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

DEPARTMENT OF COMMERCE
RESEARCH PERFORMANCE PROGRESS REPORT (RPPR)

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

AWARD INFORMATION	
1. Federal Agency: Department of Commerce / NOAA	2. Federal Award Number: NA20NES4320003
3. Project Title: Proposal for the continuation of The Cooperative Institute for Meteorological Satellite Studies at the Univers	
4. Award Period of Performance Start Date: 07/01/2020	5. Award Period of Performance End Date: 06/30/2025
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR	
6. Last Name and Suffix: Wu , null	7. First and Middle Name: Wenhua ,
8. Title: Senior Admin Program Specialist	
9. Email: wenhua.wu@ssec.wisc.edu	10. Phone Number: 608-263-8890
AUTHORIZING OFFICIAL	
11. Last Name and Suffix: Roberts , null	12. First and Middle Name: Dawn-Marie , M.
13. Title:	
14. Email: drobert4@rsp.wisc.edu	15. Phone Number: 608-262-0152
REPORTING INFORMATION	
Signature of Submitting Official: Dawn-Marie M. Roberts	
16. Submission Date and Time Stamp: 04/28/2022	17. Reporting Period End Date: 03/31/2022
18. Reporting Frequency: (●) Annual ( ) Semi-Annual ( ) Quarterly	19. Report Type: (●) Not Final ( ) Final
RECIPIENT ORGANIZATION	
20. Recipient Name: UNIVERSITY OF WISCONSIN SYSTEM	
21. Recipient Address: 21 N PARK ST STE 6301, MADISON, WI 53715-1218 USA	
22. Recipient UEI: LCLSJAGTNZQ7	23. Recipient EIN: 396006492

ACCOMPLISHMENTS

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

CIMSS addresses four research goals that are central to maximizing the benefit of satellite observations to NOAA's mission:
• Improve and increase the use of satellite data in numerical weather prediction at all scales;
• Advance satellite remote sensing, machine learning/artificial intelligence, and data assimilation techniques for environmental satellite applications;
• Help NOAA and other stakeholders, both public and private, effectively exploit satellite observations to make society more resilient to environmental change; and
• Develop a workforce knowledgeable in satellite meteorology and remote sensing.
These objectives are addressed through an integrated program of research and education activities using innovative computational methods, value-added data interpretation, and effective communication to users and stakeholders, including the general public.
By addressing these goals, CIMSS provides end-to-end support of meteorological satellite applications including instrument design and demonstration; sensor calibration; data product development, validation, data archiving and dissemination; research-to-operations (R2O); data assimilation; and training and outreach. CIMSS is supporting new initiatives in artificial intelligence and machine learning, impact assessment and social sciences, community modeling, including the Earth Prediction Innovation Center (EPIC), and defining next-generation environmental satellites. Our approach includes the following specific elements:
• Fostering inter-disciplinary relationships to accelerate the development of revolutionary approaches for effectively extracting actionable information from current and future environmental satellites, including artificial intelligence and machine learning;
• Transferring important advances in satellite data interpretation to the operational setting where they can be of direct benefit to society;
• Engaging communities throughout the US and world to develop strategies for utilizing NOAA datasets to model risks and vulnerabilities;
• Soliciting and implementing feedback from users including NWS forecast offices and other NOAA centers to develop new satellite analysis tools that fuse distinct satellite outputs into value-added combined products to facilitate real-time decision making;
• Providing subject matter expertise (SME) and working with NESDIS/STAR, other federal agencies, industry partners, and other NOAA CIs to refine the instrument specifications for future NOAA weather applications from low-earth orbiting and geostationary platforms;
• Applying scientific computing methodologies for the integration, testing, and support of satellite algorithms, data stewardship, and data delivery;
• Distributing software allowing direct broadcast users to process data received from geostationary satellites in near real-time with low latency;
• Advancing application of satellite data in nowcasting;
• Curating multi-satellite, multi-sensor products to produce long term climate data records (CDRs);
• Contributing to NCEP's operational NWP modeling and assimilation efforts by increasing data usage, advancing data assimilation methods, developing radiative transfer models and observational operators, and verifying models;
• Performing GOES-R program post-launch test and validation activities;

