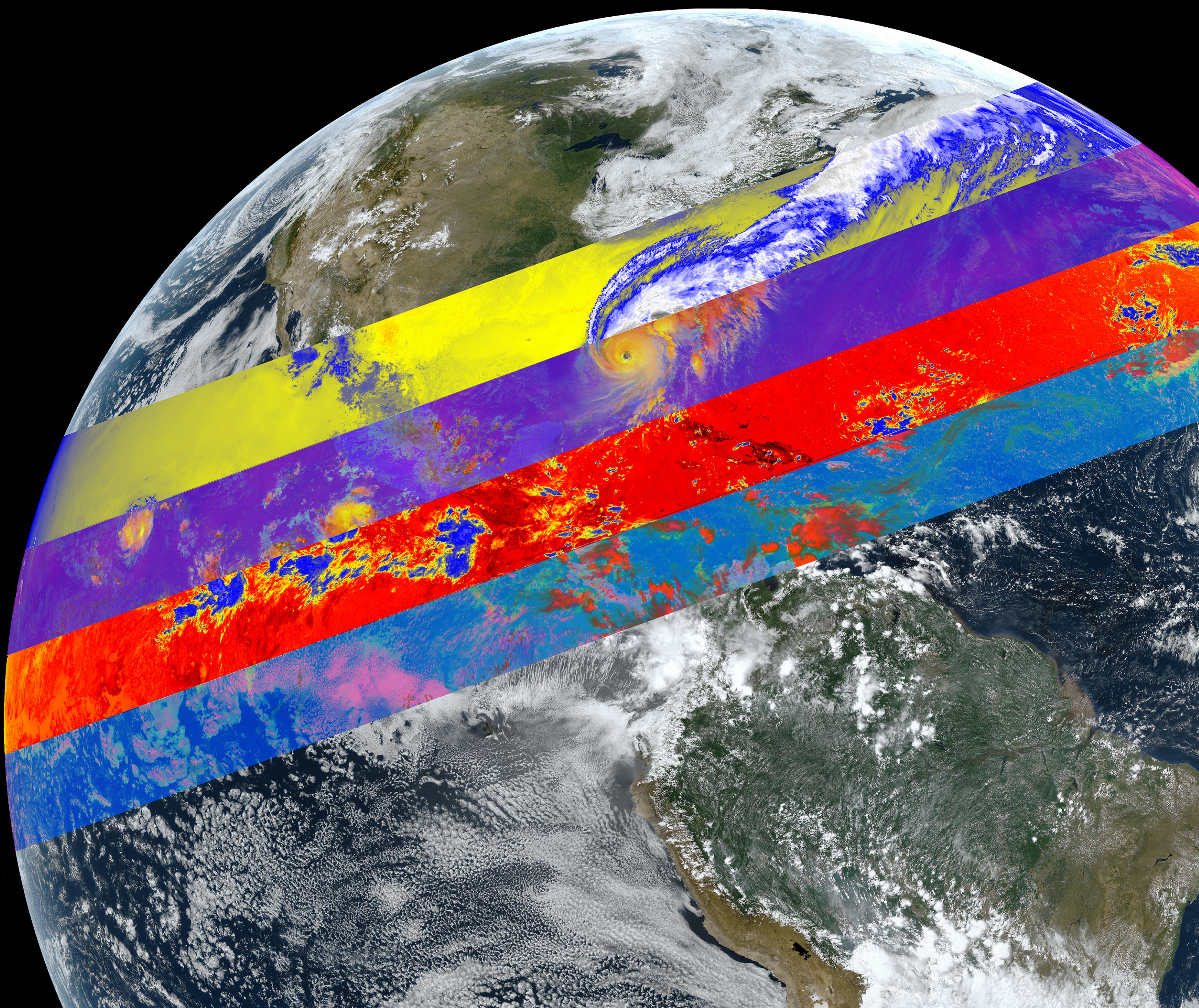
CIMSS

Cooperative Institute for Meteorological Satellite Studies
Five-year Science Review Briefing Book
July 2020 — March 2024



The Cooperative Institute for Meteorological Satellite Studies
at the University of Wisconsin–Madison

Five-year Science Review

Principal Investigator: Dr. Tristan L'Ecuyer

Covering the Period:
1 July 2020 to 31 January 2024

Executive Summary

This report summarizes progress toward CIMSS goals defined when it was established in June 2020. It is submitted in response to the letter from Assistant Administrator Dr. Steve Thur, dated July 24, 2023, charging the NOAA Science Advisory Board (SAB) to review the Cooperative Institute for Meteorological Satellite Studies (CIMSS). This document furnishes reviewers with a thorough summary of CIMSS research efforts, education and training activities, major accomplishments, and efforts to increase diversity, promote equity, and foster an inclusive work environment within CIMSS. Responses are provided to all questions outlined in the revision of the Cooperative Institute Handbook in effect at the time of writing (Version 5.0, dated May 2023).

CIMSS research is grounded in more than four decades of successful end-to-end satellite product development to meet the nation's needs for reliable and timely weather and climate information. CIMSS' research and education efforts are organized around four central themes: (1) Satellite Research and Applications, (2) Satellite Sensors and Techniques, (3) Environmental Models and Data Assimilation, and (4) Outreach and Education. Building upon strong collaborations with the National Environmental Satellite, Data, and Information Service's (NESDIS's) Center for Satellite Applications and Research (STAR), CIMSS researchers address several unique topics within these broad themes by: 1) serving as a hub to foster collaborative research between the university, NOAA, other agencies, and non-governmental and international partners; 2) bringing extensive scientific, education, and outreach expertise to satellite research relevant to NOAA; and 3) engaging and training the future NOAA workforce in satellite remote sensing for weather and climate applications.

CIMSS operates as a Cooperative Institute within the Space Science and Engineering Center (SSEC), an interdisciplinary research center within the University of Wisconsin–Madison (UW) Office of the Vice Chancellor for Research (OVCR). Through SSEC, CIMSS can access a state-of-the-art satellite data ingest and archival center, powerful on-site computing facilities, instrumentation and engineering expertise, an experienced outreach and education team, and a dedicated communications team. This infrastructure supports innovative weather and climate research to address the nation's needs for improved situational awareness, accurate weather forecasts, and environmental monitoring central to predicting, adapting to, and mitigating the effects of climate change and severe weather hazards. CIMSS scientists work closely with NOAA to maintain the scientific integrity of this research as NOAA implements the findings at its operational centers. Furthermore, the close association between CIMSS and the UW Department of Atmospheric and Oceanic Sciences (AOS), a leading atmospheric science education program offering undergraduate and graduate degrees, provides a pathway to engaging students and postdoctoral scientists in NOAA-funded research.

During the period covered by this review, CIMSS has leveraged these resources to support specific activities under its four guiding themes. Examples of accomplishments under the current cooperative agreement include:

Theme 1: Satellite Research and Applications

- Developed and tested new retrieval algorithms for application to significant weather events.
- Provided operational upgrades for Joint Polar Satellite System (JPSS) and Geostationary Operational Environmental Satellite (GOES)-R series atmospheric motion vector (AMV) products.
- Researched, developed, and optimized objective methods for incorporating data from multiple satellite platforms to analyze tropical cyclone intensity and structure more accurately.
- Supported global aviation with advanced satellite-based volcanic ash and turbulence products.
- Implemented a North America geostationary fire monitoring system.
- Evaluated and enhanced satellite-based estimates of cryosphere properties including sea ice cover, snow cover, and sea ice thickness.
- Researched new methods for detecting clouds and estimating their properties from satellite observations.
- Analyzed multi-platform fused cloud, fire, and sea/lake ice climate data records (CDRs) to diagnose climate change signatures.
- Applied innovative machine learning methods to improve the accuracy and increase lead time of satellite-based hail, wind, heavy rain, lightning, and tornado warnings.
- Engaged partners at the Aviation Weather Center, National Hurricane Center, and the National Weather Service to increase the use of satellite products and understand their performance.
- Researched new methods for characterizing retrieval uncertainties to increase satellite data assimilation into forecast models.

Theme 2: Satellite Sensors and Measurement Techniques

- Developed new instrumentation and methods to assess the performance of satellite sensors and inform the design of next-generation low-earth orbiting and geostationary satellite sensors.
- Analyzed sustained ground-based measurements at long-term climatological validation sites.
- Participated in targeted field campaigns to validate and advance satellite retrievals.
- Advanced data fusion techniques to increase the temporal and spatial resolution of satellite soundings and established their impact in forecast models.
- Researched and implemented new methods for mitigating the GOES-17 Loop Heat Pipe (LHP) anomaly.
- Applied revolutionary Artificial Intelligence/Machine Learning (AI/ML) approaches to maximize the benefits of NOAA environmental satellites for characterizing the physical environment.

Theme 3: Environmental Models and Data Assimilation

- Researched and tested new approaches for assimilating thermodynamic and dynamic information provided by hyperspectral sensors and geostationary imagers.
- Developed new bias correction methods, improved observational error estimates, and advanced QC methods to increase the use of all-sky infrared brightness temperatures data assimilation systems.
- Improved radiance assimilation over land surfaces by separating surface and atmospheric contributions.
- Explored the assimilation of satellite observations sensitive to soil moisture and vegetation properties in Numerical Weather Prediction (NWP) and land surface models.
- Extended the Realtime Air Quality Modeling System (RAQMS) Aura Reanalysis beyond 2016 using the next generation of operational trace gas retrievals.
- Advanced innovative model verification methods to support NWP model development.

