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DEPARTMENT OF COMMERCE
RESEARCH PERFORMANCE PROGRESS REPORT (RPPR)

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AWARD INFORMATION	
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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 help 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 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 research themes are enhanced by cross-cutting activities in Societal and Economic Impacts and Education and Outreach at the graduate and post-doc levels. Throughout these pursuits we endeavor to be intentionally mindful of diversity, equity, inclusion, social justice and accessibility as guiding principles of our conduct and engagement with society. These activities help NOAA to fulfill its mission to benefit society, and reflect our 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 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 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.
• 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 National level.
• Conduct research in an environment is relevant and readily transferable to other operational prototyping activities.
• Maintain employment opportunities that ensure CIRA staff have a well-defined and competitive promotion and career track.

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 summarized briefly within the confines of the RPPR; those materials can be made 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 continued development of multi-satellite (and small-sat) tools for analyzing storm formation, intensity, and prediction. We employed machine learning to estimate microwave imagery from GEO sats, yielding a new tool for tracking TC structure. Our products are used operationally by the NHC, the JTWC, and myriad NWS forecast offices. We supported the GOES-R and JPSS programs via cal/val, algorithms for imagery, 3D cloud, vapor applications, and advising on future satellite capabilities. Fire incident meteorologists used CIRA fire imagery in real-time. We showcased a capability to detect bioluminescence by the Day/Night Band. We demonstrated imagery both on our (SLIDER) website (https://rammb-slider.cira.colostate.edu), raising the public awareness of NOAA, and to forecasters on AWIPS2. We lead national/international satellite training efforts in coordination with the World Meteorological Organization.

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 support development of the Unified Forecast System (UFS) and its Rapid Refresh Forecast System (RRFS), including analysis/verification tools, radiative transfer parameterization, physics upgrades, code maintenance, benchmarking, the assimilation of direct broadcast, lightning, and synthetic radar derived from satellite data, as well as high performance computing (HPC), and managing the massive database feeding the model. We also develop Science on a Sphere (SoS), tools for tracking weather hazards in AWIPS, and customized model tools for aviation.

Our team at the Aviation Weather Center in Kansas City, MO supports NOAA's Aviation Support Branch (ASB), including its information technology, web management, science functions, and its entire research to operations (R2O) process. We supported the NWS Operations Proving Ground (OPG) in experiment-based and testbed evaluation of new tools, data sets, forecast techniques, and decision aids assessing forecaster value of the satellite data within the mesoanalysis process for severe weather forecasting and fire weather. We made continuous improvements to the AWC's website (https://www.AviationWeather.gov) .

Our team at the NOAA Center for Weather and Climate Prediction (NCWCP) in College Park, MC, focus 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 retrieved atmospheric and surface products from polar microwave sensors, generated global gap-free ocean color data, and tuned the community radiative transfer model (CRTM) for the recently launched GOES-18 ABI.

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 an umbrella award comprised of various NOAA technical projects. Our diversity of groups and tasks makes it difficult to provide a coherent description of training and professional development opportunities representative of all CIRA staff. Nonetheless CIRA offers high-level training and professional development opportunities to all its employees.

1. Through CSU, CIRA offers training in both Diversity, Equity and Inclusion, Social Justice and Accessibility, and well as supervision/management fundamental courses.
2. CIRA supports Machine Learning training for both CIRA and NOAA partners, via introductory courses, discipline-targeted training (e.g., the eTCeTerra package for tropical cyclones, and modules for merged satellite water vapor products), and integration within projects. Risk communication within the Artificial Intelligence (AI) institute helps us understand forecaster attitudes toward using AI tools.
3. CIRA's software support group connects across all CIRA locations to share best practices in software development and maintenance. In the past year these offerings included a basic to mid-level Python programming course, as well as training related to high performance / parallel computing and containers.

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 Sessions have been developed in connection with VIIRS multispectral imagery products. Imagery and image loops viewed on SLIDER are downloaded and saved as content for these training purposes. Proving Ground provides opportunities for product demo/training, and graduate student involvement.

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. Nationally, we delivered 50 webinars reaching 100 NWS offices, and recorded over 2500 module completions on the NOAA Commerce Learning Center. Expanding beyond the US, CIRA plays an important role WMO efforts. Internationally, we coordinated and delivered 15 virtual sessions and two virtual workshops, all conducted in English and Spanish. The virtual sessions attracted over 975 participants from 32 countries predominantly representing Central and South America and the Caribbean. An additional 240 people were engaged during virtual workshops hosted by Colombia and Chile.