25. What was accomplished under these goals?

In the past year, CIMSS researchers developed and improved satellite retrievals of atmospheric humidity, surface properties, clouds, atmospheric motion, fire characteristics, volcanic ash, tropical cyclone track/intensity, and severe weather probabilities. CIMSS played an integral role in validating radiance GOES-17 products and generated sounder products at greatly enhanced spatial resolution using novel data fusion techniques. We also developed innovative satellite retrieval approaches including new applications of machine learning to derive atmospheric motion vectors and identify severe weather.
CIMSS engaged stakeholders at NOAA to translate the products of our research to actionable information. CIMSS worked closely with NWS forecast offices to provide situational awareness and the National Centers for Environmental Prediction Center to assimilate this information into NWP models to improve short-range forecasts and to support rapid and accurate decision-making. Our tropical cyclone research team collaborated with the Tropical Prediction Center in Miami to develop new satellite-derived wind products. We also worked directly with the Storm Prediction Center and the National Severe Storms Laboratory (NSSL) in Norman, OK to implement severe weather forecasting tools.
Satellite Meteorology Research and Applications: CIMSS researchers developed new approaches for interrogating geostationary and polar orbiting satellite observations to extract information to improve weather analyses and supported their transition from research to operations (R2O). For example, we developed operational algorithms for tracking convective initiation, increasing lead times for severe weather threats, and identifying aviation hazards from GOES observations. CIMSS also developed a deep neural network (DNN) to retrieve soundings from partially cloudy CrIS FOVs with the help of clear sky ABI radiances with promising results. CIMSS pioneered the transition of satellite algorithms and products to the cloud and developed well documented visualization software allowing products to be easily accessed by the NOAA NWS, NHC, SPC, OPC, WPC, and AWC.
Satellite Sensors and Measurement Techniques: CIMSS contributed to the calibration and validation of radiances and geophysical data products from JPSS-1 and GOES-17. CIMSS assisted NOAA in conducting trade studies to demonstrate the value of geostationary hyperspectral infrared sounding and provided subject matter expertise to the System performance Assessment Team (SAT). CIMSS researchers have worked with experts on campus and at other universities to develop new artificial intelligence and machine learning-based approaches for converting "big data" to useable products such as turbulence and severe weather indicators.
Environmental Models and Data Assimilation: The other essential element in realizing the benefits of environmental satellite observations is assimilating them into forecast models. CIMSS scientists continued to develop approaches for improved cloud screening and cloudy-sky radiance assimilation. CIMSS is also contributing to the conceptual design of the NOAA Earth Prediction Innovation Center (EPIC) community modeling framework that seeks to engage the broad community of weather and climate modeling scientists to improve NWP.
Outreach and Education: Working closely with faculty in the collocated department of Atmospheric and Oceanic Sciences, CIMSS researchers advised several graduate students, on research utilizing NOAA satellite observations and forecast systems. CIMSS scientists developed new training modules that explain new products from GOES-R series satellites and conducted virtual short courses at multiple major international meteorological conferences. CIMSS also actively engages in K-12 education and public outreach to encourage students to pursue STEM careers and foster a more informed public.

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?

CIMSS' location at the UW-Madison, the birthplace of satellite meteorology, maximizes NOAA's potential to engage a world class workforce in science, technology, engineering and mathematics (STEM). The UW is renowned for educational excellence and regularly ranks among the top ten in national research rankings for public and private universities. The institute's collocation with the Department of Atmospheric and Oceanic Sciences at UW-Madison affords opportunities to engage students in NOAA research and to develop tools for training professionals and the public. CIMSS has engaged in activities, trainings, and collaborations that support and advance NOAA's Education Strategic Plan:

• CIMSS offers a rich selection of on-line satellite education resources and activities for all segments of society and users.
• CIMSS led a teacher workshop via the Earth Science Information Partners (ESIP) and conducted numerous NWS trainings through the Virtual Institute for Satellite Integration Studies (VISIT).
• CIMSS hosted the Weather Camp for High School students, now in its 30th year. Forty-two students attended the virtual camp from more than 30 states, including Alaska and Puerto Rico.
• CIMSS collaborated with the Department of Atmospheric and Oceanic Sciences at UW-Madison to design a course for non-atmospheric science majors to teach them about the essentials of climate change. See p.32-33: https://www.ssec.wisc.edu/wordpress/wp-content/uploads/2020/11/TtA_Summer_Fall_2020_s.pdf
• CIMSS investigators advised 17 graduate students conducting research on a range of NOAA-related topics such as imager-sounder fusion, assimilation of atmospheric ozone data into air-quality models, machine learning-based cloud retrievals, and modeling tornadogenesis in severe thunderstorms.
• Nuo Chen, the first William Smith Graduate Fellowship awardee, continued her Ph.D. research to improve tropical cyclone forecasts within the CIMSS Tropical Cyclone Group. She has completed the third year of her research.
• CIMSS Satellite Blog contributors wrote and published more than 150 case studies and training-related posts for use by researchers, educators, trainers, the media, and others.
• CIMSS researchers provided case study imagery for NOAA's GOES-R short Course at American Meteorological Society (AMS) 2022 Annual meeting, January 2022.
• Provided training to end-users at the NWS Alaska Sea Ice Program and the US National Ice Center.
• Developed a virtual satellite training course for graduate and undergraduate students. Presented it at Annual Meeting of the AMS, Houston, TX, 23-27 January 2022.

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

CIMSS shares a consistent message with internal and external audiences to broaden awareness and visibility of its research, as well as demonstrate its impact and value to NOAA, other funders, the citizens of Wisconsin and beyond. The results of research are initially shared with the scientific community through scholarly communications networks, peer-reviewed articles, conference presentations, seminars, websites and training programs (See Q29).

SSEC News and UW News published stories showcasing important research results from CIMSS, field campaigns, accomplishments of students, outreach activities, and more. Here are some stories of impact:

• UW hurricane model gets upgrade in time for 2022 hurricane season
Developed by researchers at CIMSS, the Advanced Dvorak Technique is receiving a significant upgrade within NOAA operations in time for the 2022 Atlantic hurricane season.
• Fog detection software helps airlines keep travelers safe
New fog detection software developed by CIMSS and NOAA scientists is assisting NOAA National Weather Service offices as they issue warnings that are used by airlines to anticipate conditions, avoid delays and reroute flights if necessary.
• Shark fins and internships – Solving real world problems through mentorship
The NOAA Experiential Research and Training Opportunities 12-week internship provided a research fellow an opportunity to explore a research topic under the guidance of a NOAA scientist stationed at CIMSS.

