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

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| **RECIPIENT ORGANIZATION** | |
| 20. Recipient Name:<br>COLORADO STATE UNIVERSITY | |
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| 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 helping forecasters understand and make the most of environmental satellite information.
Regional to Global Scale Modeling Systems: leveraging 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: improving short to long-term forecast models via integration of multi-sensor observational datasets, system process-oriented research.
Data Assimilation: Developing tools/techniques that connect forecast models with observations to provide the best possible description of the current 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 research themes are enhanced by cross-cutting activities in Societal and Economic Impacts (connecting our research to societal benefit), and Education and Outreach at the graduate and post-doc levels within our research. These activities help NOAA to articulate its mission to benefit society, and reflect our core mission as a University-based Institute to educate students, engage the public, and populate the future technical workforce of NOAA and the Nation.

CIRA's Strategic Plan to achieving our goals is as follows:
• Entrain skills beyond the traditional meteorology disciplines in support of proposals and infrastructure development.
• Diversify our funding portfolio 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 excellence in these areas.
• Identify research projects and evolve research themes in coordination with NOAA and in light of the long-term research trends and resident 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.
• Facilitate transitional activity between pure and applied research and develop applied research results that are both relevant to our government sponsors' missions and supportive of the CSU 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, exploitation, and optimization of satellite, aircraft, and ground sensors.
• Partner with Federal and State agencies and laboratories to assure that our federally funded research is both cost-efficient and non-redundant at the National level.

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

CIRA is collocated not only with Colorado State University in Fort Collins, but also with a number of NOAA Labs and Centers across the nation. These connections offer opportunities to address our research goals in multi-faceted ways. The following are two examples demonstrating synergy with our partners at the AWC and GSL respectively. CIRA's internal report has more detailed accomplishments in the RPPR format for each of our CA projects.

CIRA's Regional and Mesoscale Meteorology Branch (RAMMB) focuses on Satellite Algorithm Development, Training and Education. Within the GOES risk reduction framework, CIRA worked on a Machine Learning project for low cloud detection from satellite imagery. Such clouds are difficult to detect when multiple cloud layers are present, but very important for aviation. This project led to CIRA now publishing an experimental cloud cross sections based on ABI observations, for use by general aviation pilots.

In a separate project to connect GOES-R with Rapid-Update Numerical Forecast Models for Advanced Short-Term Prediction and Data Fusion Capabilities, CIRA scientists developed the GOES Radar Estimation via Machine Learning to Inform NWP (GREMLIN) – described in Hilburn et al. (2021). This code simulates ground based radar observations such that HRR model can directly assimilate GOES data where no ground based radars are available (e.g. Gulf of Mexico). Parallel work under OAR auspices, trying to assimilate the GOES Lightning mapper are ongoing at GSL.
CIRA's staff in the Global Systems Laboratory (GSL), hold scientific, engineering, and leadership roles in every division in GSL plus the Director's Office and across a wide range of projects. We provided research, development, demonstration, and management support of Data Distribution, Data Assimilation, and Regional to Global Scale Modeling Systems goals. Some examples include work on the Advanced Computing Project. A key focus is on preparing for efficient operation on soon-to-emerge exascale platforms, which will allow 1018 floating point operations per second, roughly 50-100 times the speed of the fastest hardware available currently.
CIRA researchers in GSL's Data Assimilation Branch made progress on Satellite Radiance Data Assimilation for RAP/HRRR – highlighting the synergy between data assimilation work funded by NESDIS in Fort Collins and OAR in Boulder.
CIRA also supports the Aviation Support Branch (ASB) at the Aviation Weather Center in Kansas City. CIRA staff is split into three teams including IT, Web, and Science. Major accomplishments have focused on expanding the graphical products to Alaska and the Pacific, implementation a new World Area Forecast System (WAFS) 0.25 degree hazard grid, and testing new products including Convective Probabilities, Icing in Alaska.

CIRA's NESDIS Environmental Applications Team (NEAT) in College Park, MD, focuses on developing, demonstrating, and transition cutting-edge new capabilities to convert environmental sensors' data to actionable information. CIRA's efforts focused primarily on NOAA's Ocean Color (OC), Microwave integrated Retrieval System (MiRS), and the Community Radiative Transfer Model (CRTM) teams, expanding each to work with new satellites to produce complete, well calibrated, climate data records.

*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?