CIRA-developed teacher training workshops to address standards-based education for second, fourth, and fifth-grade weather competency have been on hold due to the ongoing COVID-19 pandemic, with planned re-engagement in Fall 2022. Some efforts to support direct education through remote learning and virtual presentations were successful.

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

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

The primary avenues of CIRA research results dissemination are through external methods through 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 high-profile publications and presentations on our key research activities, especially with regard to new satellite product retrievals.

Specific means of dissemination include: retrospective and 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 team meetings/webinars, discipline-specific working groups, technical interchanges, training sessions, NWS testbed participation, conference presentations, operational partner coordination, code repository/delivery coordination, release/change notes and help desk functions, and technical progress reports on monthly, quarterly, semi-annually, and annually (project dependent).

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 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.

Via its cutting edge imagery and products, CIRA has afforded NOAA with 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. In particular, CIRA's Geocolor imagery of GOES data is a flagship form of imagery for GOES-R, used widely by the media and forecasters alike.

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 being used by the national and international media on daily basis; the Hunga Tonga-Hunga Ha'apai volcano eruption (14-15 Jan 2022) circulated globally. New data visualizations with accompanying descriptive information were distributed to SOS and SOSx sites using automated FTP sites as well via the SOS website. Total data distribution totaled over 20 TB per month. Imagery for SOSx Mobile was distributed via the Amazon cloud and

ACCOMPLISHMENTS *(cont'd)*

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

Our RAMMB-affiliated 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 satellite sensors, and prepare for the next-generation satellite observing system. Our work with GOES-R ABI imagery and 3D clouds will include coordination with CIRA's ASB team. Our machine learning (ML) initiative will infuse ML into CIRA projects, design novel solution architectures, enable new ways to assimilate satellite data into NWP, improve soundings, and synthesize new observations. Satellite training will engage national and international communities. We will develop vignettes of social science to assist forecasters in communicating forecast impacts. We will coordinate with the NHC/JTWC to update tropical cyclone (TC) tools, develop ML-based satellite products including synthetic microwave and nighttime visible from GOES, and debut a blended GeoColor / nighttime visible application called "GeoProxy."

Our 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 RRRFS in coordination with EMC, and serve as subject matter experts to our transition partners. We will pursue RRFS implementation with radar, ground and satellite-based (GLM flash extent density) lightning data, and ABI radiances as inputs. We will serve gatekeeper to WRF-Chem code, supporting new releases and improving/debugging, visualization/analysis tools. We will complete the transition of the SOS development and operations infrastructure to the NOAA Office of Education. In verification, we will add new tools for tropical storm forecasting in METexpress, including a Method for Object-Based Diagnostic Evaluation (MODE) capability.

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 on distance learning for LINUX courses to support NWS engineers. Interactions with the CIRA RAMMB group and connections to Federal Aviation Administration (FAA) will grow via 3D cloud demonstrations and GOES imagery applications. We will support and evolution of AWC web interfaces and tools.

Our team working with NESDIS/STAR staff in College Park, MD will conduct calibration, processing, and algorithm development. We will improve our models and algorithms for ocean parameters, strengthen user support services with a coastal focus. 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, and continue work with the MiRS team to explore an AI-based radiometric bias correction to minimize errors in retrieved geophysical parameters. We will advance our web-based application to visualize ocean parameters and associated natural events, providing decision makers with interactive and viewable maps and events.

Our team affiliated with MDL 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. We will lead of VLab and migration of various tools to the Cloud. We will add functionality to the Whole Story Uncertainty and Probabilities (WSUP) tool. We will implement forecasts of ceiling height, visibility, and flight category every 15 minutes for the continuous US in support of aviation

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. Numerous journal papers, conference papers, and presentations were published during this reporting period – a comprehensive list which are provided as an attached Appendix. Some representative examples spanning CIRA's research themes are provided here:

Apke, J. M., and J. R. Mecikalski, 2021: On the Origin of Rotation Derived from Super Rapid Scan Satellite Imagery at the Cloud-Tops of Severe Deep Convection. Mon. Weather Rev., 149, 1827–1851.

Back et al., Novel Convection-Indicating Satellite Products Assimilated in Experimental Rapid Refresh Systems, 102nd AMS Annual Meeting.

DeMaria, M., et al., 2021: Operational Forecasting of Tropical Cyclone Rapid Intensification at the National Hurricane Center, Atmosphere, 12(6), 683.

radiances to retrieve daytime low-level water vapor for convective forecasting. Electronic J. Severe Storms Meteor., 16 (2), 1–19.