- Conducted regional Observing System Simulation Experiments to assess the impacts of advanced infrared sounders and imagers onboard geostationary and CubeSat satellite platforms.

Theme 4: Education, Training, and Outreach

- Developed new educational activities that facilitate the use of satellite observations from all NOAA missions in K-12 Earth science education.
- Expanded access and usage of the community Climate Digest.
- Engaged and nurtured a diverse pool of prospective STEM students by expanding the highly successful satellite virtual science fair to include all NOAA and NASA missions.
- Created dynamic content for the CIMSS website and CIMSS Satellite Blog to convey CIMSS research to wide audiences.
- Conducted in-person training visits to NWS forecast offices and ran remote sensing schools.
- Conducted satellite education programs for students jointly with STAR's CESSRST.
- Developed new distance learning modules aimed at helping to prepare tomorrow's forecasters for the next generation of meteorological satellites.
- Increased the societal benefits of satellite and weather information through communication, social science, public engagement, and collaboration with other agencies.

These activities, conducted in collaboration with NOAA scientists, support the research and development needs for the nation's operational weather satellites. CIMSS continuously works closely with NESDIS to refine our research portfolio to maximize the value our skilled research staff brings to the public. This fruitful collaboration has led to the publication of more than 300 papers since 2020, including some of the most highly cited in their fields. CIMSS researchers have presented innovative research at numerous conferences, workshops, panel discussions, and symposia and shared their unique subject matter expertise to inform strategic planning exercises at the highest levels. Through the SSEC Data Center, CIMSS has shared an average of about 1200 PB of data per year to a wide range of stakeholders that include government agencies, the commercial sector, and the public. This report presents a representative cross-section of the research and training accomplishments at CIMSS in general terms with specific examples that illustrate the quality and impact of the work.

The Cooperative Institute for Meteorological Satellite Studies at the University of Wisconsin–Madison

Five-year Science Review

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1. CIMSS 5 Year Renewal Science Review Agenda

The CIMSS Science Review panel will convene in Room 351, Atmospheric, Oceanic, and Space Sciences, 1225 West Dayton St, Madison, WI.

Final agenda here

2. Science Review Panel

Bios to appear here

3. About CIMSS

The Cooperative Institute for Meteorological Satellite Studies (CIMSS) is a long-standing partnership between NOAA and the University of Wisconsin–Madison (UW) focusing on satellite-based weather, environmental, and climate research. Founded in 1980, CIMSS filled a need for global leadership in these emerging fields, finding a home appropriately at the UW Space Science and Engineering Center (SSEC), the birthplace of satellite meteorology. For more than four decades, our institute has worked with NOAA to meet society's needs for timely, accurate, and reliable satellite data to support short term weather forecasting, identify atmospheric hazards, and monitor the Earth-atmosphere system. Our principal investigators, researchers and support staff develop new methods and tools to support NOAA's mission and we develop the future leaders in satellite Earth observation by engaging students from diverse backgrounds.

CIMSS' history is encapsulated in Figure 3.1 that shows geostationary satellite imagery from the day CIMSS was founded (left) and early 2024 (right), all produced using CIMSS visualization software and data archived at UW. The monochromatic Synchronous Meteorological Satellite – 2 (SMS-2) images on the left, captured Hurricane Howard off the coast of California on August 5, 1980. The true-color images on the right combine the three visible wavelength channels on GOES-16 to reveal severe storms over south central Wisconsin on February 8, 2024. These storms later produced the first recorded February tornadoes in the state. Through the power of modern machine learning, the CIMSS ProbSevere algorithm leveraged GOES-16's four times higher spatial resolution and 15 times better temporal resolution to identify this severe weather threat several minutes before the tornadoes struck near Evansville, WI, a few miles southeast of UW. This is a good example of how CIMSS research is providing forecasters and the public critical lead time to protect both life and property.

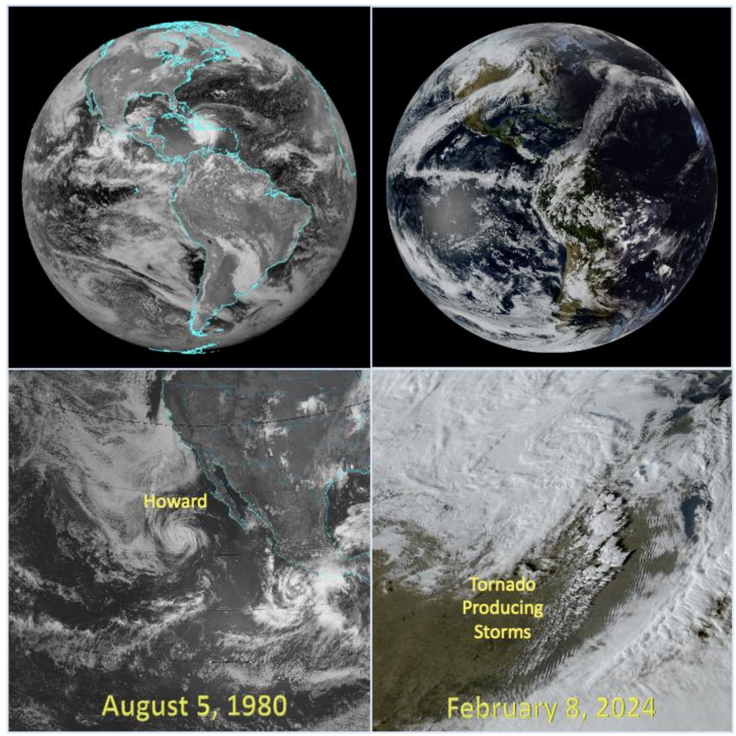

FIGURE 3.1: CIMSS Imagery Then and Now: GOES observations from the founding of CIMSS on August 5, 1980 (left) and the first February tornado outbreak in Wisconsin February 8, 2024. Images were produced with Community Satellite Processing Package (CSPP) software developed at CIMSS.

Implicit in this nostalgic satellite look back at the early days of CIMSS, lies the fact that our researchers have been involved in all phases of NOAA's polar orbiting and geostationary meteorological satellite programs since NOAA-6 and SMS-2. In fact, CIMSS founder and first director, Professor Verner Suomi, conceived of, built, and tested the first successful meteorological satellite instrument more than ten years before NOAA was established. A small sample of CIMSS milestones over the past four decades are highlighted in Figure 3.2. Building on Suomi's legacy, CIMSS engineers, scientists, and students have informed satellite instrument design and calibration, led algorithm innovation, pioneered visualization and processing tools, distributed data, and provided training resources for end users for nearly 44 years.

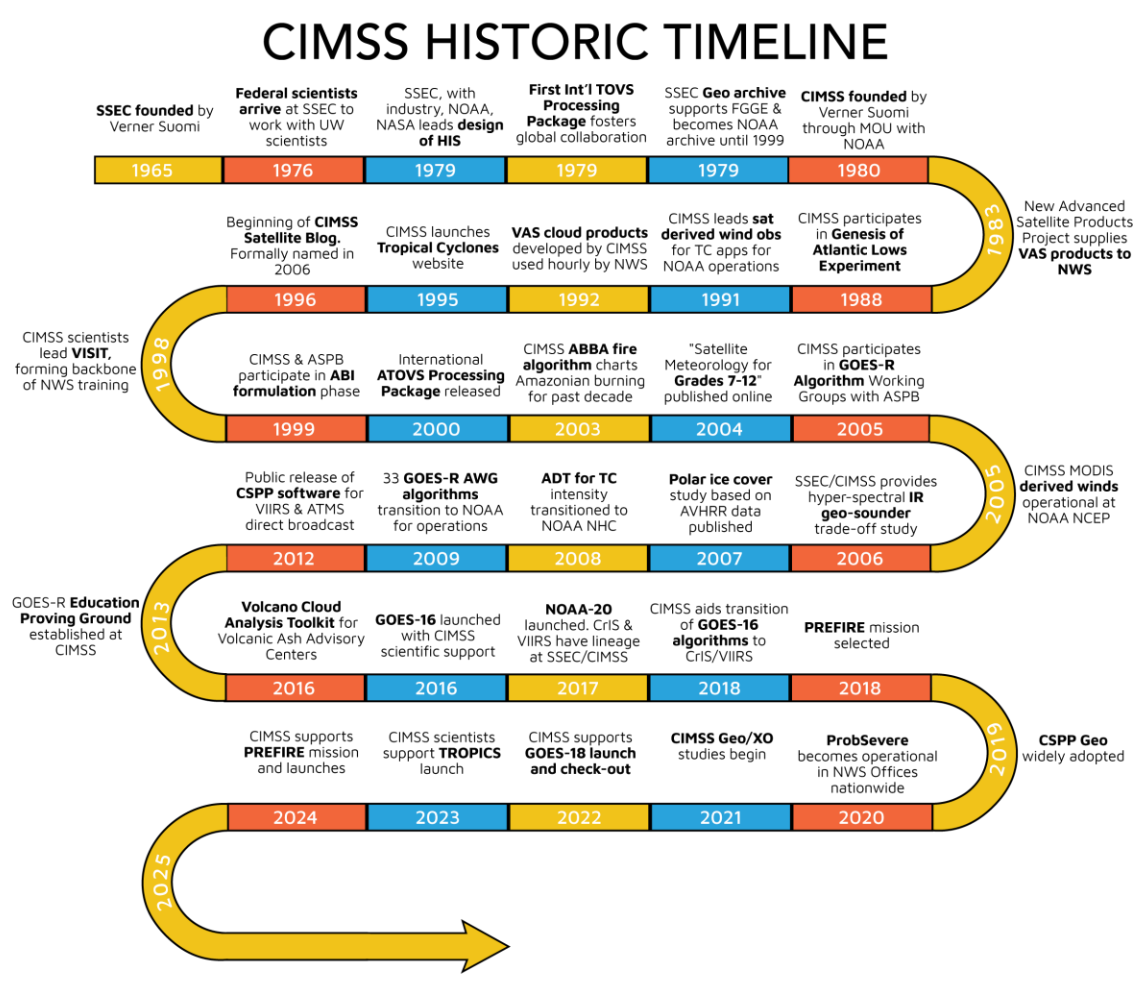

FIGURE 3.2: CIMSS historical timeline: Examples of major highlights and achievements in our history.