Research results are further disseminated to communities of interest through these outlets:

• Through the Atmosphere: Biannual magazine featuring research and education news of CIMSS and SSEC, with print and online distribution to stakeholders and public audiences.
• 2020-2021 Biennial Report: Highlights research, field programs, collaborations and scholarly products of SSEC and CIMSS with federal, UW-Madison and other partners.
• CIMSS Satellite Blog: With a 30-plus year history, nearly 4,000 visits per month, and over 290 posts for 2020-2021, the blog presents case studies of weather events or phenomena using satellite imagery for training, as well as for use by other scientists, the media, and public audiences.
• UW-Madison Featured Experts: In the last year, experts from CIMSS have been available to speak with local and national media on breaking news and trends in areas of expertise, such as tornadoes, drought, volcanic eruptions, fog, and atmospheric aerosols.
• Media Mentions: CIMSS and SSEC stories and imagery have been further amplified by news media across the country including UW News, The New York Times, The Washington Post, Wisconsin Public Radio, PBS News Hour, The Cap Times, NBC News, Reuters, Associated Press, and Policitfact, among others.
• Social Media: CIMSS and SSEC Twitter and Facebook have garnered more than 40.1K total followers. These numbers continue to grow as our content is shared, increasing visibility and reach.
• K-12 Programming: Most onsite, pre-college programs at UW-Madison are cancelled through spring 2022 due to the pandemic. As a result, K-12 school visits to CIMSS and SSEC were cancelled; however, the section on EPO details virtual and some in-person

ACCOMPLISHMENTS *(cont'd)*

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

During the next reporting period, CIMSS will leverage its strong heritage as a center of excellence in satellite meteorology to contribute to NOAA's mission to serve society's needs for accurate, timely weather and climate information. This will be accomplished through several interrelated research tasks approved by different project sponsors. An abbreviated but representative list of the complementary activities planned for the coming year include:

- Maintain routine operational Cryosphere products and improve the Cryosphere product retrieval algorithms as needed;
- Continue developing nowcasting tools, which will allow evaluation of future GeoXO instruments;
- Continue to participate in GEO-XO planning and provide SME to the SAT to further plan the best configuration of NOAA's Leo and Geo capabilities;
- Develop and release software packages, including new products and upgrades to existing products and capabilities;
- Continue to support evolving data production software needs and develop new tools and techniques to support current and future instrument systems;
- Transition promising research methods, algorithms and products to operational frameworks;
- Collaborate with NESDIS partner on the Enterprise Fire Algorithm on algorithm improvements that can be moved into Operations quickly;
- Continue validating all GOES-R AWG LAP products, especially GOES-18;
- Continue to coordinate with STAR ASSITT as needed;
- Analyze and verify mountain wave turbulence dataset;
- Continue developing the Himawari-8 cloud, QPE, near-surface visibility, and aircraft icing products and upgrade the typhoon intensity code previously delivered to the CWB;
- Continue presentations to the SAT regarding best configuration of Leo and Geo advanced sounders;
- Develop, release, and provide user support for data ingest and visualization software with an emphasis on new products, science upgrades, and GOES-18;
- Continue supporting NOAA's migration of data products to the cloud;
- Assess NUCAPS v3 products for selected case studies;
- Implement CRTM NLTE bias correction scheme and quality control procedures in FV3GFS;
- Implement CEMS emissions in UFS-RAQMS and conduct full year (October 2019-November 2020) UFS-RAQMS Control and JPSS data assimilation experiments;
- Port UFS-RAQMS forecasting capability for real-time forecasts to ESRL/GSD;
- Build the Incident-Based Web tool (InSTRIDE) to lessen the burden of the incident manager by sifting Fire and Smoke Initiative and related product inputs for the specific incident they face;
- Finish testing and documenting Polar2Grid Version 3.0, and release it to the public as part of CSPP;
- Evaluate METimage cloud products against VIIRS and Metop and explore new applications for METimage CO2 and H2O bands;
- Complete work on the Google Earth Engine project.
- Researchers will directly engage with NOAA line offices and, especially, collocated NESDIS ASPB researchers to ensure that the

PRODUCTS

29. Publications, conference papers, and presentations

CIMSS research was published and presented in numerous peer-reviewed papers, conference proceedings, and presentations throughout the reporting period. A complete list of CIMSS-authored publications that were published during the reporting period are provided as an appendix A. Some noteworthy examples include:

- Dworak R, Liu Y, Key J, Meier WN. A Blended Sea Ice Concentration Product from AMSR2 and VIIRS. Remote Sensing. 2021; 13(15):2982. https://doi.org/10.3390/rs13152982.
An effective blended Sea-Ice Concentration (SIC) product has been developed that utilizes ice concentrations from passive microwave and visible/infrared satellite instruments, specifically the Advanced Microwave Scanning Radiometer-2 (AMSR2) and the Visible Infrared Imaging Radiometer Suite (VIIRS). The blending takes advantage of the all-sky capability of the AMSR2 sensor and the high spatial resolution of VIIRS, though it utilizes only the clear sky characteristics of VIIRS.