The CIRA Cooperative Agreement is not a single project but consists of individual projects carried out in Fort Collins with NESDIS' Regional and Mesoscale Meteorology Branch (RAMMB), OAR's GSL and NWS's MDL and AWC. Some of these groups work on a single project while other work on distinct individual projects. As such, it is difficult to provide a single or coherent description of training and professional development opportunities for CIRA staff. Nonetheless CIRA offers some high-level training and professional development opportunities to all its employees.
1. The Colorado State University, CIRA offers training in both Diversity, Equity and Inclusion, and well as management fundamentals to those individuals who are already, or are expecting, to supervise others.
2. Through investment from Colorado State University and CIRA, we offer support in Machine Learning. This is done through a core team consisting of 1.5 FTE whose sole purpose is to help CIRA staff interested in Machine Learning to become proficient in the basics. They teach introductory courses (on line during the pandemic but always intended to be remote for the benefit of all the remote CIRA staff), as well as working with staff to find individual solutions to problems. They have also been effective in connecting CIRA staff from various locations who are using similar techniques and can thus benefit from each other's work.
3. Through investments by CIRA, we have a software support group that connects across all CIRA locations to share best practices in software development and maintenance.

CIRA, through funded projects and Task 1 funding, also offers a host of training opportunities to the NOAA community. An important component of transferring research results into operational utilization of satellite information is a strategy for engaging, educating, and training the operational user community on the best use of new products and applications. CIRA continues to provide 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. To expand training efforts beyond the US, CIRA utilized and played an important role in the progress of the WMO Virtual Laboratory for Education and Training (VLab) and its management group (VLMG).

For the first year of the new Cooperative Agreement, CIRA developed teacher-training workshops covering fifth- and third-grade weather standards, with a goal that educators be able to effectively teach weather and climate topics and meet education standards. CIRA planned to offer a one-week workshop at the end of the school year, hosted by the Poudre School District, as part of a district-wide professional development/continuing education program for teachers. The 2020 workshop series was cancelled as a result of the coronavirus pandemic, but the planned workshop will continue in early summers for the rest of the award period.

As with the teacher training, CIRA partnered 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 Colorado State University. Improving upon previous recruitment efforts, CIRA traveled to New York to host a seminar, in-person and live-streamed to minority- and Latinx-serving institutions (including Howard University and the University of Puerto Rico.) This program too, was on hold during 2020 but is resuming in 2021 with CIRA providing slots for 3 undergraduate students.

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

The results of CIRA research were disseminated widely to several communities of interest. For convenience, it's possible to group those communities into four general types:

• To the scientific community, results were disseminated externally through peer-reviewed publications and presentations at scientific conferences
• Internally to the scientific community, workshops and professional development opportunities were provided to further extend CIRA research results
• To the general public, through media engagement on scientific results and/or for real-time events (e.g. hurricanes, fire weather, etc.), and to
• Education – through K-12 interaction, educator professional development, citizen science engagement, and public affairs activities.

The primary avenues of dissemination of CIRA research results are through external methods through publications and presentations, and through internal methods including workshops, professional development courses, and collaborative research. A comprehensive response to how results were disseminated externally through publications and presentations is included in our response to question #29 – a wide range of presentations, publications, and conference papers covering the breadth of CIRA research is provided. Notably, CIRA has had several high-profile publications and presentations on our key research activities, especially with regard to new satellite product retrievals.

Likewise, a good deal of detail on CIRA's efforts to expand research results and knowledge for training, workshops, and professional development was provided in our response to question #26. A good deal of learning materials were disseminated through in-person workshops led by CIRA, through the training VLab and VISIT programs, as well as through webinars, online modules, blog entries, 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.

Significant media exposure during severe weather events, notably tropical storms, is another avenue of dissemination of CIRA research products. Through articles in major newspapers (New York Times, Washington Post, etc.) and through in-person interviews with subject matter experts at CIRA, the research products developed at CIRA are given a wider audience. CIRA's Geocolor imagery of GOES data is used in many press products.

Finally, direct dissemination of select CIRA research results is made possible through education and outreach efforts. The aforementioned fire temperature product, in concert with GeoColor imagery and through use of the SLIDER tool, becomes a powerful tool in the hands of teachers and K-12 students, requiring minimal training to use to diagnose fire conditions and critically, smoke impacts for mountain communities. SLIDER, Science on a Sphere (SoS), and other public-facing imagery products provide a public interface for interested citizens to have hands-on experience with CIRA-derived research products, including educational activities on tropical storms, lightning, and the impacts of severe weather.