Ebert-Uphoff, I., et al., 2022: CIRA Guide to Custom Loss Functions for Neural Networks in Environmental Sciences – Version 1. arXiv:2106.09757.

Haynes, J. M., et al., 2021: Low Cloud Detection in Multilayer Scenes using Satellite Imagery with Machine Learning Methods. J. Atmos. Ocean. Tech., https://doi.org/10.1175/JTECH-D-21-0084.1

Knaff, J., et al., 2021: Estimating tropical cyclone surface winds: Current status, emerging technologies, historical evolution, and a look to the future. Trop. Cycl. Res. & Rev.. 10.

Higginbotham, T., Providing Context for Digital Aviation Services: A Climatology of the Occurrence Frequency of Multiple Cloud Layers Based on FAA Flight Rules and METAR, AMS Annual Meeting

Hilburn, K. A., et al., 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.

Miller, S.D., et al. Honing in on bioluminescent milky seas from space. Sci Rep 11, 15443 (2021). https://doi.org/10.1038/s41598-021-94823-z

Lagerquist, R., Turner, D., Ebert-Uphoff, I., Stewart, J. and Hagerty, V., 2021. Using Deep Learning to Emulate and Accelerate a Radiative Transfer Model. JAOT, 38(10), pp.1673-1696.

Layne, A. K., et al., 2022: Increasing the Temporal Resolution of LAMP Forecasts for High Impact Aviation Weather. AMS 22nd Conf. on Aviation, Range, and Aerospace Meteorology.

Lee, Y.-K., et al., 2021: Preliminary Development and Testing of an EPS-SG Microwave Sounder Proxy Data Generator Using the NOAA Microwave Integrated Retrieval System, IEEE J. Selected Topics in App Earth Obs and Rem Sens, 14, 3151-3161.

Liu, X. and Wang, M., 2022: Global daily gap-free ocean color products from multi-satellite measurements, Int. J. Appl. Earth Obs and Geoinf., 108 (2022) 102714.

Pettegrew, B., and A. Korner, Examining Consistency of Icing and Cloud Forecasts for GFA Improvement - Brian Pettegrew and Alex Korner, NWA 2021.

Searight, K., Experiences of the NOAA Science On a Sphere Project during the COVID-19 Pandemic, 2nd Science Museum CEO's

PRODUCTS *(cont'd)*

30. Technologies or techniques

The products CIRA develops and transitions NOAA are often the result of longer-term programs, and thus difficult to assign to individual grants or projects. This underscores the importance of the longer-term relationship established by Cooperative Agreements. Listed here are some examples of the technologies and techniques, organized thematically, emerging from this partnership, with emphasis on the current reporting period.

New applications developed by CIRA's NESDIS team via its Proving Ground and Risk Reduction projects are shown 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 GeoColor imagery is used frequently at WFOs, OPC, NHC, AWC, and the Center Weather Service Units (CWSUs). GeoColor is now available in AWIPS-II and NAWIPS displays thanks to collaboration with the NOAA Toward Operational Weather Readiness-Satellites (TOWR-S) program. We generated a first-ever global, gap-free ocean color products, and released a new viewer for oceans https://www.star.nesdis.noaa.gov/socd/ov/

Our work in 3D clouds transformed an application that was on the chopping block (cloud geometric thickness) into a core tool for aviation support. We demonstrated the value of small-satellites for microwave and low-light sensing, including calibration techniques based on simultaneous nadir overpasses (SNOs). We demonstrated positive impacts of assimilating Aeolus lidar wind observations into the Hurricane WRF model. CIRA's precipitable water products, based on multi-satellite blends, support forecasters in the NOAA WPC.

CIRA's Machine learning focus has led to new technologies and techniques. We demonstrated use of linear regression, random forest, fully-connected and convolutional neural networks, , and deep residual U-Nets to improve NUCAPS temperature and moisture profiles, estimate multi-layered cloud scenes. We showed how the GOES Radar Estimation via Machine Learning to Inform NWP (GREMLIN) convolutional neural network model produces synthetic radar reflectivity fields from GOES ABI and GLM that improve RRFS forecasts. We are advancing the state of the art in knowledge-guided machine learning (KGML), identified as a key research direction in the geosciences.

CIRA's Global and Regional Model Development provides key contributions to upgrading the Finite-Volume Cubed-Sphere (FV3) model. We upgraded the RAPv5/HRRRv4 radiation package. Our support of the Weather Information Systems Branch at GSL's Evaluation and Decision Support Division continues to yield useful verification tools implemented in the cloud on Amazon Web Services (AWS), including the "verification as a service" web application.