- Smith, W. L., H. Revercomb, E. Weisz, D. Tobin, R. Knuteson, J. Taylor, and W. P. Menzel (2021). Hyperspectral satellite radiance atmospheric profile information content and its dependence on spectrometer technology. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 14:4720-4736. DOI10.1109/JSTARS.2021.3073482
This article demonstrates that there is much more information available in current IR sounding data than is being used to benefit the current NWP operation and it illustrates the importance of the spectrometer technology used for achieving the vertical profile resolution required to improve both extended range and localized severe weather forecasts.

- Ma, Z., Li, Z., Li, J., Schmit, T. J., Cucurull, L., Atlas, R., & Sun, B. (2021). Enhance low level temperature and moisture profiles through combining NUCAPS, ABI observations, and RTMA analysis. Earth and Space Science, 8, e2020EA001402. https://doi.org/10.1029/2020EA001402
In this study, a deep neural network (DNN) is applied to fuse multiple data sources to enhance the NUCAPS temperature and moisture profiles in the lower atmosphere. The enhanced soundings from fused data capture the large surface-based convective available potential energy structures in the pre-convection environment, which is very useful for severe storm nowcasting and forecasting applications.

CIMSS researchers regularly present the results of their research at conferences, workshops, meetings and symposia. During the reporting period, CIMSS researchers gave more than 40 presentations at international conferences. Many meetings were delayed or cancelled due to the pandemic; thus, the number of presentations is less than in previous years. A complete list of CIMSS presentations is provided as an appendix. Some noteworthy examples include:

- Greenwald, T., Y. Liu, M. J. Brodzik, W. N. Meier, M. Lawson, and E. Niebuhr, 2022: Improved Operational AMSR2 Sea Ice Products in the Arctic, 12th Conference on Transition of Research to Operations, AMS Annual Meeting, Houston, TX

PRODUCTS *(cont'd)*

30. Technologies or techniques

• New technique for assimilating multi-spectral ozone retrievals was developed and their impact assessed;
• Methodology for combining Arctic satellite composite imagery;
• Several web apps and web map services;
• Best linear unbiased estimators for atmospheric property retrievals;
• Demonstration of the ECMWF Hybrid PCA approach to CrIS data;
• Advanced processing strategies for enhanced atmospheric motion vectors (AMVs) around hurricanes;
• Updated ABI data quality monitoring pages: http://cimss.ssec.wisc.edu/goes-r/abi-/16band_mainmenu.html
• ABI data quality statistics monitoring page for GEO-GEO comparisons: http://cimss.ssec.wisc.edu/goes-r/abi-/band_statistics_imagery.html
• VIIRS, ABI, AHI, joint ABI/VIIRS, joint AHI/VIIRS, and composite VIIRS flood products;
• New short-term forecast model employing strictly satellite retrievals for quick predictions of near-term significant weather environments using real observations;
• New data assimilation techniques for cloudy sky radiance assimilation in weather forecast models;
• New global-scale water quality products for coastal and inland waters. This work will be leveraged through potential grants from UW SSEC, World Bank and Google Earth Engine;
• Calibrated Enhanced-Resolution Passive Microwave EASE-Grid 2.0 Brightness Temperatures (CETB) software system;
• Modified software to implement NCEP/EMC at NCEP Central Operations.

31. Inventions, patent applications, and/or licenses

• RealEarth™: a data discovery and visualization platform developed by scientists at SSEC and CIMSS
• GEOSphere a 4-D data discovery and visualization platform for displaying earth image layers

PRODUCTS *(cont'd)*

32. Other products

• Updated real-time satellite-derived analyses for tropical cyclone monitoring via the CIMSS TC web site;
• Updated ABI flood products on RealEarth in geotiff, shapefile, and AWIPS format;
• Near-real-time ice motion products at an ice motion distribution server maintained by the Geographic Information Network of Alaska for analysts at the Alaskan Ice Program;
• Automatically-updating webpage of cryosphere products;
• Arctic satellite composite imagery;
• Contributions to the open source SatPy Python libraries;
• VIIRS Ice products (Age, Concentration, Motion, Temperature and Thickness);

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

33. What individuals have worked on this project?

Please see attachment of full list of individuals that work on the new CIMSS Cooperative Agreement.

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?

NA

35. What other organizations have been involved as partners?

- Australian Bureau of Meteorology (ABOM)
- Alaska Aviation Weather Unit
- Alaska-Pacific River Forecast Center
- AOML-HRD
- AquaWatch
- Aviation Weather Center
- Boeing Corporation
- CalFire
- Chinese Meteorological Agency (CMA)/NSMC
- CESSRST
- CIRA
- CSIRO
- DoD/JTWC
- DOE/ARM
- ECMWF
- EMC
- EUMETSAT
- ESA
- FEMA
- Geographic Information Network of Alaska (GINA)
- George Mason University
- Honolulu WFO
- JAXA
- JCSDA
- JMA
- L3Harris
- Logistikos
- Michigan Tech University MTRI
- NASA
- NCAR
- National Hurricane Center
- National Weather Service
- NOAA Ocean Prediction Center (OPC)