Today, the collaborative relationship between NOAA and UW upon which CIMSS is built continues to provide numerous benefits to the atmospheric science community and to the nation by advancing the use of satellite, aircraft, and ground-based remote sensing measurements in research and applications. It also furnishes a framework for developing a robust education and outreach program to train students, professionals, and other stakeholders in the use of environmental satellite data. Through close interactions with the UW Department of Atmospheric and Oceanic Sciences (AOS) and the NOAA NESDIS Center for Satellite Applications and Research (STAR), CIMSS:

- Fosters collaborative research among NOAA, other federal agencies, and the University in those aspects of atmospheric and earth system science that exploit the use of environmental satellite technology.
- Serves as a center at which atmospheric scientists and instrument/sensor engineers can work together on problems of mutual interest to focus on satellite-related research in atmospheric and earth system science.
- Stimulates the training of scientists and engineers in the disciplines involved with remote sensing of the atmosphere.

CIMSS achieves these objectives by conducting an integrated program of research and education activities that maximize the information gleaned from environmental satellite data through innovative computational methods, value-added data interpretation, and effective communication to users, stakeholders, and the public. This research is organized under four interconnected themes: *Satellite Sensors and Measurement Techniques*, *Satellite Research and Applications*, *Environmental Models and Data Assimilation*, and *Outreach and Education.* Though the specific approaches to addressing each theme vary, CIMSS engineers, scientists, educators, communicators, and students share the vision that they connect in a single, continuous cycle (Figure 3.3). CIMSS acquires satellite data through the SSEC data downlink capabilities on the Atmospheric, Oceanic, and Space Sciences building rooftop. Researchers apply state-of-the-art methods to assess data quality and monitor instrument performance before archiving it on-site to support processing using innovative algorithms that produce meteorological information tailored to a wide range of stakeholders. While CIMSS researchers develop algorithms generating petabytes of data to meet the needs of the operational and research communities, they also research and apply sophisticated approaches for distilling this vast data volume into actionable weather and climate information that can be disseminated to broad audiences. Our shared core value is that everyone should have access to unbiased, reliable, accurate, and easy to use weather and climate information.

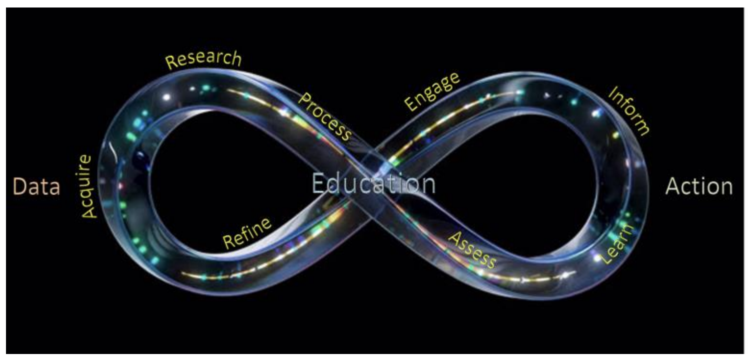

FIGURE 3.3: The CIMSS Research Cycle. Education is the bridge from Data to Action. Translating satellite observations to actions is a continuous process involving acquiring, researching, processing, assessing, learning, informing, engaging, and refining meteorological satellite data and downstream data products.

To meet this goal and ensure that meteorological satellite data is accessible to underserved communities, CIMSS creates visualization tools and provides training for end users. CIMSS hosts numerous conferences, workshops, and symposia on aspects of modern satellite meteorology. We provide training for meteorologists and online instructional modules for the public. CIMSS has a robust K-12 education program that includes teacher workshops, virtual science fairs, online and in-person summer camps for students, and tours of our facility. CIMSS also plays a unique role in providing NOAA an academic partner via our link to UW undergraduate and graduate students. As employees of an internationally recognized research university, our staff mentor the next generation of scientists who will support future partnerships between CIMSS and NOAA.

This combination of reliable observations, refined information-centric products, comprehensive data sharing and communication tools, and education/training ensures that the data collected by NOAA's weather satellites is translated into actions that protect lives and property. By routinely engaging stakeholders to gather feedback, CIMSS researchers continuously refine products to meet user needs. CIMSS subject matter experts also inform the design of the next generation of satellite instruments, by analyzing meteorological data collected from aircraft and conducting simulation experiments. This work increases the quality and understanding of satellite remote sensing datasets and supports their application to a wide variety of problems including numerical weather and air quality prediction, improving tropical cyclone track and intensity forecasts, detecting aviation hazards, wildfire, and severe weather, and diagnosing the effects of climate change.

Through this process, and working closely with NOAA, CIMSS research has contributed to creating a Weather Ready Nation and is contributing to developing a Climate Ready Nation. With planned improvements in lightning, air quality, and ocean color observing capabilities as well as new geostationary sounders, the coming decades promise even greater value from our satellite observing systems. As a long-term partner of NOAA, CIMSS serves as part of the NESDIS ‘corporate memory’ applying lessons learned from early geostationary and polar orbiting programs to the Geostationary Extended Observations (GeoXO) and JPSS programs. CIMSS researchers, engineers, and students will continue to play a critical role in maximizing the value of these improvements and ensuring that everyone benefits from these advances. Continuing CIMSS ensures that the “Suomi tradition” of translating innovation to action lives on at the University of Wisconsin and NOAA.

4. Science Evaluation

The subsequent subsections respond to each of the 5-year Science Review questions outlined in the latest revision of the Cooperative Institute Interim Handbook (Version 5.0 dated May 2023). Additional supporting materials including lists of all staff and students supported on CIMSS projects, publications, awards, and several examples of scientific advances, societal impacts, and user engagement from CIMSS research, are provided as supporting materials in Section 6.

4.1 Science Plan

4.1.a What is the scientific (not programmatic) vision for the institute?

CIMSS is embedded within SSEC at the UW. As such, CIMSS’ vision builds upon the principles defined by the SSEC vision that states, “SSEC will strive to advance our technical excellence in the areas of:

- **Observational Science** (instrumentation, spacecraft system/mission design, field programs, and space flight instrument fabrication);
- **Analytical Science** (satellite and conventional data analysis, technique development, and modeling);
- **Computational and Visualization Science** (hardware and software systems for information generation, data management, and communication);
- **Campus Science Support** (Physics, Astronomy, Botany, Geology); and
- **Education and Public Outreach** (UW undergraduate and graduate programs, K–12 collaborations, science engagement with the public).”

This scientific vision was developed in 2022-23 as part of the SSEC 5-year Strategic Plan that solicited input from all SSEC staff. SSEC leadership, which includes the CIMSS Director and Deputy Director, were the primary authors of this plan with input from center staff via surveys and a center retreat. The SSEC Strategic Plan follows the themes of the UW–Madison Strategic Plan in promoting research and learning, building collaborations, locally to internationally, and supporting professional growth.

Within SSEC, the CIMSS scientific vision is to conduct interdisciplinary research in the atmospheric sciences, focusing on using satellite observations, numerical models, and state of the art data analysis techniques to better understand the behavior of the Earth system and convert this understanding into actionable information to benefit the public. The process for realizing this vision is encapsulated by the continuous research cycle shown in Figure 3.3 that characterizes CIMSS research strategy. CIMSS analytical, computational, visualization, and stakeholder engagement activities provide the means to flow from *data* acquisition through *information* processing to *knowledge*. This knowledge is conveyed to wide range of stakeholders enabling them to take *action* to meet the needs of a geographically, ethnically, and socioeconomically diverse population. Stakeholder and public engagement provide feedback for refining products and stimulate new ideas for increasing the value of NOAA assets for all.

4.1.b. Does the CI have a Scientific Mission and/or Vision Statement?

CIMSS' Scientific Mission is to advance the use of meteorological satellite data to enable the National Oceanic and Atmospheric Administration to meet the nation's weather and climate needs.

CIMSS' Scientific Vision is a more informed society, prepared for and resilient to weather and climate changes through the effective use of meteorological satellite observations.