Our team supporting the AWC/ASB develops, tests, and evaluates nascent scientific techniques, products and services. This includes tools to decrease weather impacts to the National Airspace System (NAS) including the FAA Command Center, Traffic Flow Management (TFM), and public aviation. We added Alaska and Pacific Region to the AWC website https://www.AviationWeather.gov, implemented new algorithms onto the NOAA's supercomputing system, and built AWC forecast technologies into AWIPS2

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. The VLab project's objectives are to (1) Reduce 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

31. Inventions, patent applications, and/or licenses

CSU Ventures is an on-campus service who handles interfaces with industry, licenses and patents. Based on the number of requests for its distribution we are considering a licensed software arrangement for CIRA's GeoColor application. Similarly, CIRA's lunar irradiance model is currently undergoing 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.

In recent experience, the pursuit of patents has been 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 as this has not been an expressed priority of the Cooperative Institute managers we have not been as aggressive as we could be. 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:

• CIRA produced synthetic GOES imagery and a 3-band product for low-level water vapor, with demonstrations at several NWS WFOs. CIRA's blended TPW and RR are official NOAA operational near real-time products.
• We conducted satellite orbit/swath/constellation trade studies which NOAA might consider if they seek to pursue a swarm-approach of small-satellite/CubeSats in the future.
• 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.
• We have developed products to analyze the impact of lightning observation operators in HWRF, as part of our data assimilation theme activities.
• 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 VISIT program, we have generated numrous 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 online tools as SLIDER.
• Our Machine Learning based radiative transfer work has led to a spin-off project at Univ. Lausanne, using our data and code, for equation discovery.
• The Meteorological Assimilation Data Ingest System (MADIS) is now incorporating more Department of Transportation (DOT) and aircraft data.
• CIRA has become more aggressive in 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?

Significant changes in senior CIRA leadership have occurred over the reporting period. After two very productive terms as CIRA Director, Prof. Chris Kummerow begin making plans to transition back to a full Faculty role. As part of CIRA's successful re-competition, a new Faculty Line was granted to the Atmospheric Science (ATS) Department for the express function of Directing CIRA while also serving as an ATS Faculty (with reduced teaching load) in the Department. This position was advertised in Spring 2021.

Dr. Steven Miller, Deputy Director of CIRA since 2007, was among the applicants, and ultimately was selected for the CIRA Director position. He commenced this position on 1 July 2021. Prof. Miller holds strong science and administrative background in CIRA operations, and hopes to build even stronger ties between CIRA and ATS moving forward.

Dr. Renate Brummer was named by Miller as Acting Deputy Director. She will assist the Director in various technical and administrative items. Particular emphasis will be put on helping CIRA our NESDIS-oriented research program in Fort Collins while better connecting it to the many other parts of CIRA both on-campus and off-campus, including to the OAR and NWS line offices. This position remains as a 50% appointment.

Natalie Tourville has taken over for Michael Hiatt (who retired at the end of 2021) as CIRA's Information Technology (I/T) Manager. Part of our plan is to find new ways to connect CIRA with Atmospheric Science (ATS) which includes sharing of best practices, closer strategic planning done between our units and with the University, and identifying ways for CIRA and ATS to connect in data and resources for the benefit of both CIRA researchers and ATS Faculty and especially their students.

Heather Cronk has been appointed as CIRA Infrastructure Coordinator, a new part-time role in the Director's Office. This position will help respond to our recognized needs to optimize the management of CIRA's diverse compute ecosystem, identify opportunities for holistic-minded systems. She will help us to become more self-aware and leverage the strengths and resources of different groups within CIRA, become more proactive and strategic with regard to things like cloud computing and nascent technologies, and identify and facilitate professional development opportunities. Importantly, she will help our I/T Manager coordinate with ATS to make sure we are sharing best practices and, to the greatest extent possible, move toward common frameworks that will provide connection between CIRA and ATS such that Faculty and their students can better access CIRA and in turn we can interface more readily with them.