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

36. Have other collaborators or contacts been involved?

• AquaWatch Secretariat, Dr. Merrie Beth Neely on programmatic issues
• CMA/NSMC
• ECMWF
• FAA
• MIT Lincoln Labs
• NASA/GMAO
• NOAA/NCEP/EMC
• NOAA/NESDIS/STAR/ASPB
• NOAA/NESDIS/STAR/JPSS
• NOAA/NESDIS/OSPO
• Paul DiGiacomo and Emily Smail at NOAA
• Ronald O. Adomako (CESSRST) -- NOAA Experiential Research and Training Opportunities (NERTO) student intern in 2021.
• UKMO
• U of Colorado – Boulder
• U of Fairbanks – GINA
• U of Oklahoma Atmospheric Sciences
• Volcanic Ash Advisory Center (VAAC) – Anchorage/Washington DC

IMPACT

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

CIMSS provides end-to-end support of meteorological satellite applications from concept to application and training. As a result, CIMSS research encompasses several sub-disciplines of satellite meteorology including: airborne and in situ observation, remote sensing, numerical modeling, weather forecasting, data assimilation, education and outreach, data visualization, and advanced computational techniques, including artificial intelligence and machine learning. Selected examples illustrating how CIMSS research has impacted the development of these disciplines include:
• Polar winds derived at CIMSS used in operational NWP models at more than 10 meteorology centers throughout the world to improve weather forecasting;
• Advancements in storm structure and strength have improved hurricane forecasting;
• Advances in state-of-the-art volcanic cloud detection and tracking algorithm (VOLCAT) for usage in real-time forecasting of volcanic hazards as well as utility in climate applications;
• Bias corrections to all-sky infrared brightness temperatures facilitate assimilation into numerical weather prediction models;
• Innovative methods have been developed for using GOES Cloud Algorithm Working Group products to infer lake effect snowfall to augment the NEXRAD network in the Great Lakes region;
• CIMSS has improved data delivery mechanisms for remote sensing data (e.g., VIIRS Imagery EDRs);
• CIMSS developed and applied new vicarious calibration approaches to spaceborne hyperspectral sounders and imagers (CrIS and VIIRS);
• CIMSS research has improved weather and hydrodynamical forecasting potential by improving the fidelity of water vapor distribution in the atmosphere;
• By substantially improving the capability of GeoIPS, CIMSS has developed a multi-agency TC satellite image ingesting package;
• CIMSS is advancing new concepts for using satellite sounder products to improve ice cloud retrievals from imager observations;
• New advances in data visualization have advanced the state and availability of real-time satellite imagery used by the US polar orbiter meteorological and environmental decision makers;
• A new STAR ocean infrared emissivity model is aiding the assimilation of infrared sensors into NWP;
• Next-generation sensors (e.g., ICI) are improved through the development of realistic proxy global proxy datasets;
• CIMSS has advanced techniques for assimilating satellite chemical data within the Next Generation Global Prediction System;
• Enhanced-spatial-resolution AMSR2 products will be used in operations for the first time;
• CIMSS unique Arctic Composite satellite imagery (made from both polar-orbiting satellite and geostationary satellite imagery) provides an essential view of the Arctic in support of weather forecasting and monitoring activities across the Arctic Ocean and adjacent continents;
• CIMSS has become the focal point or centralized forum for remote sensing of water quality advocating for advancing Earth observation approaches;
• CIMSS imagery is used by broadcasters to inform the public, private sector businesses to inform their decision-making, and

IMPACT *(cont'd)*

38. What was the impact on other disciplines?

To further our objective of supporting end-to-end utilization of meteorological information and address the NWS mission to "protect life and property," CIMSS has fostered collaborations with other government agencies, academic, private sector, and non-profit groups that expand our research into several other disciplines. Government agencies provide public policy and guidance, the academic sector provides new and innovative science, the private sector adds work resources and non-profit groups work to help bring communities, our team, and additional outside resources together. Through these interactions, CIMSS data, products, and expertise have had an impact on risk management, insurance, urban planning and management, and disaster relief. For example, CIMSS has engaged communities throughout the US and world to develop strategies to become more resilient to the risks and vulnerabilities to people, infrastructure, and local economies posed by natural disasters. In addition, CIMSS recently collaborated with the Association of State Floodplain Managers (ASFPM) and The Polis Center at Indiana University, Purdue University – Indianapolis to develop a Flood Recovery Risk Index. This index identifies locations in the Toledo, Ohio area that will have longer recovery times after a flooding event and is being used by planners to understand the spatial patterns of risk for increased resilience building activities. In early 2019, we also completed a project with the Georgia Department of Natural Resources to model the impacts of flooding and hurricane winds along 11 coastal communities–finding that the dollar losses due to such events in the future could be between three and eight times higher than they are for similar events today.
Each of CIMSS' external collaborations serves a unique purpose. Some specific examples of impacts on other disciplines that have resulted from engaging these groups include:
• Improved methods for communicating warnings through community engagement (social science);
• General demonstrations of novel applications of deep learning;
• CIMSS research contributes to air quality, water quality, hydrology, climate science, and social science;
• CIMSS software and data visualization tools have replaced some licensed graphics packages to expand their utility beyond the satellite community to include climate and hydrologic sciences;
• CIMSS has researched and implemented improved data archival and search tools that have expanded the use of GOES and JPSS data beyond primary users and have applications to other 'Big Data' fields;
• CIMSS researchers have worked with water resource managers to better understand their needs and provide new tools for the monitoring and management of water quality;
o NOAA River Forecast Centers are using products to assess current floodwater conditions in areas not covered by river gauges;
o Using similar products, FEMA is able to assess floodwater conditions to estimate the scale of a flood;
• CIMSS atmospheric composition studies and modeling contribute to improving NWS National Air Quality Forecasting Capability providing better air quality forecasts through better constraints on long-range pollution transport and timely updates of global NOx emission inventories;
• Improved hurricane forecasts have both economic and societal benefits;
• NWS forecasters refer to the GEO-GEO difference web page to gauge the impact of LHP anomaly on GOES-17 data they are using for forecast analysis.