## ACCOMPLISHMENTS *(cont'd)*

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

CIRA's Meteorological Satellite Applications, Tropical Cyclones, and Satellite Training teams will continue to support NESDIS across a broad spectrum of projects ranging from basic research to implementation, and from calibration/validation of current sensors to assisting NOAA with envisioning its next-generation satellite observing system. CIRA's work with GOES-R ABI imagery and cloud geometric thickness products will continue with algorithm refinements and demonstrations in AWIPS/NAWIPS. Our strategic investment in machine learning will continue to advance, both via dense and convolution neural network architectures, enabling new ways to assimilate data into NWP, advancing sounding capabilities, and synthesizing new channels of information. CIRA's participation in the Satellite Proving Ground, offering direct connection between researchers and forecasters, will continue to afford opportunities to accelerate research to operations.

Together with our partners at GSL, CIRA's main goals may be summarized as:
- Releasing another major MADIS upgrade and transferring to operations. Included in the release are many new sfc provider and aircraft data.
- Finalizing the implementation of GSI into the RRFS development prototypes running at GSL, continuing the transfer of RAP/HRRR physics into the FV3- LAM, and testing the new North-American RRFS 3-km domain.
- Testing the JEDI DA software package and the creation of a real-time RRFS ensemble.
- Migrating the radiance assimilation capabilities (including JPSS DB data and GOES-16/17 radiance data) to the FV3-based Rapid Refresh Forecast System (RRFS).
- Creating a new forecast verification infrastructure to read in weather data, manage it, and connect it to plotting software that is dynamically created by an analyst.
- Continuing impact-based assessment of products in support of aviation needs

- At the Aviation Weather Center, goals for next reporting period consist of:
- Building out a mobile capability for https://www.AviationWeather.gov
- Developing a Graphic Forecasts for Aviation - Low Altitude to use as a replacement for HEMS
- Continuing AWIPS development for the operational forecast desk transition project
- Rebuilding the workstation and dataflow setup at the AWC backup sites
- Providing demonstrations of forecast consistency of icing and cloud forecasts on GFA
- Collaborating with the FAA and NCAR to advance the operationalization of the Ensemble Prediction of Oceanic Convective Hazards (EPOCH)

Together with STAR employees in College Park, Maryland, we will continue to conducted calibration, processing, and algorithm development. The MiRS team will explore an AI-based radiometric bias correction to minimize errors further in retrieved geophysical parameters. A modern web-based application to visualize multiple ocean parameters and associated natural events, developed in the Satellite Oceanography and Climatology Division (SOCD) and currently in the alpha phase, will provide the public with interactive and

## PRODUCTS

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

A considerable number of publications, conference papers, and presentations as a result of CIRA research were published during the previous reporting period – a comprehensive list of all publications, papers, and presentations are provided as an attached appendix. An example from each of CIRA's 5 research themes are provided here.

Weather and Climate processes project: Enhancing NIDIS drought monitoring and early warning in the Intermountain West
We are now producing soil moisture maps that include available plant water and dryness percentiles for drought monitoring. This includes producing crop-specific products to highlight drought stress (related to precipitation deficits and atmospheric demand) on specific crops.

Goble, P.E., R.A. Bolinger, and R.S. Schumacher, 2021: A CONUS-wide standardized precipitation- evapotranspiration index for major U.S. row crops. Journal of Hydrometeorology. Under revision.

Satellite Algorithm Development, Training and Education project: CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting. GOES-R Water Vapor Products.
A new blended TPW product was created, which is informally called BTPW_2020. Based on forecaster evaluations and validation completed during this project, a hierarchical blending approach was created with datasets overlaid in this order: GOES_R > GPS > Advected Microwave. Following on to encouraging forecaster reviews and validation results in 2018-2019, a new blended TPW product is being produced hourly and is available at http://cat.cira.colostate.edu/btpw_2020.

National Weather Association Annual Meeting. John Forsythe presented the virtual talk: "Multisensor Satellite- Driven Water Vapor Products for Forecasters". There were about 300 attendees.