Bonny Strong remains as the Associate Director and GSL Team Lead
Beth Kessler remains as the Assistant Director
Prasanjit Dash remains our NESDIS Environmental Applications Team Lead
Amanda Terberg remains our Aviation Weather Center 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, to other NOAA laboratories outside of the direct CI partnership, to other governmental and non-governmental agencies. Collaborative research with other CIs, including the CI for Research in the Environmental Sciences (CIRES), the CI for Meteorological Satellite Studies (CIMSS), the CI for Mesoscale Meteorological Studies (CIMSS), 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), 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
• OAR/NESDIS/NOS/NWS (and its numerous WFOs)
• OPC/OPG/WPC/CPHC
• STAR/ASSISTT
• TOWR-S
• 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

Other-Agency / University
• EPA

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

36. Have other collaborators or contacts been involved?

As part of Colorado State University, CIRA is well positioned to collaborate with various academic departments to bolster skillsets available to pursuing NOAA sponsored 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. The School of Global Environmental Sustainability (SOGES) and the Geospatial Centroid at CSU offer opportunities to interface on multidisciplinary topics. Members of the Geospatial Centroid assisted CIRA researchers in analysis of satellite-observed city light changes during the March-May 2020 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: A major aerospace contractor that has been active in the environmental space sector. CIRA has partnered with staff from Raytheon on NASA Earth Ventures and DoD satellite opportunities.

Southwest Research Institute: Major aerospace contractor that has been active in the environmental space sector. CIRA has partnered with staff from their San Antonio base 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 roll-out. We are currently collaborating with them on the study of radio frequency interference (RFI) in microwave sensors.

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), but no formal arrangements were made as CIRA algorithms/products are in the public domain.

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. CIRA has engaged in discussions with them, but these did not lead to a formal partnership.

Maxar Technologies: Formerly Digital Globe, a Colorado-based company specializes in high resolution photography of the earth (the kind used for Google Earth/Maps, and even higher resolution). A formal partnership was made with CSU/ATS for support of students. CIRA may have some involvement in the future.

Blue Canyon Technologies: Colorado-based company that creates spacecraft busses (which carry the instruments), specializing in cubesat/smallsat/microsat, and various components of satellites (solar arrays, star trackers, attitude control, reaction wheels, etc.). CSU has formal interactions related to the NASA TEMPEST-D mission.

IBM: This company has made several in-roads to atmospheric science and solar energy over past decade, especially on the machine learning front, leveraging their major compute resources. CIRA partnered with IBM on an EPIC proposal (not selected).

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 (see Boxes 35-36) 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 small sensors can reproduce the qualitative and quantitative performance of conventional systems—helping NOAA prepare for the SmallSat era. 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.

Our algorithms have made important impacts. Our rawinsonde-modified NUCAPS mixed-layer soundings show improvements over the Great Plains where the need is greatest; several NWS WFOs have requested this product. Our 3D cloud rendering efforts benef aviation users and open the door for interagency collaborations. Continued research into aviation weather hazards is offering new ways to improve analysis and nowcasting. Our blended TPW product provides forecasters a way to visualize and forecast atmospheric rivers. We learned how infrared-based nocturnal low cloud detection algorithms can produce false alarms, leading to better cloud masks. 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. Our satellite training has increased 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. Our new ML-based radiative-transfer parameterization offers faster computation than the current RRTM parameterization, enabling more frequent calculations and improving NWP. Our real-time RRFS prototype provides the first step toward a future, operational convection-allowing ensemble model that will replace the current regional models. Evaluation of this prototype and its associated physics suite has allowed model and physics developers to understand where they need to focus their efforts to improve performance and accelerate transition.

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

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

IMPACT *(cont'd)*

38. What was the impact on other disciplines?

As the community considers the implications of climate change, we are beginning to recognize the need to regard our various discipline-specific fields as "parts of the elephant," and that true advances to knowledge and our ability to mitigate changes will require a holistic perspective instead of a stove-piped one. CIRA's cross-disciplinary theme, articulated in its CI re-competition proposal, encourages this mindset. Our training and research efforts have extended 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.

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 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. Our team is helping to determine the accuracy of forecasts at critical times and impactful locations, including "big misses" in temperature, precipitation, and wind. Through this effort we help NOAA to understand performance and biases differences in model development, and help forecasters communicate the appropriate information to decisions makers in a more effective ways.

CSU has helped CIRA make a significant strategic investment in Artificial Intelligence and Machine Learning. CIRA has infused ML into 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 modeling improvements. We have taken a multi-scale approach to socializing these tools, ranging from small technical exchanges, to moderate workshops, to larger community-wide multi-day conferences. In the spirit of eliminating stovepipes, CIRA is merging some aspects of its ML initiative with the Societal/Economic impact studies—helping to advance risk communication, response, and the interpretation (via explainable AI methods) of ensemble forecast model guidance. Human behaviors are extremely complex, and unexpected correlations where ML can potentially bear significant dividends.

