects, team members often have specific expertise that is difficult to replace, which can lead to complications when there is staff turnover or staff that work on multiple projects. A retirement on one team required training a new team member on use of the CRTM. Other projects, including GeoFLOW and the Operations Proving Ground, lost key team members to new positions and are working to hire replacements that will need to be onboarded and trained. The Feature Matching for the National Blend of Models (NBM) project is reliant on a sole developer with competing priorities and the team is working to update tasking and deliverables. The RRFS project experienced delays due to resource deficiencies, specifically lack of JCSDA JEDI training in 2022 and lack of access to JCSDA-internal for code check-in. The team expects to attend the next JEDI Academy and has requested JCSDA repository access.

Other projects experienced delays due to changes in mission milestones and data availability. For example, the delay in the NASA TROPICS mission, the delay in Metop-C data availability, the delay in availability of polar-orbiting satellite wind data, the delay in RRFS timeline, and the delay in overall adoption of JEDI for regional FV3 system led to adjusting the timeframe and/or scope of affected CIRA projects.

Infrastructure changes have impacted the timeline of several projects. The Scott Data Center on the CSU Campus that houses the computing and storage hardware for many CIRA projects is currently at capacity and undergoing an expansion. Hardware purchases at CIRA in Fort Collins have been put on hold until the expansion is complete. Operating system upgrades to flavors of RHEL8 have been made at CIRA and NCEP NCO, which affected many pieces of software. Finally, mitigations and resolutions for a network issue between the NCO datacenter in Boulder to a main IMS data source, NESDIS' PDA are being investigated.

47. Changes that had a significant impact on expenditures

Several staff member's allocations on SOS were reduced in 2020 due to funding a shortfall. These allocations were never fully restored even after new NOAA funding was obtained for the program, so expenditures on salary remained at a lower level. Those staff members departed the project at the beginning of 2023 and will be replaced this year by new staff, including one at CIRA.

The expansion of distance learning training courses that take advantage of online coursework reduced travel expenditure and reduced the training timeline by one day each.

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

The pandemic and ongoing remote-work arrangements have affected all CIRA staff. The University has been very flexible to allow telework via a formal process that ensures a safe and productive at-home work environment and with proper management/oversight of CSU Supervisors.

The SOS program staff and responsibilities was split between GSL in Boulder, CO and NOAA Office of Education in Silver Spring, MD.

PROJECT OUTCOMES

50. What were the outcomes of the award?

CIRA supports the NESDIS, OAR and NWS line offices and several different Labs therein. As such our research outcomes span a diverse range of themes.

We continued to develop multi-sensor satellite products for weather hazards and tropical storms, atmospheric motion, 3D cloud and moisture related products, provided cal/val support to ABI and VIIRS imagery/cloud products. We produced cutting-edge imagery enhancements used widely by NOAA. Our training efforts accelerated NWS awareness of JPSS and GOES-R capabilities, enabling better integration into the operational weather forecast cycle, with extension to international partners. As subject matter experts we helped prepare NOAA for future sensors, advised on priorities for future GeoXO capabilities. We remain a world-leader in nighttime visible science.

We spearheaded novel Machine Learning (ML) techniques to advance environmental prediction and to process/extract/synthesize new information from satellite data. We have synthesized microwave imagery for tropical analysis, assimilated GOES ABI/GLM-derived synthetic radar data into the RRFS, and developed super-spatial resolution imagery. We conducted to socialize ML, coordinated internal, lab-wide, community-scale meetings, and made strategic investments to align CSU's ML expertise with the needs of NOAA toward trustworthy AI tools.

We provided core support for NOAA's migration to the UFS, including transition of tools (e.g., UPP) from the DTC. Ongoing improvements in numerical modeling, data assimilation (including radar and lightning), and computational methods led to increased accuracy and faster runtime. We further advanced the RRFS prototype. We released several versions of WRF-Chem and HRRR-Smoke, and demonstrated improved forecasts in areas affected by wildfires.

Our work with the DTC provides a framework for collaboration, accelerating the transition of new techniques into operational weather forecasting and introducing new verification metrics for the RRFS. Our development and maintenance of web-based verification toolset supports key Regional/Global weather modeling development and assists modelers in their effective use of those tools.

Our support of the Aviation Weather Testbed and Operations Proving Ground enabled cutting-edge products/tools to enter the operational pipeline, exposed NWS field offices to the power of satellite products and their impact on social science and decision support tools. We fostered partnerships in R2O supporting aviation weather safety and related improvements in national traffic flow management, assessments, training, and evaluations of internal, external, and AWRP-sponsored research. These R2O initiatives continue to involve collaboration across the FAA and participating NOAA testbeds.

We continue to integrate, demonstrate and evaluate new forms of information in the forecaster environment. We made various NWS Impact-based Decision Support Services, VLab, WSUP, TIM, LAMP, SBES and NBM guidance tools more reliable, robust, and socialized among NWS users and partners. These tools are gaining traction in the forecast offices, and we are working to develop a framework for nationally consistent and

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.