Satellite Algorithm Development, Training and Education project: CIRA Support to Connecting GOES-R with Rapid-Update Numerical Forecast Models for Advanced Short-Term Prediction and Data Fusion Capabilities
This project simulated ground-based radar reflectivity from GOES VIS/IR imagery using Machine Learning methods. The other important outcome of this project was development of visualization techniques to explain what the ML was learning and how it is making its predictions

Hilburn, K. A., I. Ebert-Uphoff, and S. D. Miller, 2021: Development and interpretation of a neural network- based synthetic radar reflectivity estimator using GOES-R satellite observations. J. Appl. Meteor. Climatol., 60, 3-21, doi: 10.1175/JAMC-D-20-0084.1.
Ebert-Uphoff, I., and K. A. Hilburn, 2020: Evaluation, Tuning and Interpretation of Neural Networks for Meteorological Applications, Bull. Amer. Meteor. Soc., 101, E2149-E2170, https://doi.org/10.1175/BAMD-D- 20-0097.1.

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

30. Technologies or techniques

Development of technologies and techniques that are transferred to NOAA are invariably part of longer-term interactions between NOAA and CIRA and thus difficult to assign to individual grants or projects. Nonetheless some projects are more research related and tend to produce publications while the projects listed here tend to focus more on product development.

CIRA's Satellite Algorithm Development, Training and Education, aside from developing the Slider tool for visualizing satellite VIS/IR data, has now also developed a proxy night-time visible radiance product from GOES-ABI radiances. The full application suite of this new product are still being tested but include applications such as fog, and fixing TC centers when the low level circulation is displaced from the high clouds.

CIRA developed the GeoColor product which has gained widespread use at the NWS WFOs, as well as at the Ocean Prediction Center (OPC), National Hurricane Center (NHC), Aviation Weather Center (AWC) and the Center Weather Service Units (CWSUs). GeoColor imagery is regularly featured in materials shared by these groups on social media (Fig. 1). This product is available in AWIPS-II and NAWIPS displays. Forecaster feedback has been overwhelmingly positive. Based on a user request, GeoColor is now being transitioned into operations as a "baseline" GOES-R product.

CIRA Research Collaborations with the National Weather Service Meteorological Development Lab
The National Weather Service (NWS) has created a service and IT framework that enables NOAA, in particular the NWS, and its partners to share ideas, collaborate, engage in software development, and conduct applied research from anywhere. The following represent key technologies being developed.

VLab - The project's objectives are to (1) Reduce the transition time and cost of NWS field innovations to enterprise operations; (2) Minimize redundancy and leverage complementary, yet physically separated, skill sets; (3) Forge scientific and technical solutions based on a broad, diverse consensus; and (4) Promote a NOAA/NWS culture based on collaboration and trust. CIRA efforts are integral to the development and maintenance of the following systems:

AWIPS - an open source, service-oriented architecture (SOA) used by the National Weather Service for interrogation/display, forecast preparation and dissemination of weather data and products.

CIRA's Global and Regional Model Development, along with CIRES researchers, has contributed heavily to efforts to upgrade and improve the Finite-Volume Cubed-Sphere (FV3) model. These groups have also been instrumental as RAPv5/HRRRv4 was operationally implemented at NCEP on December 2020. The upgrade packages of RAPv5/HRRRv4 included radiance upgrade from the work Radiance Data Assimilation for RAP/HRRR project.

Work at the Weather Information Systems Branch at GSL's Evaluation and Decision Support Division created a number of tools

31. Inventions, patent applications, and/or licenses

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.
Status: The patent application has gone back and forth through three rounds of office actions between the Patent Office and Kevin Micke, CSU Ventures, and the Polsinelli law firm representing CIRA. There has been no progress since the last report.

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

32. Other products

CIRA develops several other products related to our research:

• GeoColor imagery is in extremely high demand, especially by the commercial sector. Although the product is beyond the disclosure window eligible for patent, the source code can still be licensed to facilitate distribution and tracking.

• CIRA's Loop of the day, displayed on the CIRA Landing page https://www.cira.colostate.edu/ 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.

• Through the auspices of the VISIT program, a good deal of 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've encountered online, either through CIRA social media or through use of such tools as SLIDER.

CIRA has also created updated brochures for public dissemination, detailing the basics of CIRA research. The CIRA brand has also extended online, through a greatly updated website with improved navigation and product delivery, to social media, 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?