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

CIRA's our 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. In the past year, CIRA's Cooperative Agreement funded twenty-eight (28) graduate students, working on NOAA-sponsored projects. Of these, seven (7, or 25%) were fully funded on CA projects.

Three (3) CIRA employees were offered and accepted Federal positions with NOAA during this period: Jakir Hossen, Robert Hepper, and Lee Powell. These transitions continue in the longstanding CI tradition of helping to build the NOAA work force.

IMPACT *(cont'd)*

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

The ongoing pandemic in 2021 curtailed activities for students. That said, our research still provided opportunities for teaching and student engagement. As examples, a graduate student worked on machine learning for RAP model temperature / moisture profile improvement, and another used a "toy" version of our GREMLIN model a class project. Our support of COLMA for GLM validation enabled a graduate research thesis, revealing how GLM detection efficiency is greatly reduced in anomalous (or inverted-charge) storms common to the High Plains. Teachers used products from VLab for educational purposes. Our GSL verification team will support a student hackathon at George Mason University to develop new METplus use cases for seasonal-to-seasonable metrics. CIRA's corporate knowledge of the satellite enterprise extends to the beginning of the satellite era. We are developing 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 will be used in the classroom, and provided to NOAA and the general community a way to inform and educate members of the operational satellite workforce.

CIRA continued its involvement (remotely) with the Research Experience for Undergraduates (REU) programs, in concert with the Department of Atmospheric Science. Undergraduate researchers, often recruited from minority-serving institutions (MSI), are immersed over the Summer months in a scientific research topic of interest to the student and of practical need to the CIRA mentor. The projects are often tied to NOAA sponsored research. For example, we worked with an REU student to calibrate the forward operator for GLM flash extent density, and assess forecast skill. This student presented a poster on their work at the AMS.

We also continue our home-grown MSI program to foster collaborations between CIRA researchers and the NOAA Cooperative Science Center (CSC) Faculty and their students. We funded two projects that each support a graduate student's tuition and research assistantship, as well as one month of summer salary for the host Faculty member (CIRA staff participation leverages existing project coverage from NOAA-sponsored activities, or as an additional investment form CIRA Central). Students are based at their parent institutions but are encouraged to visit CIRA.

In 2021, CIRA was asked to host the NESDIS Cooperative Research Program (CoRP) Symposium. Due to the pandemic, and given the importance of in-person interactions to build connections, we opted to defer this meeting to 2022. The theme of this meeting will be on connecting students of NOAA CSCs with the Cooperative Institutes to inform them about fruitful career pathways in our field. Participants in CIRA's MSI initiative will participate in this meeting. We are in the midst of planning this Symposium for Summer 2022, and expect a good turn-out of students and NOAA senior staff, with some fun activities (including a hands-on Drone flight session at CSU's Christman Air Field).

Faculty are involved with NOAA research under our Cooperative Agreement, which CSU has incentivized (as a cost-share) via a reduce overhead rate to NOAA projects. This has enabled projects in NIDIS forest/crop-specific drought monitoring in partnership with the US Forest Service, the building of a drought monitoring and early warning system, evaluation of satellite-based machine learning orographic precipitation estimates in the West, and public engagement in climate monitoring through the Community Collaborative Rain, Hail, and Snow (CoCoRAHS) program, connected with the Colorado Climate Center based at CSU.

The CIRA Director will be bringing in 5 ATS students to interface with CIRA projects, launching a new model for student interface with CIRA/NOAA staff that is expected to grow.

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). To minimize processing time associated with data transfers, we have deployed a cluster of processing machines adjacent to the data ingest system.

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 in fact 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 supports GSL efforts to develop and maintain systems that acquire, process, store, and distribute global meteorological data in support of weather analysis, modeling, and information systems projects. We collaborate with systems, networking and security specialists, and numerous researchers to provide reliable services that meet project requirements. The team improves/extends data handling and monitoring capabilities to increase reliability, better utilize GSL resources, and provide additional services. We are coordinating our Ft. Collins and Boulder team interactions, sharing best practices and building the CIRA infrastructure. CIRA's new Infrastructure Manager will facilitate these interactions. The GSL verification team's work advances 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.