These mission and vision statements were developed in concert with the SSEC Strategic Plan but are further guided by CIMSS unique partnership with NOAA and its vision to create a CI dedicated to advancing the use of meteorological satellite data to benefit the public. These statements were composed by CIMSS leadership, to reflect the outcomes of a broader collaborative strategic planning exercise that engaged all CIMSS and SSEC researchers and administrative staff. The process was rooted in a climate survey and a self-study questionnaire that were posed to all employees to define our core values:

- **Foster Innovation**: Leadership derives from pursuing transformative ideas, pioneering new methods, and developing new technologies.
- **Engage Stakeholders**: Data should inform action.
- **Enhance Education and Communication**: Education is the root of realizing the benefits of NOAA's Earth observing satellite fleet.
- **Ensure Equitable Data Access**: Accurate, reliable, and timely weather and climate data should be open and accessible to everyone.
- **Cultivate Diversity, Equity, and Inclusion**: An inclusive community celebrates diverse identities, cultures, backgrounds, experiences, and opinions for enhancing creativity, innovation, education, and outreach.

These core values form the basis for CIMSS' mission and vision statements and the associated goals listed in Section 4.1.a. The final statements derive from several iterations of review to integrate feedback from all CIMSS staff and a final review by SSEC leadership prior to publication.
CIMSS' mission, vision, and goals are communicated to employees during onboarding and at all-hands meetings. These statements are also widely communicated to the public through the openly accessible CIMSS website. CIMSS mission, vision, and core values are embodied in the research we do, presentations we give, and education and outreach we engage in.

Relationship to NOAA's Strategic Goals

Cooperative Institutes provide a bridge between academia and the federal government. As such, CIMSS' vision, mission, and goals integrate elements of the University's education and research missions from both the UW Strategic Framework and NOAA's strategic objectives outlined in the NOAA Strategic Plan for FY2022-26 and the NESDIS Strategic Plan. In what follows, language specifically found in these reports is highlighted in italics.

All CIMSS research contributes to NOAA's science, service, and stewardship mission "*to understand and predict changes in climate, weather, ocean, and coasts.*" Our meteorological satellite products translate vast volumes of raw data into tangible information about our environment including surface properties, atmospheric composition, air quality, severe weather, and natural hazards. Our climate data records (CDRs) track long term changes in clouds, moisture, fires, and sea/lake ice concentrations at local to global scales. Our students and researchers analyze these records to understand how weather systems, hazards, and water resources are changing and evaluate models that predict how they will evolve in the future.

Our technical computing, education, outreach, and communications teams ensure this information is conveyed to stakeholders and the public, addressing NOAA's mission "*to share that knowledge and information with others.*" We archive and distribute more than 15 petabytes of satellite data from more than four decades of geostationary and polar orbiting satellites but also develop value-added products and imagery that make these data accessible to the public. We develop training modules to teach users of all types how to interpret meteorological satellite data and act on the information they provide. We engage STEM educators and their students from K-12 to ensure this pursuit of knowledge is carried forward by future generations of STEM researchers.

This combination of research and development, data sharing, and education and outreach are necessary to realize NOAA's vision of "*healthy ecosystems, communities and economies that are resilient in the face of change*" and reflected in CIMSS vision of "*a more informed society, prepared for and resilient to weather and climate changes.*" As a NESDIS CI, CIMSS' vision parallels the NESDIS vision to "*expand understanding of our dynamic planet as the trusted source of environmental data.*" The NESDIS Strategic Plan identifies specific goals for achieving this vision under six categories: *Continuity*, *Data and Information*, *Architecture*, *Use-Inspired Science*, *Partnerships*, and *People*. By design, CIMSS research contributes to each of these goals.

Addressing NESDIS' Continuity goals, CIMSS calibration and validation research and data center help ensure "*the continued high-reliability, secure and timely delivery of data and services that the Nation requires*" while our subject matter experts conduct research central to defining the requirements for future observing systems. CIMSS researchers have developed 63 unique data products to "*serve user's needs*" and continues to refine methods for sharing and visualizing this data to help realize NESDIS' Data and Information goal of "*ensuring data reaches new users to assure maximum benefit to the nation and scientific community*." Through SSEC's Direct Broadcast antennas (Section 6.8.1), CIMSS contributes to NOAA's Architecture goal of "*developing a shared infrastructure based on common ground services*."

NESDIS' Use-Inspired Science goals are at the heart of the CIMSS Research Cycle illustrated in Figure 3.3. CIMSS research helps NESDIS "*provide state-of-the-art science products*" and our climate data records (CDRs) "*provide integrated reference data sets that describe the state of the environment*." CIMSS pioneering research into new AI and ML methods for translating satellite observations into actionable information is directly tied to NESDIS' goal to "*enhance mission value of environmental data*." To achieve NESDIS' Partnership goals of "*acting as a good partner*" and "*strategically managing partnerships*" CIMSS researchers cultivate partnerships with a broad spectrum of from universities (Section 4.1.e). Finally, CIMSS' K-12 outreach program inspires youth from diverse backgrounds to pursue Science, Technology, Engineering, and Math (STEM) careers while our education and mentoring efforts help train the next-generation of NOAA scientists. Through these activities (that will be articulated in more detail below), CIMSS research directly addresses many elements of NESDIS mission to "*provide secure and timely access to global environmental data and information from satellites and other sources to both promote and protect the Nation's environment, security, economy, and quality of life*." It is CIMSS mission to curate data, research new methods for ensuring environmental data are accurate and reliable and provide resources that ensure this data is available and accessible with low latency to anyone who wants to use it.

4.1.c What are the CIs goals and objectives within the Scientific Plan?

CIMSS' overarching role is to enhance communication and interaction between subject matter experts, stakeholders from academia, government, non-governmental organizations, and industry, educators, students at all levels, and the public. This role is defined by three primary goals that focus on developing, advancing, and promoting satellite meteorology:

- Foster collaborative research among NOAA, other federal agencies, and the University in those aspects of atmospheric and earth system science that exploit the use of environmental satellite technology.
- Serve as a center at which atmospheric scientists and instrument/sensor engineers can work together on problems of mutual interest to focus on satellite-related research in atmospheric and earth system science.
- Stimulate the training of scientists and engineers in the disciplines involved with remote sensing of the atmosphere.

CIMSS Research and Educational Activities

- ❑ Conduct cutting-edge research to maintain global leadership in environmental satellite observations and applications.
- ❑ Research and develop novel techniques to advance the use of satellite data in weather analysis and forecasting.
- ❑ Study new ways to effectively utilize satellite observations to respond to the challenges posed by climate change.
- ❑ Train a workforce knowledgeable in satellite meteorology and remote sensing.
- ❑ Build a scientifically literate society, ready to embrace and act on meteorological satellite information.

CIMSS achieves these goals through a comprehensive research, education, and outreach program that furnishes end-to-end enhancements to meteorological satellite information systems, incorporates input from users, adapts to changing infrastructure and societal needs, and engages students. To successfully meet our goals, CIMSS prioritizes the five primary research and educational activities summarized in the box on the right. The outcomes of these efforts are described in Sections 4.2 and 4.3 of this report with many other examples provided as supplemental material in Section 6. Many of these accomplishments rely on CIMSS' partnerships with NOAA, other agencies, universities, and industry (summarized in Section 4.1.5) and, especially, the NOAA employees collocated at CIMSS.

i. What criteria are used to measure progress in accomplishing these goals and objectives?

To maximize the value of CIMSS research to the government, other stakeholders, and the public, CIMSS regularly assesses progress toward achieving its goals and objectives through a combination of traditional and contemporary metrics. Indicators of a successful educational research center include the number of publications in refereed journals, how frequently these papers are cited, conference presentations, the success rate for submitted proposals, the number of graduating students, international scientist engagement, software and data distribution, awards of recognition, and unsolicited positive feedback from stakeholders. We closely track these metrics (see Section 4.4.m), and other less quantitative measures of performance, to assess progress toward each of CIMSS' five core research and educational activities summarized in Section 4.1.c.

Progress in "*conducting cutting-edge research*" is quantitatively measured by proposal submission success and publications in refereed journals. CIMSS tracks all publications to which our researchers contribute as a co-author. To further assess the impact of our research, we also track how often these papers are cited by others as one measure of the value of our work as recognized by the scientific community. For example, a CIMSS-led study in 2021 documenting the distribution and drivers of flash droughts has already been cited more than 100 times (Table 4.2).

CIMSS also tracks national and international recognition of its staff through awards, society fellowships, and other direct acknowledgments. While many other contributions made by our researchers to advancing cutting edge research are too numerous to aggregate into institute-wide statistics, all individual CIMSS researchers report their lectures, seminars, presentations, and non-peer reviewed publications during semi-annual performance evaluations. This progress as well as service on national and international committees, participation on panels, and contributions to the peer review process form the basis for compensation increases and promotions.

Success in "*researching and developing novel techniques*" and "*effectively utilizing satellite observations*" for weather and climate change research, is judged by tracking the breadth of data products with heritage at CIMSS, the volume of data downloaded by end users, and the number of research algorithms developed at CIMSS that have been transferred to NOAA for use in its operational mission. For example, the NOAA Office of Satellite and Product Operations (OSPO) data products page lists several products that derive from CIMSS research, often in conjunction with NOAA colleagues. CIMSS also contributes to the GOES-R ABI Key Performance Parameter (KPP), Cloud and Moisture Imagery Product (CMIP), which is generally referred to as "ABI Imagery."