Nothing to report. Senior management remains in place, with
Christian Kummerow, Director
Steven Miller, Deputy Director
Bonny Strong, Associate Director
Beth Kessler, Assistant Director

35. What other organizations have been involved as partners?

CIRA researchers enjoy a wide range of collaboration, within NOAA laboratories outside of the direct CI partnership chartered by CIRA, to other governmental and non-governmental agencies. Collaborative research with other CIs, to include the Cooperative Institute for Research in the Environmental Sciences (CIRES), the Cooperative Institute for Meteorological Satellite Studies (CIMSS), and the Cooperative Institute for Mesoscale Meteorological Studies (CIMSS) constitute many of the most fruitful interactions CIRA has with outside partners. 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), Federal Aviation Administration (FAA), and the National Center for Atmospheric Research (NCAR). There exists considerable collaboration with the National Aeronautic 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 with includes:

- NSSL
- NHC
- NCEP
- CIMSS
- CIMMS
- CIRES
- NRL
- NREL
- JTWC
- NASA
- FEMA
- FAA
- United States Air Force
- University of Oklahoma
- University of Akron
- University of Alaska-Fairbanks,
- Bureau of Meteorology, Australia
- Taiwan Central Weather Bureau
- UCAR/COMET
- NCAR

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

### 36. Have other collaborators or contacts been involved?

The bulk of CIRA research happens through organizational contacts (see response to question #35 for comprehensive details on which organizations.) For the most part, contact between CIRA researchers and individual points-of-contacts for those organizational links comprise the collaborative work done with individuals. CIRA research work during the previous reporting period which had significant effort with individuals, rather than through the organization represented by those individuals, includes direct contact with:

- David Lewis (NRL)
- Alex Griswold (Harvard)
- Harry Lawrence (BBC)
- Kathy-Ann Caesar (Caribbean Institute for Meteorology and Hydrology)
- Marcial Garbanzo, Anthony Segura (University of Costa Rica)
- Angelica Gutierez, NOAA/NWC
- Curtis Alexander (NOAA/GSL)
- Jian-Wen Bao (NOAA/GSL)
- Mark Govett (NOAA/GSL)
- Jeb Steward (NOAA/GSL; Formerly CIRA)
- Lars Jens, filmmaker

## IMPACT

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

Connecting models with observations is a core vision of CIRA which aligns with our dual NOAA Line Office affiliations with NESDIS and OAR. CIRA has advanced cross-pollination within its principal disciplines in a number of ways—to the benefit of NOAA, our domestic partner agencies, and the international research community. CIRA's hosting of a Data Assimilation internship program has provided an infusion of knowledge to a new generation of young scientists, developing critical expertise that has produced 'graduates' that are contributing to NOAA research directly, as well as training international scientists.

Two noteworthy projects to more fully exploit GOES-16 and -17 observations to better initiate convection in the High Resolution Rapid Refresh (HRRR) model (described in box 25 – one by Fort Collins staff to simulate radar reflectivity from GOES radiances for assimilation into HRRR and one by GSL staff to assimilate GOES radiances directly into the model), This highlights the benefit of not only the traditional tracks of Satellite Algorithm Development done by NESDIS and Model improvements done by OAR, but of the synergy when both are working together towards a common goal.

CIRA's vision of connecting between models and observations is also embodied by our Data Assimilation goal. Our work to assimilate new satellite observations GLM observations (e.g., 2018 Hurricanes Florence, Gordon, and Michael), is helping NOAA assess the impact new observations on HWRF forecast accuracy. We are addressing the shortage of U.S. scientists having data assimilation skills by continuing our Data Assimilation Internship program, where interns work on NOAA problems over a six month term, learning data assimilation theory and practice, and translating this knowledge to new capabilities on NOAA systems. While 2020 was difficult for internships, we may be able to restart in 2021 or 2022 and not the benefits this may have to meet some of the workforce diversity issues that we, along with other CIs are dealing with. We have modified the HWRF workflow to support Inter-Cycle Data Assimilation (ICDA), enabling data assimilation in between full forecast cycles and vortex adjustment at non-synoptic times. Our Meteorological Assimilation Data Ingest System (MADIS) development work targets improvements to weather forecasting, weather warnings and products, and facilitation of data assimilation into NOAA models. In these and other ways, we are a core enabler of model/observation connections.

Addressing our Data Distribution goal is another way that we enable our connecting vision. Our High Performance Computing projects enable NOAA's new FV3 dynamical core and its move toward a unified forecasting system. Our development of the Weather Archive and Visualization Environment (WAVE) tool is putting forecasters in position to take advantage of new, forward-thinking methods of communicating model and observation information. Public-facing websites as are being developed by CIRA scientists at eh AWC, and Data Explorer in Realtime (SLIDER) are all examples of how CIRA communicates the fruits of NOAA research to the general public in ways that are not only informative but also practical to personal decision making in our everyday lives.