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). Doing so augments NOAA's capability to analyze, predict, and respond to challenging weather scenarios, assuring a weather-ready nation and providing societal benefit. As nearly every CIRA project targets a transition path, we cannot do them justice in the available space here, but highlighted are some representative examples.
GeoColor: the GeoColor algorithm, developed at CIRA, has been transitioned to NESDIS operational processing. GeoColor is a key tool for engaging the public, and to forecasters serves as form of baseline imagery for comparison against false-color products. Recently, we have augmented GeoColor through blending with other products like the Fire Temperature RGB and DEBRA-Dust. We are also exploring a blend with proxy-visible imagery for improved nighttime low cloud characterizations. GeoColor "on the fly" processing within the WFO environment is overcoming bandwidth issues.
The Satellite Loop Interactive Data Explorer in Real-Time (SLIDER) tool, previously transitioned to public online use, revolutionized how real-time satellite data is delivered and displayed. 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: Key upgrades to tropical cyclone formation, track, intensity, and wind radii products were delivered, 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 being used to improve forecasting and detection of storm motion at night, and is being combined with GeoColor to enhance NHC forecaster analysis of nocturnal storm formation, helping to avoid the "sunrise surprise."
Other notable technology transfers include:
•Multi-satellite blended total precipitable water product (TPW) transitioned into operations supports WPC forecasters in assessing heavy rain/flooding potential,
•Development of new data assimilation packages enables NOAA HWRF to accept new forms of wind observations.
•Multiplatform Tropical Cyclone Surface Winds Analysis (MTCSWA) product transitioned to Environmental Satellite Processing Center (ESPC).
•Integration of new (Metop-C) into existing algorithms saves resources and time while improving product performance,
•Transition of CIRA Data Processing Error Analysis System (DPEAS) codes from the IBM AIX environment to the ESPC NPP Data Exploitation (NDE) framework
•Supporting the GOES-R Product Readiness and Operations (PRO) team to prepare the operational algorithm transition.
•Consulted with Aerospace on a possible future low-light smalls-sat mission for NOAA
•A ML-based RTM model as a parameterization in the GFS model is being developed and will be transitioned once adequate performance is achieved,
•FV3 work is in preparation for an transition to operations of the RRFS.
•Support of the Short Range Weather (SRW) App is a key component in preparation for the operational implementation of the RRFS in 2024

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. A tragedy involving the loss of 17 hotshot firefighters in Prescott, AZ motivated a project to better analyze the deterministic placement of convection, for the purpose of resolving convective outflows that dramatically influence fire behavior. More timely and accurate fire detection through the use of high-resolution satellite imagery saves lives and property.

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. Detection of snowmelt improves hydrological forecasts and may increase lead times needed to prepare for flooding events. Detection of sea ice, particularly at night, improves mariner safety.

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

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

The pandemic has exacerbated recruiting as technical staff are in high demand. In certain projects that require interdisciplinary skill sets or a very unique skill set (e.g., atmospheric science + web programming skills + a societal risk communication background) we have experienced some hiring delays, which have gone on to impact our research timelines.

We attempt to be as flexible as possible in our technical approaches so as to keep abreast of nascent technology. Machine learning approaches were not initially envisioned for certain projects, but were embraced and incorporated as part of CIRA's strategic initiative in these techniques. We are making greater utilization of "cloud technology" for development and testing. Some projects are changing from Cloud service due to newly mandated IT Security vendor limitations, as decreed by the Federal Government. We continue to be as agile as possible in the face of constantly evolving guidance.

Often we are at the mercy of data streams and sensor performance that is either outside our control or cannot be forecast. Schedule adjustments related to the availability of Metop-C satellite datasets and NDE resources have affected the timeline of working with these data on certain projects. When the CUMULOS sensor died (due to a battery failure) we pivoted to examining a different sensor—the Near-InfraRed Airglow Camera (NIRAC)—which provided analogous observations.

At other times, programmatic decisions affect our assignments. For example, when NOAA Oceanic and Atmospheric Research (OAR) required that SOS operations transition from GSL to NOAA Office of Education, we reconfigured our staff support and clarified our new role. In another example, because of the COVID-19 pandemic, our MDL team had to transition our development, test, and HWT experiment environment to NOAA Virtual Laboratory (VLab) cloud services. This team has moved to utilize cloud resources to allow VLab to provide a full suite of development and test platforms. This enables users in certain groups to be more flexible and complete development processes faster, taking advantage of new Amazon Web Service technologies as they become available.

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 "par for the course." CIRA has operated in this environment successfully for 42 years and running, and its innovative staff never fail to devise creative solutions to overcome whatever hurdles confront them.