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

Central to the CIMSS mission is training the scientists and engineers of the future. Evidence of commitment to this mission includes awarding scholarships to promising students, providing research opportunities for students to work and learn alongside CIMSS researchers, educating graduate students who may become NOAA scientists, and participating in scientist exchange to enhance collaboration. Early to mid-career scientists at CIMSS also gain experience participating in and ultimately leading research tasks. Some examples from the reporting period include:

Scholarships for Students
• Verner E. Suomi Scholarship
Three accomplished high school seniors awarded 2021 Suomi Scholarship
The scholarship is competitively awarded by CIMSS to students who exhibit strong aptitude for physical sciences.
• William L. Smith Graduate Scholarship
Nuo Chen to receive William L. Smith Graduate Scholarship
Offered through NOAA and CIMSS, the scholarship advances NOAA's research and education mission. Chen continued her research and studies in year three of the scholarship.
.
2021 Graduates
CIMSS investigators advise graduate students conducting research on a range of NOAA-related topics. During the reporting period, 4 students advised by CIMSS investigators received MS degrees and 2 received PhDs, all through the Department of Atmospheric and Oceanic Sciences. Some examples include:
• Jerrold Acdan, M.S.: Contributed to the growing body of knowledge on the formaldehyde to nitrogen ratio-related research by utilizing satellite, in situ, and air quality modeling data to evaluate FNRs over the Lake Michigan region while interpreting them using two distinct sets of ozone production regime threshold values from previous studies.
https://minds.wisconsin.edu/handle/1793/82373
• Jongjin Seo, M.S.: Sought to determine whether using multiple scanning angles could improve the accuracy of Atmospheric Emitted Radiance Interferometer retrievals.
https://minds.wisconsin.edu/handle/1793/82087
• Callyn Bloch, M.S.: Funded by NOAA and NASA, Bloch worked as a science writer in communications at CIMSS. Her byline appeared on these stories: https://www.ssec.wisc.edu/news/articles/author/cbloch. She will graduate spring 2022 with a degree in Life Sciences Communication from UW-Madison.

Scientist Exchange
• CIMSS typically hosts numerous scholars from around the world. These exchanges provide opportunities for early and mid-career scientists from international remote sensing organizations to collaborate with CIMSS researchers on projects of mutual interest.

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

IMPACT *(cont'd)*

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

CIMSS maintains a robust education and outreach program to train students, professionals, and other stakeholders in the use of environmental satellite data. CIMSS educational impacts start at middle school where the CIMSS GOES-R Virtual Science Fair introduces students to the exciting field of satellite meteorology. High school students are engaged again via our STEM summer camps, including the new Tech Camp, and the Suomi Scholarship awarded to graduating high school students interested in meteorology or related fields. CIMSS researchers work with undergraduate interns and advise graduate students in the collocated AOS department to recruit top students into research fields aligned with NOAA's priorities. Through a strong commitment to mentoring, senior scientists with vast institutional knowledge of our satellite meteorological heritage provide guidance to early and mid-career scientists allowing them to gain experience managing projects, publishing results, reporting to NOAA, and overseeing undergraduate and graduate students. CIMSS also provides a wide range of satellite training materials and provides professional training to NOAA staff and a wide range of users at other agencies, the public, and other stakeholders.
Research Opportunities for Students
During the reporting period, CIMSS researchers advised 17 graduate students and several undergraduate interns. Examples of CIMSS undergraduate and graduate student research projects include:
• Callyn Bloch: As a graduate student in Life Science Communications, Bloch began working with the communications team at SSEC to gain experience in the field. Her work has been funded by CIMSS.
• Anne Sledd and Chuck White obtained PhDs in the Department of Atmospheric and Oceanic Sciences working in close collaboration with CIMSS personnel: Student research: Contributions to climate solutions

CIMSS has also provided experiential research opportunities to undergraduate and graduate students – in this instance, research related to clouds and their role in weather and climate variability:

• R. Adomako, a student at New York City College, completed a 12-week NOAA Experiential Research and Training Opportunity (NERTO) internship with NOAA ASPB scientist Tim Schmit. The internship topic was "Using machine learning to identify GOES-17 ABI instrument imagery artifacts."