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

38. What was the impact on other disciplines?

CIRA research activities interact with other disciplines in a complementary way – often a research product developed or promulgated by CIRA finds application in fields far beyond the initial sphere of influence. Specific activities are noted herein for the previous reporting period.

An important cross disciplinary interface that CIRA has fostered over the past year is socio/economic impact studies. Work coordinated between CIRA, NOAA, and CSU's Department of Economics and Agricultural and Resource Economics has led to an economic analysis of improved weather forecasts. Specific economic and personal decisions reliant on the accuracy of weather forecasts include commuting to/from work, optimizing the blend of renewable energy resources, deciding on irrigation strategies for agriculture production, and impacts on tourism. The team has focused on the NOAA HRRR model to determine the accuracy of forecasts at critical times and locations (having the greatest impact), including "big misses" in temperature, precipitation, and wind. The early results are helping NOAA to understand performance and biases differences in their developmental HRRR2 and HRRR3 models. The same team has also worked the Automated Quantitative Precipitation Information (AQPI) project to assess the economic impact of predicting catastrophic floods 6-12 hours earlier than is currently possible.

Social, behavioral, and economic sciences are also being applied toward forecaster decision support and training. CIRA participates in a team that includes NCAR, CIRES, and NOAA/ESRL/GSD on NOAA-funded research to improve high-resolution ensemble uncertainty communication for Integrated Decision Support Services. The 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. In 2020, CIRA stood up a societal impacts group, funded internally, to make progress in both decision support areas as well as health outcomes of weather events. We should have more to report next year as the internally funded activities get underway.

A major effort that couples NOAA to engineering resources at CSU is CIRA's initiative in Artificial Intelligence and Machine Learning. Over the past year, CIRA has helped to bring together a diverse NOAA community interested in taking advantage of new/emerging tools in machine learning to address a large host of problems ranging from feature detection to numerical modeling improvements. The connections have ranged from small technical exchanges, to moderate workshops, to large multi-day conferences held at ESRL, CSU, and College Park. CIRA has made a financial investment in furthering NOAA's capabilities in this discipline by connecting with Dr. Imme Ebert-Uphoff from CSU's Electrical and Computer Engineering Department, and providing resources for a postdoc who will sit at ESRL/GSL.

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

Thirty one (31) graduate students total worked on CIRA projects. Of these, seven (7) were fully funded on CA projects.

Four (4) CIRA employees were offered and accepted Federal positions with NOAA during this period: Ken Fenton, Nathan Hardin, Ken Sperow and Isidora Jankov.

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

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

The last year (2020) has been unusual in that few activities were allowed that entrained new students into the NOAA portfolio. However, CIRA expects to continue with the Research Experience for Undergrad (REU) programs, in concert with the Department of Atmospheric Science in 2021 (remotely). Undergraduate researchers, often recruited from minority-serving institutions get a comprehensive immersion in a scientific research topic of interest to the student and of need to NOAA in general. In Year Six, CIRA recruited three minority-background students from the City College of New York to participate in the 2020 REU program (since cancelled due to the ongoing coronavirus pandemic.) The three students had research interests in machine learning, numerical weather prediction, and cloud processes and radiation. Had the REU program been offered, these students would have been partnered with CIRA researchers and given opportunities to perform research leading to NOAA-focused research careers. Leveraging support from the Assistant Dean of Diversity and Inclusion, CIRA is poised to expand this recruitment effort during the new award period.

CIRA has also begun a program to foster collaboration between CIRA researchers and CESSRST faculty. To foster such collaboration, CIRA is funding two liens that each support a graduate student's tuition and research assistantship, as well as one month of summer salary for the host faculty member. The student would stay at the original institution but because of the collaborative research, it is hoped that these students would find a very natural path to employment at CIRA as soon as they graduate. The program was conceived in 2020 to start in fall of 2021.

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

CIRA's continued leadership of satellite algorithm development related to the GOES-R and JPSS programs relies heavily on access to ingest of these satellite datasets, 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.

This data ingest is accomplished by CIRA's EarthStation, comprised of both direct broadcast equipment for GOES and internet-based file transfer for JPSS. The EarthStation 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 Himawari-8 AHI, as well as selected imagery products. To minimize processing time associated with data transfers, we have deployed a cluster of processing machines adjacent to the data ingest system.