Sometimes, problems are related to data availability. Adjustments made to some of our global tropical cyclone products due to the unanticipated removal of an operational global satellite (Meteosat 8) by NESDIS. The deletion impacted our full global coverage temporarily, but processing resumed once NESDIS re-established the satellite feed. Satellite launch delays for the TROPICS mission necessitated a reconfiguration of one project, where instead of actual data we worked with pathfinder data and developed simulated datasets based on numerical model environmental state and radiative transfer modeling. In still other cases, delays in the arrival of a satellite dataset (e.g., polar-orbiting satellite winds) delays caused a change in schedule for planned upgrades.

The time required for new code development or ingest/readers of new data formats, can sometimes be difficult to anticipate, leading to necessary adjustments in schedule. Longer term, multi-scope projects can help to allay these challenges. Emulating the RRTM on a sigma-level grid turned out to be more difficult than emulating it on a standard height grid, as each profile contains the same sigma levels but different physical heights.

Supply chain delays related to the pandemic factored into some project delays. The general slowness of the new hardware has caused us to order earlier in anticipation of these delays. In other cases the slowdown has delayed progress on CIRA infrastructure planning, such as migrating hardware out of the CIRA Ft. Collins basement and overcoming the sudden decision by Google to truncate its online storage.

As the community migrates to cloud computing, unknown elements of the process (such as the cost of data egress) present sources of uncertainty. Most systems will require major overhaul to run on AWS. For example, SOS infrastructure will require such modification as well as other modifications to comply with security restrictions in an environment different from that on GSL on-premises hardware. CIRA suggests that NOAA establish an understood contract with AWS which defines the rules of engagement, such that its developers can begin to migrate in earnest to this paradigm with all costs understood up-front.

Federal budget changes can impact CIRA in unexpected ways as well. Our MDL team suffered the loss of team member because of budget cuts to the program supporting that team. Tasking was consolidated in cooperation with the customer while attempting to minimize the associated delay of deliverables. We encourage NOAA to engage CIRA early and often on budget matters such that we can anticipate and mitigate shortfalls, realizing that our teams are smaller and dedicated to specific NOAA needs in a way that is different than the "body shops" of very large contracting agencies.

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 not fully restored in 2021 after new NOAA funding was obtained for the program, so project expenditures on salary remained at a lower level.

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 responsibility was split between GSL in Boulder, CO and NOAA Office of Education in Silver Spring, MD. However, all the staff continued to be physically located in Boulder.

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 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 generated multi-sensor satellite products for weather hazards and tropical storms, demonstrated their superior environmental characterization and decision support to forecasters, improved aviation- and atmospheric river related products, provided cal/val support to ABI and VIIRS imagery/cloud products, and gave excellent visibility to NOAA in the national and world media. Our training efforts accelerated NWS awareness of JPSS and GOES-R capabilities, enabling them to better integrate these assets into the operational weather forecast cycle, with extension to international partners. We demonstrated the value of smallsat technology, prepared NOAA for future international sensors, and advised on priorities for future GeoXO capabilities. We remain a world-leader in nighttime visible science..

We have made great strides infusing Machine Learning (ML) to CIRA science to advance environmental prediction and to process/extract/synthesize new information from satellite data. Through these efforts, we synthesized microwave imagery for tropical analysis and assimilate GOES ABI/GLM data into the RRFS. We lead efforts to socialize ML, coordinating internal, lab-wide, and community-scale meetings, making strategic investments from our Task 1 and returned overhead funds to align CSU's talent in ML with the needs of NOAA.

CIRA is preparing NOAA for migration to the Unified Forecast System (UFS). Significant improvements in numerical modeling, data assimilation, and computational methods have led to increased accuracy and reduced processing time. We advanced the real-time Rapid Refresh Forecast System (RRFS) prototype running at GSL. We have released several versions of WRF-Chem and also HRRR-Smoke, whose use during the recent fire seasons has extended to public broadcasting in a remarkable new way. Our support of MADIS provides the foundational data used by NOAA NWP, and assimilation of new datasets is helping to improve NWP analyses.

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

Significant outcomes in data visualization include work in AWIPS2 which has helped develop a forecast workstation with advanced interactive display capabilities, including inter-office collaboration. Our work on WAVE provides forecasters with a powerful tool to access, evaluate and utilize new forms of information, including convection-permitting ensemble-based uncertainty for improved Decision Support. We are continuously making 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.

Our support of the Aviation Weather Testbed and Operations Proving Ground has infused cutting-edge applied satellite research in the AWC development cycle continuous improvement of its operational mission. We have 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 are shared through collaboration across the FAA and participating NOAA testbeds

In these and many other ways, CIRA plays an integral role in realizing NOAA's mission for societal benefit.

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.