To assess progress in "*workforce development*" CIMSS monitors the number of undergraduate and graduate students we mentor, how many students obtain graduate degrees conducting CIMSS research, and how many of those students obtain jobs working at NOAA, one of its Cooperative Institutes, or its external partners. CIMSS tracks the graduation rate and first employment location (as available) of graduate students who conducted research with CIMSS scientists. In addition to these quantitative measures, CIMSS also recognizes the mentoring efforts of our researchers and tracks the number of student internships and NOAA fellowships we supervise. We also regularly assess student feedback from our satellite meteorology summer camp and monitor the progress of our Suomi Scholarship recipients.

Increasing "*scientific literacy*" and cultivating a society that can benefit from the valuable information provided by NOAA's meteorological satellites, requires a combination of education, professional training, and outreach. To measure progress in professional training, CIMSS tracks the number of training modules we create as well as the number of training sessions or visits we provide to stakeholders. CIMSS further notes any training efforts dedicated to increasing participation from underserved communities. CIMSS also monitors how frequently the featured stories produced by our communications team are reshared by University Communications, NOAA Communications, and other media outlets (e.g., the New York Times and Washington Post). Another measure of our influence on scientific literacy is the number of subscribers and views our social media content receives. CIMSS monitors the volume and consumption of our social media content and shares this information with funding agencies through a biennial communications report.

A summary of these metrics for the period covered by this report is provided in Section 4.4.m. These metrics are shared with CIMSS staff at monthly meetings of project leads and at an annual all-hands meeting. In addition, they are considered during semi-annual staff evaluations, along with complementary activities like mentoring, teaching, and service. Progress toward CIMSS' goals is also reported directly to NOAA through the annual Research Performance Progress Report (RPPR) submitted online through eRA Commons that contains many similar metrics. To provide additional context, CIMSS sends separate brief synopses of all research projects attached to the CI (including Task II and other-agency activities that map to NOAA themes) and their relevance to NOAA mission goals are provided to all program managers.

4.1.d What are the major scientific themes of the CI?

CIMSS Major Scientific Themes

1. Satellite Research and Applications
2. Satellite Sensors and Measurement Techniques
3. Environmental Models and Data Assimilation
4. Outreach and Education

CIMSS conducts research under the four overarching scientific themes listed on the right. CIMSS scientists develop satellite retrievals of atmospheric humidity and temperature structure, surface properties, including snow and ice cover, clouds, atmospheric motion, radiation, fire characteristics, volcanic ash, tropical cyclone track/intensity, and severe weather probabilities. CIMSS then ensures these products are delivered to the public, in formats ranging from value-added products and training to officials to graphical representations on our public-facing website. For example, CIMSS works with National Weather Service Forecast Offices (NWSFOs) to provide situational awareness and the National Centers for Environmental Prediction (NCEP) Environmental Modeling Center (EMC) to assimilate this information into Numerical Weather Prediction (NWP) models with the goal of improving short-range forecasting applications and to support rapid and accurate decision-making. Our tropical cyclone research team collaborates regularly on new product development with the Tropical Prediction Center (NCEP/TPC) in Miami. We also work directly with the Storm Prediction Center (NCEP/SPC) and the National Severe Storms Laboratory (NSSL) in Norman, OK on satellite applications to severe weather forecasting and collaborates with the Aviation Weather Center (NCEP/AWC) in Kansas City on aviation safety projects that utilize weather satellite data.

To demonstrate the potential of new observing systems, CIMSS works with partners within SSEC, across the UW campus, and at other universities, institutes, and labs to design and test advanced instrumentation to pave the way for future advances in satellite technology. Our research played a pivotal role in establishing specifications for the Advanced Baseline Imager (ABI) aboard the GOES-16 and GOES-17 satellites, and we are actively contributing to the design of the next-generation geostationary and polar orbiting platforms through engineering studies, participation in sub-orbital field campaigns, and observing system simulation experiments (OSSEs). CIMSS is also pioneering novel applications of machine learning (ML) and artificial intelligence (AI) to extract actionable information from vast satellite datasets generated by contemporary satellite platforms.

As an institute at an internationally recognized university, education lies at the core of the CIMSS mission: educating students, training professionals, and increasing public scientific literacy. CIMSS provides hands-on experiences for high school and undergraduate students that increase exposure to NOAA research. Through active participation in the NOAA Pathway and Hollings Scholar programs, we serve as a conduit for these students to pursue career paths that align with NOAA. CIMSS and co-located NOAA scientists also mentor AOS graduate students on research projects that address NOAA needs while satisfying UW–Madison degree requirements. Based on this positive experience, many such students go on to join the NOAA workforce and supporting contractors. Finally, CIMSS increases satellite literacy by conducting extensive training programs for users at NWS, NCEP, external agencies, and international satellite organizations as well as supporting an active outreach program to engage the public assuring that our satellite products will be used to full advantage.

i. How were they identified and linked back to the themes NOAA used in the competition to create the CI?

CIMSS research themes exactly match those articulated in the Federal Funding Opportunity governing the selection of the current CIMSS and align closely with NOAA's needs for subject matter expertise in areas that maximize the utility of its satellite assets for public benefit. These themes share common threads with those identified in the memorandum of understanding that defined CIMSS in the 1990's ("*Climate,*" "*Environmental Trends,*" "*Global Hydrologic Cycle,*" "*Weather Nowcasting and Forecasting,*" and "*Clouds and Radiation*") but have evolved to include specific research areas relevant to modern satellite meteorology.

ii. What are the emerging thematic areas? Do these emerging themes arise directly from the existing CI themes, or are they based on changes since the CI was created?

The CIMSS Research Themes are very broad in scope and most research programs within them do not have a well-defined conclusion. For example, CIMSS staff will continuously engage in education, develop new training, and conduct communication and outreach activities as long as the CI remains in existence. Likewise, NOAA's satellite suite is continuously evolving and adding new capabilities that CIMSS is poised to apply to address the weather and climate needs of an ever more connected public. CIMSS research into new sensor technology and their applications to topics like weather forecasting, the energy-water cycle, and climate will continue far into the future. That said, some specific research projects are near completion, most notably those associated with the GOES-R program that will conclude after the last launch in the series (anticipated in June 2024). In addition, Version 3 of the ProbSevere suite of severe weather tools has successfully been transitioned to operations and is delivering early warning information to the public. New algorithms for estimating sea ice motion and sea ice thickness have been completed and products are distributed by the National Centers for Environmental Information (NCEI) to support Arctic research. Additional examples of CIMSS projects nearing completion will be identified in the scientific highlights presented in Section 4.2.a. However, most current CIMSS research projects we continuously adapt techniques to incorporate new computer technologies, explore new measurement capabilities, and re-direct the focus to address new research objectives. Thus, many programs are ongoing, making continuous progress as ideas and technologies advance and new challenges emerge.

Emerging Thematic Areas

ii. What are the emerging thematic areas? Do these emerging themes arise directly from the existing CI Themes, or are they based on changes since the CI was created?

The field of satellite meteorology is continuously advancing, driving CIMSS research to evolve to adapt new observational capabilities to meet public needs. One of the most important advantages of locating Cooperative Institutes on university campuses is having the agility required to adapt to meet new challenges. CIMSS' ability to attract and hire high quality postdocs and researchers without requiring a federal employment opportunity and to advise new graduate students provides flexibility to pursue new research themes as needs arise. As a result, while our guiding themes have remained unchanged for more than a decade, the specific research projects conducted under these themes can adapt as frequently as annually. In the past four years, several new CIMSS research projects have been initiated that can be grouped into five emerging themes: artificial intelligence and machine learning, next-generation satellite observing systems, climate data records, Great Lakes research, and science communications.

Artificial Intelligence and Machine Learning: Meteorology is often called "the original Big Data science." Until recently, numerical weather prediction and climate modeling were consistently at the forefront of innovations in supercomputing and hardware solutions to maximize data throughput. Now, with recent breakthroughs in machine learning/artificial intelligence (ML/AI), CIMSS has embraced a new Big Data focus that seeks to adapt new machine learning methods from outside our field, both in ways that operate on a desktop computer at the scale of less than a terabyte, and on multi-server systems at the scale of several petabytes. The scope and breadth of

AI/ML research has rapidly increased at CIMSS in recent years and now features in several of our core focus areas including aviation hazards, fire detection, tropical cyclone intensity, and cloud retrievals. This new CIMSS thematic area responds to NOAA's Artificial Intelligence (AI) Strategy that was developed as an action to the President's Executive Order on Maintaining American Leadership in Artificial Intelligence.