Advancement

• A series of recent gifts to CIMSS through the University of Wisconsin Foundation is providing funding for undergraduate research experiences and leading to research support for graduate students.
Other Examples of CIMSS Teaching and Education Impacts
• Undergraduate student interns at CIMSS have gained experience in data processing, analysis, and visualization;
• CIMSS fosters close interaction between researchers developing cutting edge satellite imagery tools and those generating training materials providing the capability to generate captivating materials from case study images and animations to support bootcamps, short courses, and summer schools;

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

• Three members of our organization are now using GIS in daily activities;
• Improved weather forecasts relating to national safety and commerce;
• AquaWatch constructed a "Knowledge Hub" that will be useful to a wide range of stakeholders, from national experts needing to report on policy commitments, to non-profit end users seeking practical solutions to local water quality challenges. The hub can be viewed as a compilation or synthesis of best practices from the community with long-term capacity development. The Knowledge Hub has six interlinked components: publications, code and models, remote sensing imagery, in situ data, results and products, and community discussion;
• New hardware and software in development provides CIMSS new incident-based training capability;
• Storage was added to the Satellite Data Services archive to allow additional storage of L1 and L2 GOES data for use by CIMSS scientists;
• The composition data assimilation experiments are conducted on the NOAA/NESDIS Satellite Simulations and Data Assimilation Studies computer (S4) at the UW-Madison Space Science and Engineering Center (S4) and has been developed to align with NOAA forecasting and data assimilation frameworks.

IMPACT *(cont'd)*

42. What was the impact on technology transfer?

• Improved wind algorithms developed at CIMSS are transferred to NOAA;
• The GOES-16/17 Fog, Low Stratus (FLS) products are integrated into the Satellite Processing Framework (SAPF) and NOAA Polar-Orbiting Partnership (NPP) Data Exploitation (NDE) for operational delivery;
• The GOES-R FLS algorithm was delivered to NESDIS operations and its products are in the NDE system and in the final stages of going into full operational status;
• Validation codebase is well established and will be used to validate future JPSS VIIRS instrument volcanic ash EDRs;
• NOAA-20 VIIRS volcanic ash EDR was granted Full Maturity status;
• CIMSS transitions new value-added products to operations (e.g., ProbSevere AWIPSII plug-in capabilities to NWS operations);
• New visualization capabilities were developed for the ProbSevere AWIPSII plug-in for NWS forecasters and are being transferred to NWS operations within a future release of AWIPSII;
• Applied research to improve NEXRAD QPE for lake-effect snow events and develop a GOES lake-effect snow QPE product for operational use by the National Weather Service and other stakeholders in the Great Lakes region;
• Taiwan CWB has new products for use in their forecasting and environmental monitoring;
• CIMSS delivers daily remote sensing data to OU CIMMS;
• CIMSS delivers additional information during severe weather events related to cloud-top signatures and their translation to surface features;
• Greater understanding on the best approaches for forecasting flash flooding;
• Software changes to CLAVRx will be migrated to NOAA's ASSISTT software framework;
• CIMSS is exploring opportunities for transferring knowledge learned in developing AI-ProbSevere models to international entities, as some of them rely only on geostationary satellite data;
• Atmospheric composition products transferred to NOAA global atmospheric composition forecasting and assimilation system.

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

Satellite data play a critical role in supplying actionable timely weather, water, air quality, and hazard information of direct benefit to society. Some examples that illustrate how CIMSS research, products, and education directly impact society include:
• Improved hurricane forecasts lead to fewer casualties and reduce economic losses;
• Improved accuracy for detection of Volcanic Ash for commercial aviation avoidance;
• Improved warning of aviation atmospheric turbulence hazards;
• Deployment of the turbulence model into rapid, global computation;
• Nowcasting improvements reduce disruptions to commerce;
• Satellite data products used in weather forecasting and disaster mitigation (e.g., wildfire detection and monitoring, volcanic eruption detection) help save lives and property;
• Provide timely JPSS satellite-derived burn intensity estimates to enable NWS-WFOs to craft accurate warnings and support their emergency management and response partners;
• New mapping software has the potential to support emergency operations in fire-scarred areas by saving lives with earlier warnings;
• Improved air quality prediction;
• A demonstration of the commitment for the NWS to be effective stewards of federal resources that will help the NWS best allocate its resources to best serve all sectors of society;
• Short courses developed for the US Broadcast Meteorology community raise science literacy and broaden the impact of NOAA satellite data across many user communities;
• Through social media, NOAA frequently posts for the public interesting GOES ABI images that were generated at CIMSS or using CIMSS tools;
• Satellites provide water quantity and quality information to many regions of the world where such data are scarce. These data are critical for human and ecosystem health and mitigating far reaching implications that include education, women's rights, food insecurity and political instability;
• Improved air quality prediction helps mitigate exposure to air pollution and reduce associated health risks that include increased respiratory symptoms, hospitalization for heart or lung diseases, and even premature death.

IMPACT *(cont'd)*

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

0 , NA

CHANGES/PROBLEMS

45. Changes in approach and reasons for change

During the first half of the reporting period, CIMSS research and education continued to be performed largely via remote work due to the global pandemic. Research activities were frequently conducted in isolation as opposed to the collaborative setting on campus. Education, advising, and outreach shifted from in person to virtual. Despite these changes in modality, CIMSS was able to accomplish the vast majority of its stated objectives. At the time of submission, most CIMSS staff have now returned to predominantly on-site work.

Other changes in proposed approaches include:

• Reduced travel during the pandemic and reduced FTEs due to family leave resulted in some carry over of tasks from the prior cooperative agreement via a second NCE;
• Changes were made to the monitoring web pages for data validation in response to changing circumstances with GOES-17's evolving data quality issues;
• The development of the quality control schemes for cloud and surface contamination is being delayed until after the radiance tendency assimilation technique is finalized. This will ensure the response observed is due to the quality control procedures only;
• Reduced budget resulted in descope of OMPS NO2 assimilation development;
• Development of sea ice thickness products was postponed due to reduced funding;
• Computer resource limitations delayed the transition to NCEP/EMC and its implementation by NCEP Central Operations.
• Due to the pandemic, visits from scientists outside of CIMSS had to be replaced with less frequent virtual exchanges.