Riding atop 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 has blossomed into a premier satellite imagery interface that is used regularly by researchers and the public alike. SLIDER imagery has supported flight planning for the WE-CAN experiment, CAMP2Ex, and FIREX-AQ to name only a few examples. SLIDER is now regarded as a key element of CIRA's infrastructure—the tip of the iceberg in terms of visualizing the outcomes of CIRA's mature satellite data processing infrastructure.

CIRA's Research Collaborations with Information and Technology Services in the ESRL Global Systems Division's (GSD) Information and Technology Services (ITS) group develop and maintain systems that acquire, process, store, and distribute global meteorological data in support of weather analysis, modeling, and information systems projects throughout GSD. The CIRA team collaborates with ITS systems, networking and security specialists and numerous GSD researchers to provide reliable services that meet project requirements. The team works to improve and extend ITS data handling and monitoring capabilities to increase reliability, better utilize GSD resources, and provide additional services. In the past year, the GSD team has begun to interface with the CIRA Software Engineering Group (CSEG) in Fort Collins, sharing best practices and building the CIRA infrastructure.

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

42. What was the impact on technology transfer?

One of the key goals of the Cooperative Institute program, and CIRA research in particular, is the transitioning of research products to operations (R2O). Any time active research is transitioned to an operational sphere marks a major impact on the improvement of our national capability to analyze, predict, and respond to our evolving Earth system, in support of NOAA goals for a weather-ready nation. A comprehensive detailing of technology transfer brought about by CIRA research during the previous period would greatly exceed the scope of this summary; notable examples of technology transfer include:

GeoColor algorithm and SLIDER: the GeoColor algorithm, developed at CIRA, has been delivered to NOAA in an operational sense, and represents a key tool for NOAA's ability to communicate data from the ABI instruments aboard GOES-R series spacecraft and for forecasters to readily assess and understand the state of the atmosphere as observed from space.

The Satellite Loop Interactive Data Explorer in Real-Time (SLIDER) tool, which was transitioned to public online use in the last reporting period, represents a paradigm shift in how real-time satellite data is delivered. Operational and research products alike are readily displayed in an intuitive, user-friendly manner, including the ability to create URL-saved custom loops and imagery, and has seen widespread use by multiple government agencies, media outlets, and interested citizens alike.

National Hurricane Center Products: Several key upgrades to track and intensity forecast products, including LGEMS, SHIPS, and GRII were delivered by CIRA researchers, including capabilities to ingest lightning data and retrieved cloud-top particle size to improve hurricane forecasting. Development of proxy-visible imagery from GOES (to supplement polar-orbiting low-light imagery from the Day-Night Band (DNB) instrument) is also being used to improve forecasting and detection of storm motion, as well as provisional implementation of the Satellite Eye Detection Algorithm (SEDR).

Flagship website delivered: the premier site for aviation weather, www.aviationweather.gov, was launched as part of the effort of CIRA researchers in collaboration with the Aviation Weather Center.

Other notable technology transfers include:

- The blended total precipitable water product (TPW) developed at CIRA has been transitioned into operational use within AWIPS,
- Flash-flood geospatial dataset delivered to Fresno WFO AWIPS,
- Lightning menu, WP-3D doppler, and GOES-17 data into NHC guidance/AWIPS-II ingest
- Updated HGPROF rain-rates delivered to NHC through AWIPS-II
- The GPROF2020 algorithm for precipitation from the AMSR2 instrument
- Cloud-base-height algorithms delivered for VIIRS use (under development for GOES)
- HRRR variants for partner use (VORTEX, ICICLE, etc.) delivered to partners,
- ExCAVE – deployed through AWIPS-II

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

The research performed by CIRA naturally has a much broader scope than merely making incremental progress in the atmospheric and environmental sciences. Forecast improvements in hurricane track and intensity, for example, inherently improve the ability of society to prepare for hurricanes, either for landfalling storms or for marine and aviation applications. For this case, greater forecast accuracy gives better logistical support for emergency managers and improved public confidence in the individual forecasts issued by the NHC, using CIRA-derived products integrally in their workflow. Quantifying the exact amount of improvement of CIRA improvements to NOAA forecasting, and to NOAA forecasting in general, remains a difficult task as the various NOAA Labs and Cooperative Institutes work hand in hand to continuously improve weather forecasts to save lives and property, optimize air and marine operations, improve the economic vitality of business, and support outdoor recreation.