Climate Data Records: As recently as ~10 years ago, satellite records were generally considered too short to diagnose secular trends climate parameters. With more than 40 years of reliable observations dating back to the late 1970's, however, that is no longer true. Long-term satellite records provide a unique opportunity to study many facets of climate change ranging from clouds to ice cover, provided care is taken to account for instrument changes, sampling drift, and algorithm changes. CIMSS is increasingly leveraging our expertise in meteorological satellite product development to create and analyze homogeneous CDRs to quantify and understand the impacts of anthropogenic climate change. Among the longest satellite CDRs available, CIMSS' Pathfinder Atmospheres-Extended (PATMOS-x) CDR uses AVHRR data from 1981 to present to produce global cloud fields from sixteen different satellites mapped to an equal-angle global grid (Foster et al., 2023). To ensure that the decades of observations from legacy sensors can be integrated with those from more advanced sensors, PATMOS-x integrates water vapor and CO_2 channels from the HIRS instrument using a fusion process from CIMSS researchers (Weisz et al., 2017). Figure 4.1 shows how global cloud cover has decreased since 1981, shortly after CIMSS was established. CIMSS students and researchers are analyzing this record, along with a separate clear-sky total precipitable water (TPW) CDR also developed at CIMSS, to better understand physical processes driving these changes and determine whether cloud changes are related to a modest 35-year drying trend owing to decreases in tropical TPW during La Nina events.

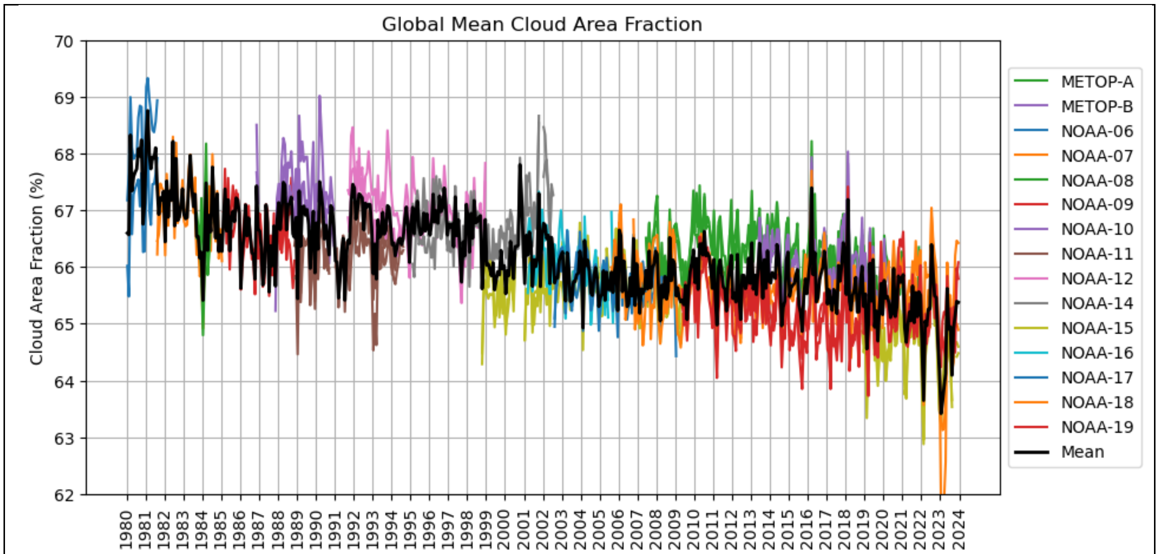

FIGURE 4.1: Global mean cloud area fraction from the PATMOS-x CDR (1981 – present). The individual satellite records that contribute to the dataset are color-coded with the mean value presented in black.

Great Lakes Regional Climate Change: To address NOAA's increasing focus on coastal resilience and inland waters, CIMSS has extended its remote sensing expertise to the Great Lakes that are important to many of the citizens of Wisconsin and our neighboring states. Growing satellite data records covering many atmospheric and lake surface parameters, are ideally suited to analyzing regional climate changes to Great Lakes ice cover, surface temperatures, biomass, cloud cover, surface radiation, humidity, and winds. We are actively exploring additional collaborations with the UW Sea Grant Institute and the Cooperative Institute for Great Lakes Research (CIGLR) at the University of Michigan.

Next-generation Satellite Observing Systems: CIMSS has played an important role in establishing the science traceability underlying meteorological instrument requirements since Earth observations began. As NOAA prepares to launch the next generation of geostationary and polar orbiting platforms, trade studies and observing system simulation experiments have emerged as a key focus area at CIMSS. For example, CIMSS staff are researching options for a shorter wavelength water vapor channel on the next-generation geostationary imager (GXI) to improve boundary layer moisture measurements (Miller et al, 2023). CIMSS is also conducting assimilation experiments to demonstrate the value of the geostationary hyperspectral sounder (GXS) to optimize the temporal frequency of those observations. In the future, CIMSS will continue to study the benefits of new observing capabilities, including lightning measurements for severe weather identification and higher resolution infrared window measurements for fire detection, and implement new algorithms that take advantage of these capabilities to support the nation's meteorological satellite needs.

Science Communication: Communicating the results of federally funded research projects to policy makers and the public is a critically important function of CI researchers, yet conveying key results in a way that resonates with non-expert audiences remains a challenge. Communication has always been a high priority for CIMSS. We have supported a strong communications team within SSEC to disseminate key findings to wide audiences through a variety of platforms. We have recently realized that we can have an even greater impact on science communications by training students in the skills required to communicate science from any field after graduation. To these ends, CIMSS has supported several student internships within our communications group to provide undergraduate and graduate students opportunities to learn how to produce content for a full spectrum of formats including feature stories, newsletters, reports, and social media. In 2020, we advanced this effort even further by offering our first graduate fellowship to an M.S. student in Life Science Communications (LSC) to study communications while writing about CIMSS research. Last year, a new PhD student with a background in astrophysics and marketing began interdisciplinary studies in the AOS and LSC departments at UW-Madison with a goal of defining a career that includes both scientific research and science communications.

iii. What are the drivers behind the emerging themes, and how does the CI fit them within the current science plan?

One primary driver of these emerging themes are NOAA's evolving priorities to utilize its powerful Earth observing capabilities to respond to the urgent need to address the growing challenges posed by climate change. Adapting to our changing climate requires both advances in early detection of extreme events and accurate predictions of future climate. The new observing capabilities afforded by NOAA's modern weather satellites produce many terabytes of weather data daily. CIMSS AI/ML efforts grew out of the need to translate this vast resource into useful information about increasingly common hazards from severe thunderstorms to drought and wildfire. This requires modern computational techniques capable of ingesting and processing large volumes of data to quickly identify the fingerprints of features of interest across all 50 states and convey this information to forecasters, decision makers, and users. While the application of AI/ML for this purpose is new, this represents a natural evolution of CIMSS historical expertise in satellite remote sensing. We have tailored our science plan to incorporate greater use of AI/ML in our existing projects, increased staffing with expertise in these techniques, and expanded educational opportunities for our students to learn them.

NOAA's growing archive of meteorological satellite observations is also a critical asset for studying climate trends and processes and assessing their representation in climate models. CIMSS' historical role in developing the first Earth observing satellites and its continuous role in monitoring instrument performance and interpreting algorithm outputs naturally translate to generating reliable, homogenous CDRs. Many of the same parameters useful for monitoring daily weather are also drivers or impacts of climate change (or both). Furthermore, residing in the upper Midwest, CIMSS researchers share the intent interest of the citizens of Wisconsin in documenting and predicting climate change in the Great Lakes region. Since most CIMSS datasets span all 50 states, if not the whole globe, it is relatively straight-forward to extract and refine subsets of these products to support Great Lakes research.

Like weather data, climate information is only useful if it can be communicated to decision makers and the public who use it. While CIMSS has prioritized communication throughout its history, our work with interns and students has demonstrated our potential to train a new generation of experts in science communications and communications research with complementary research backgrounds. CIMSS is gradually incorporating more exposure for students to science communications into our graduate curriculum and creating new opportunities for students interested in pursuing careers in this emerging field.

4.1.e Scientific Partnerships

Throughout its 44-year history, CIMSS scientists have worked to develop methods of collecting and transforming data into knowledge about the atmosphere. We achieve our goals through close partnerships with NOAA, NASA, the Office of Naval Research (ONR), the National Science Foundation (NSF), and the UW Department of Atmospheric and Oceanic Sciences (AOS) as well as many national, international, and industry partners. The research environment at CIMSS has proven to be effective in developing, demonstrating, and implementing techniques to interrogate large datasets to extract valuable insights into our weather and climate. Our location within SSEC at the UW and partnership with NOAA enable us to share this information broadly to a wide range of stakeholders and the public.

i. What is your relationship to the NOAA Research Laboratories, Program Offices, Cooperative Science Centers, and other NOAA entities?

NOAA Research Laboratories, Program Offices, Cooperative Science Centers, and Other NOAA Entities

While CIMSS is not collocated with a NOAA research laboratory, our researchers maintain close connections with several NOAA entities that include both local NOAA employees and a larger number of remote partners and NOAA laboratories and Cooperative Science Centers (CSCs). The strength of these collaborations is exemplified by noting that more than 40% of CIMSS publications from the past four years feature a NOAA co-author. Some of these relationships are briefly described here.