CHANGES/PROBLEMS *(cont'd)*

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

• In rare cases, COVID-19 impacts slowed down progress; a specific example was testing of antenna components has been slower during the pandemic, however, hardware was installed in advance of the GOES-T launch;
• COVID-19 significantly impacted communicating the results of CIMSS research activities over the past year at conferences, workshops, and symposia – this was mitigated by CIMSS scientists' participation in virtual meetings to maintain channels to users and the research community;
• We experienced delays in acquiring computer hardware as a result of global supply chain issues – we temporarily repurposed existing hardware for our development until the dedicated hardware arrived;
• The unstable quality of GOES-17 radiances impacted delivery of some retrieval products – this will improve with the transition to GOES-18;
• NUCAPS science retrieval has not been implemented within operations impacting our proposed 1-year re-analysis – we are working with STC NUCAPS team to generate science retrievals at the UW-Madison Space Science and Engineering Center;
• We have found it impossible to obtain large statistical databases from external model developers; therefore, we have decided to generate a synthetic database that contains a sufficiently large number of metrics and variables to explore the alternative scorecard methods;
• NCEP/EMC transition to the Joint Effort for Data assimilation Integration has impacted some data assimilation work – we will continue to coordinate with NCEP/EMC on their transition to using the Joint Effort for Data assimilation Integration and transition when applicable.

47. Changes that had a significant impact on expenditures

• The ongoing pandemic severely curtailed travel during the past year;
• Budget cuts to some GOES-R related activities limited the FTEs but the shortfall should be temporary due to the upcoming transition to GEO-XO.

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

NA

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

A significant fraction of CIMSS research activities shifted from the Atmospheric, Oceanic, and Space Sciences building at UW-Madison to telework from home during the pandemic. CIMSS researchers have largely returned to work as of the time this report is submitted.

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?

The outcomes of the research conducted under the CIMSS cooperative agreement align with our four central themes: (1) Satellite Meteorology Research and Applications, (2) Satellite Sensors and Techniques, (3) Environmental Models and Data Assimilation, and (4) Outreach and Education. CIMSS provided end-to-end support of meteorological satellite applications from instrument calibration to data assimilation to training and outreach. CIMSS further supported new initiatives in community modeling, generated and dispersed operational cryosphere climate data records (CDRs), introduced novel artificial intelligence and machine learning approaches for maximizing the information yielded by NOAA assets, led economic impact assessments, and helped define next-generation environmental observing systems.
CIMSS contributed calibrating and validating NOAA's geostationary and low-earth orbiting satellites (Suomi-NPP, NOAA-20, GOES-16, GOES-17, and GOES-18) and associated data products. A key outcome of these efforts is calibrated radiances and intercalibrated water vapor, atmospheric motion, and trace gas datasets that can be assimilated to improve weather and pollution forecasts. CIMSS research has also yielded a suite of advanced high-impact weather products that support the NWS mission to protect lives and property and produced software to allow users to access satellite data and imagery with low latency. The Geostationary Community Satellite Processing Package (CSPP Geo) developed at CIMSS has been widely adopted by U.S. government agencies, researchers, private industry, and other meteorological services to process GOES Rebroadcast (GRB) data from GOES-16 and GOES-17. This included completing several important steps toward transitioning VOLCAT processing to NOAA AWS cloud infrastructure for eventual operational processing. CIMSS researchers also demonstrated the impact of assimilating VIIRS Aerosol Optical Depth and OMPS ozone retrievals within the global Unified Forecast System (UFS) with Real-time Air Quality Modeling System (UFS-RAQMS) global composition forecasting. Finally, CIMSS also provided guidance concerning GEO-XO instrument requirements including leading efforts to demonstrate the potential of a Geostationary hyperspectral infrared sounder for determining moisture profiles, deriving 3D winds, and improving precipitation and severe weather forecasts.

CIMSS scientists are dedicated to sharing their work and results with others. In addition to 7 peer-reviewed papers published in 2021-22, CIMSS and SSEC maintain several web sites for external audiences beyond the news stories sites noted earlier (in http://www.ssec.wisc.edu/news/articles), including:
- Educational resources for students and teachers: https://cimss.ssec.wisc.edu/education/
- The CIMSS Satellite Blog for case study discussion and analysis: http://cimss.ssec.wisc.edu/goes/blog/
- Data and imagery used by external media outlets, researchers, and many others: http://cimss.ssec.wisc.edu/data/ and http://www.ssec.wisc.edu/data/

CIMSS also continued its support of NOAA's education and outreach goals with involvement in K-12, undergraduate, graduate and professional training. CIMSS awarded three scholarships to incoming freshmen, supported undergraduate interns, supported several graduate students, including the William Smith Graduate Scholar, working on NOAA research with CIMSS and ASPB scientists. These efforts reinforce the pipeline of talent into the NOAA enterprise as evidenced by recent hires into NOAA positions.
In summary, through successful completion of a diverse portfolio of activities, CIMSS has supported the full lifecycle of environmental satellite

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.