Outside of the integral impact of improved forecasting, several direct impacts on society beyond science and technology are noted. CIRA provides world-leading capabilities for public viewing of NOAA science observations, and through a comprehensive education and outreach program including extensive integration with local K-12 institutes, provides public support and education for utilizing these projects. Widespread use of the CIRA-derived SLIDER product gives the interested public a behind-the-steering-wheel sense for understanding what NOAA researchers do. Having real-time satellite observations in the hand of the taxpayer, in a user-friendly format, replete with products that are interesting and useful to the general public represents a paradigm shift in how NOAA observations are seen by the public, and will, over time, build the NOAA 'brand' in the public eye.

For more focused use in museums and other institutes of learning, CIRA's ongoing support of Science on a Sphere® advances NOAA's cross-cutting priority of promoting environmental literacy. SOS displays and animates global data sets in a spatially accurate and visually compelling way on a 6-foot diameter spherical screen. CIRA provides essential technical leadership and developments to the SOS project, particularly research and implementation of effective controls and user interfaces for the system, new visualization techniques, the project website, and new data sets.

Non-meteorological professional development developed by CIRA, including teacher-training workshops for meeting weather-related educational standards (tied to NGSS and state-level standards) and resiliency workshops related to fire, flood, and drought products provide a wealth of information and resources for K-12 educators and the general public. By leveraging CIRA and NOAA observations in concert with university resources in education, social science, and extension activities, CIRA's programs integrate NOAA observations into valuable societal programs, improving society's ability to educate the next generation in weather and climate studies as well as enhance their ability to be resilient in the face of extreme and/or severe weather threats – all the while, proficiently using NOAA resources to make informed decisions.

Finally, CIRA's connections through Colorado State University and the NOAA Public Affairs Office continues to bear fruit in spreading the NOAA 'brand' – through media use of CIRA-derived imagery products to in-person interviews with CIRA subject-

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

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

0 , 0 percent, neglecting foreign travel expenses for U.S. researchers

**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

Nothing to Report

47. Changes that had a significant impact on expenditures

Nothing to Report

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

**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

Nothing to Report

*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?

CIRA's broad scope of goals, supporting NESDIS, OAR and NWS yields a commensurately diverse range of outcomes:

Our meteorological satellite algorithm developments developed new products, enabled superior environmental characterization and decision support to forecasters, and gave excellent visibility to NOAA in the national and world media for notable events (e.g., major storms and natural disasters). CIRA's training efforts accelerated NWS awareness of JPSS and GOES-R capabilities, enabling them to better integrate these new assets and their products into the operational weather forecast cycle.

Significant improvements made in multiple areas of numerical model and data assimilation computational methods have led to improved model accuracy and processing time. Serving as a bridge between operations and research, our work with the Developmental Testbed Center (DTC) is providing a framework for the two communities to collaborate, accelerating the transition of new scientific techniques into operational weather forecasting.

Our development and maintenance of a modern web-based verification toolset supports weather modeling development and modelers in their effective use of verification tools, addressing key needs in Regional/Global model verification. Our worked with NCAR has helped to meet numerous DTC verification tasks, and outlined a plan for the longer-term development of process-oriented verification tools and enhanced use of satellite data for model verification.

These long-term plans include increased use of Machine Learning (ML) technology. Here, we lead research into applying machine learning to advance environmental prediction and exploring Deep Learning for processing and extracting information from satellite data. Through these efforts, satellite-based object detection using a Convolution Neural Network (CNN) helped to identify regions of interest (ROI). We are lead efforts in the socializing of ML, coordinating internal, lab-wide, and community-scale meetings, while also making strategic investments from our Task 1 and returned overhead funds to align CSU talent in ML with the needs of NOAA.

CIRA's NOAA testbed research resulted in expanded or improved ensemble model forecasts based on the HRRR model. In ongoing analysis of forecast model output in the Hazardous Weather Testbed, preliminary results has revealed more variability in WRF output than FV3, and that FV3 generally performs as well or better than WRF in ensemble forecast products (e.g., reflectivity). These studies help NOAA to understand where the new model is adding value.

Significant outcomes in data visualization have occurred across CIRA. Our work in AWIPS-I/II has helped to develop a forecast workstation with advanced interactive display capabilities including inter-office collaboration. Our work on WAVE provides NWS forecasters with a power tool to access, evaluate and utilize new forms of information, including convection-permitting ensemble-based uncertainty information for improved Decision Support. CIRA's demonstration of GOES and JPSS products on SLIDER has revolutionized the way we view communicate these next

## 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.*