NESDIS:
As a NESDIS cooperative institute, CIMSS strongest relationships are with scientists from the NESDIS laboratories. Of the seven NOAA scientists stationed at UW-Madison, six work with NESDIS. All NESDIS scientists work closely with CIMSS researchers and occasionally co-advise students as adjunct professors in AOS. This collaboration meets NOAA's interest in partnering with academic institutions to explore new concepts and applications through robust weather and water research. CIMSS provides NOAA with a strong link to the university research environment. The NOAA employees stationed at CIMSS provide continuous communication of issues important to NOAA. This association enables CIMSS to provide input into the NOAA research planning process and for CIMSS to quickly react to NOAA’s changing needs.

NWS:
CIMSS works closely with the National Weather Service on several levels. CIMSS has always maintained a strong relationship with NWS leadership to identify observational needs, develop new

observing capabilities, and ensure that these capabilities translate to improved forecasts. We have worked with the NWS Office of Observations to demonstrate the value of new products (e.g. 3D winds) using OSSEs and participated in NWS testbeds to engage forecasters and get feedback about the utility of new satellite products. For example, the ProbSevere suite of severe weather products was highly rated by the NWS Analyze, Forecast, and Support Office (AFS) survey of forecasters in 2022-23. CIMSS has also developed training materials and frequently offers satellite bootcamps to train forecasters in the effective use of satellite products. Our relationship to NWS has resulted in several CIMSS and AOS graduate students being hired into NWS positions. In addition to the recently retired NOAA Assistant Administrator for Weather Services and Director of the NWS, Dr. Louis Uccellini (BS 1971; MS 1972; PhD 1977), Dr. Jordan Gerth (BS 2009; MS 2011; PhD 2013) currently serves as the NWS Lead for Leveraged Observations.

NHC:
The CIMSS Tropical Cyclone research group works closely with the NOAA National Hurricane Center (NHC) to improve hurricane track and intensity forecasts using satellite observations. CIMSS TC imagery, intensity estimates, wind retrievals, intensification probabilities, eyewall replacement probabilities, and water vapor are all produced in near real-time and disseminated to users by both NHC and the Joint Typhoon Warning Center (JTWC). It is not uncommon for forecasters to acknowledge CIMSS as the source of their products and imagery during broadcasts.

Other CIs and CSCs:
CIMSS also has close relationships with several other NOAA CIs and Cooperative Science Centers (CSCs). CIMSS researchers frequently collaborate with researchers at the two other NESDIS CIs, the CI for Research of the Atmosphere (CIRA) at Colorado State University and the CI for Satellite Earth System Studies (CISESS) at the University of Maryland. For example, CIMSS researchers work closely with the tropical cyclone team at CIRA to improve hurricane intensity predictions. CIMSS also has an active collaboration to combine radar and satellite observations to research new methods of detecting severe weather with the CI for Severe and High-Impact Weather Research and Operations (CIWRO) and the collocated National Severe Storms Laboratory (NSSL) at the University of Oklahoma. As part of this collaboration, one NOAA scientist stationed at CIMSS works for the National Severe Storms Laboratory (NSSL) and another NSSL employee visits frequently. Several recent CIMSS graduates were hired by CIRA, CISESS, CIWRO, and NCEI (see Table 6.2).

CIMSS also has collaborations with the NOAA Center for Earth System Sciences and Remote Sensing Technologies (CESSRST, formerly CREST), a multidisciplinary center led by the City College of the City University of New York (CUNY). CIMSS has a formal collaboration through a Memorandum of Understanding (MOU) with two CREST members, CUNY and Hampton University, a Minority Serving Institution. CIMSS engages CESSRST leadership on monthly collaboration calls and through an annual student symposium. NESDIS scientists stationed at the UW have hosted student interns from CESSRST and we continue to seek develop new educational relationships.

Universities and Other Government Agencies

An important function of the Cooperative Institutes is to provide bridges between NOAA and universities, other government agencies, commercial entities, and international partners. The Venn diagram in Figure 4.2 illustrates how CIMSS' position within SSEC facilitates this role (with CIMSS as the focal point). CIMSS is an institute within SSEC and is collocated with AOS. SSEC is an interdisciplinary research center within the UW Office of the Vice Chancellor for Research (OVCR) that oversees all research centers across campus. AOS is an academic department within the College of Letters and Sciences (L&S), the largest college at UW. Thus, our close relationships to both SSEC and AOS immediately connect CIMSS to the broader research and educational communities across campus.

FIGURE 4.2: CIMSS Scientific Partnerships: *From its position within SSEC, CIMSS provides bridges between NOAA, universities, other government agencies, commercial entities, and international partners.*

AOS consists of 17 faculty and approximately 60 graduate students and 65 undergraduate majors. The department provides education and research programs spanning a broad range of weather, climate, and ocean topics. The department is particularly strong in the areas of climate dynamics, satellite remote sensing, and weather systems. AOS faculty frequently collaborate with CIMSS researchers and serve as academic advisors to numerous graduate students supported by CIMSS projects. AOS also administers a Professional MS program that provides professional development for students and requires that students undertake an internship with either a government agency or a private company. CIMSS benefits from the relationships AOS fosters with these outside entities to increase stakeholder engagement and place students in internships (e.g., with the NWS). AOS is also recognized as the hub for weather and climate-related studies on campus. As such, AOS has affiliate faculty from many other departments including Civil Engineering, Computer Science, Chemistry, and the Nelson Institute for Environmental Studies, providing CIMSS with links to faculty in a diverse range of subject areas relevant to the themes listed in Section 4.1.d.

CIMSS' home within SSEC provides strong links to other agencies. SSEC applies demonstrated expertise in engineering hardware, satellite remote sensing, environmental modeling, and software development to research unique applications of satellite data supported by NOAA, NASA, the Department of Energy (DOE), the Office of Naval Research (ONR), the National Science Foundation (NSF), and other U.S. government departments. For example, researchers at CIMSS collaborated with the National Renewable Energy Laboratory (NREL) to create the National Solar Radiation Database (NSRDB) using high fidelity satellite cloud products. The NSRDB provides an historical record of surface insolation over the United States that is used by universities, utilities, research institutes, and governments in a variety of applications that include photovoltaic grid placement, building design, and creating models to simulate power output or assess project feasibility. In a recent annual report NREL noted 166,000 annual users of the NSRDB, highlighting how such applications amplify the benefits of NOAA research, products, and services by expanding their distribution. CIMSS scientists at SSEC are also active in developing advanced meteorological instrumentation, most recently participating in the design and implementation of the NASA Earth Ventures TROPICS and PREFIRE missions. SSEC also has ongoing projects with several commercial entities engaged in weather and climate research, including Google, Boeing, and Panasonic.

While CIMSS is not a consortium of universities, we foster numerous collaborations with other academic institutions across the country. A new collaboration with Northern Illinois University and the University of Illinois Urbana–Champaign is highlighted in Section 4.2.b. Other examples include research into flood mapping using satellite observations in conjunction with researchers at George Mason University and research into improving satellite-derived sea ice products with researchers at the University of Colorado. CIMSS' other university partnerships are summarized in Figure 4.3.

International Collaborations

To foster broader collaborations world-wide, CIMSS hosts and supports visiting scientists from around the world and has strong ties with research and operational centers in the U.S., Australia, Southeast Asia, and across Europe. CIMSS maintains these connections through scientist exchange programs with many research partners (Figure 4.3). Between 2020 and 2024, CIMSS researchers maintained active collaborations with researchers from at least 30 agencies in more than 17 countries. These connections have strengthened through the development of several international scientific organizations. CIMSS and NOAA fostered the creation and growth of the International TIROS Operational Vertical Sounder (TOVS) Working Group (ITWG) after the inception of the NOAA series of operational polar orbiting satellites. ITWG continues to organize International TOVS Study Conferences which have met every 18-24 months since 1983. CIMSS and NOAA also organized the International Winds Working Group together with EUMETSAT and JMA; this group has been meeting since 1991 to achieve uniformity of atmospheric motion vectors derived from geostationary satellite image loops along with the associated quality flags and reports to the Coordination Group for Meteorological Satellites (CGMS). More recently we assisted in the formation of the International Cloud Working Group that also reports to the CGMS.

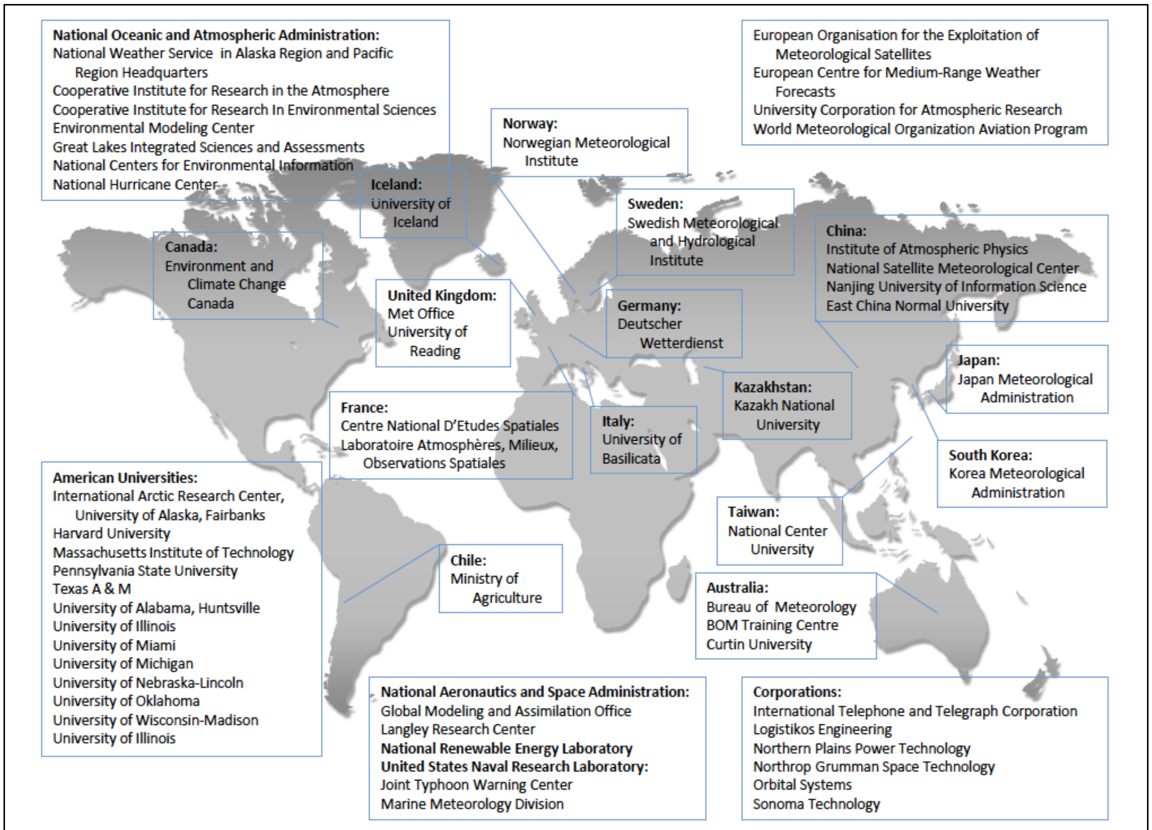

FIGURE 4.3: CIMSS International Collaborations: *Domestic and international institutions with which CIMSS has had direct collaborations from 2020-2024.*

CIMSS collaborations with government, academic, private sector, and non-profit groups continue to grow. Each engagement serves a unique purpose within the collaboration. 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.

ii. What, if any, formal procedures do you have for cooperative planning?

CIMSS has a planning process that allows us to identify evolving themes and research directions. The process is illustrated in 4.4 and patterns itself after the strategic process followed by many on the UW campus. This process allows us to chart the broad course for the institution and identify themes that are emerging, transforming, or becoming outdated. The blue boxes are important milestones that are set or revised during CIMSS assessment and planning. The blue arrows mark the flow of formal and informal processes that lead to setting goals, priorities, and principles. The yellow boxes list some of the questions addressed during this process. This is a continuous evaluation that allows planning that is sensitive to the evolving external needs and involves a variety of stakeholders along the way.

Integral to our cooperative planning approach are internal meetings of individual research teams to discuss results and future research directions. The CIMSS director, executive director, and a representative task lead meet weekly to discuss the CIMSS relationships to NOAA and research priorities. Regular meetings, approximately once a month, of CIMSS PIs are convened to discuss CIMSS issues and to inform each other about opportunities, such as research collaborations. Annual SSEC all-hands meetings provide updates on the state of the center, including all associated CIMSS research. All CIMSS task leads were involved in the writing of the proposal that resulted in CIMSS being awarded in 2020. In house CIMSS seminars are routinely held to exchange research ideas within the center and with visitors. Each spring a half-day poster symposium is held for the entire AOS/SSEC/CIMSS/CCR enterprise where presentations of ongoing research are made, and new opportunities discussed.

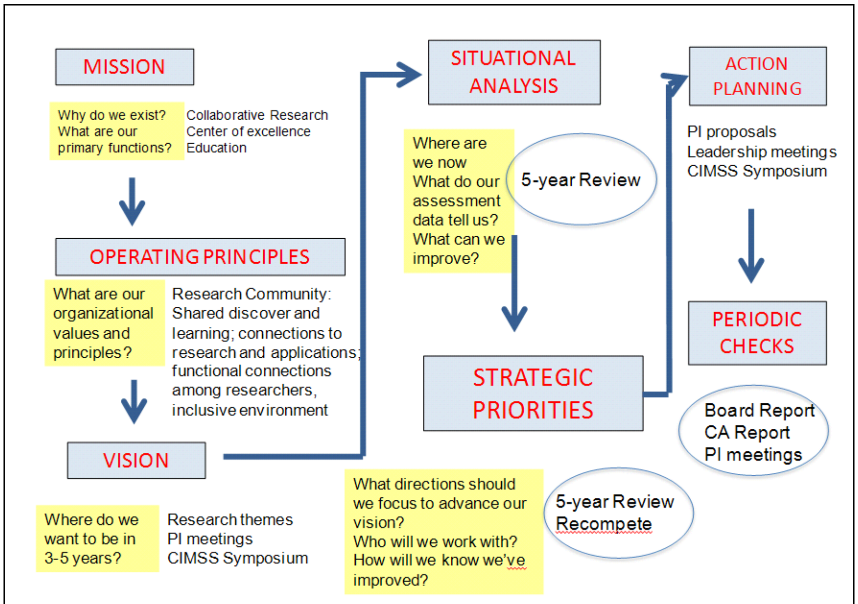

FIGURE 4.4: CIMSS Cooperative Planning Process. Blue boxes describe important milestones in the process. Yellow boxes summarize some of the questions considered at each stage.

CIMSS leadership also participates in OAR's annual meeting of the Cooperative Institute directors, where a range of issues are discussed including inter-CI collaborative opportunities and challenges. CIMSS meets with NESDIS leadership at annual American Meteorological Society and American Geophysical Union meetings to initiate and coordinate the broad research and development activities associated with the GOES-R and JPSS programs. CIMSS also hosts NESDIS project managers approximately annually to provide research updates and learn about future research priorities. To foster interactions with other NOAA CIs, CIMSS personnel frequently travel to other CIs to give seminars and meet with other researchers. For example, the CIMSS director recently visited (in-person) with staff at CIGLR resulting in new ideas for collaborating to improve regional climate models in the Great Lakes region.

4.2 Science Review

The CIMSS research cycle presented in Figure 3.3 shows how we leverage our location on the UW campus to use Education to transform Data into Action. CIMSS research follows a continuous process from data acquisition to user engagement that maximizes the value of NOAA satellite investments. The first step is to acquire, verify, archive, and distribute data. Research results in tools for processing raw data into products and tools for analyzing these products to learn about our environment. Findings are communicated to a wide range of stakeholders to inform actions that range from issuing weather warnings and implementing climate mitigation strategies to informing the research of scientists at other institutions. Engaging stakeholders serves another important purpose, feedback gained from these interactions identifies gaps in data or information that are addressed by acquiring new measurements and refining analysis tools … and the process continues.

Education enters every step of the process: summer interns learn how to assess data quality and evaluate research products; undergraduate and graduate students apply math and computer science training to extract weather and climate information from this data; students further learn atmospheric physics to analyze their results; researchers share results with colleagues at conferences, workshops, and symposia while learning about their new research; and educators develop training modules to inform users at all levels, from K-12 to forecasters and policy makers, how to interpret data and findings.

The questions that guide the remainder of this renewal review align well with this research philosophy and provide an exciting opportunity to document the many accomplishments of CIMSS researchers in progressing toward our goals. This section highlights some of CIMSS research accomplishments while Section 4.3 discusses the many forms of education that are the foundation of our education and outreach program.

4.2.a What are the Institute's most recent scientific highlights and accomplishments?

CIMSS research couples observations with scientific hypotheses about how the atmosphere works, which leads to developing new knowledge about the atmosphere. Interpreting observations in the context of hypotheses developed from theory, numerical analyses, and model simulations, translates the information contained in observations to knowledge about the Earth system. Model simulations further provide context leading to a better understanding of the physical processes that govern the weather, large-scale circulation patterns, air-sea interactions cycles, biogeochemical cycles, etc. that collectively make up our climate. It is this analysis framework that motivates our three research themes: *Satellite Sensors and Measurement Techniques*; *Satellite Research and Applications*, *Environmental Models and Data Assimilation.*

For each research theme we have selected accomplishments that illustrate progress toward CIMSS goals and interconnectivity of CIMSS research. A top-level summary of major highlights is provided in the form of a list at the start of each theme section. These should provide sufficient insights into CIMSS major research accomplishments, but the interested reader may continue to read longer summaries of selected research results. To appreciate the full breadth and depth of science conducted at CIMSS, we have also compiled many additional highlights in an accompanying Powerpoint slide show: "*Research and Education at CIMSS*" that can be found on the CIMSS 5-year review website.

Satellite Sensors and Measurement Techniques

Most NESDIS-sponsored research would not be possible without reliable data obtained from NOAA's low-Earth orbiting and geostationary satellite fleet. CIMSS research plays a central role in calibrating existing NOAA sensors, as well as helping to define the sensors of the future, including the imagers and sounders for GeoXO and the National Environmental Observatory

Network (NEON) hyperspectral sounders. Highlights of CIMSS progress under the Satellite Sensors and Measurement Techniques theme include:

- Developed new instruments and methods to assess satellite sensor performance and inform the design of next-generation low-earth orbiting and geostationary satellite sensors.
- Analyzed ground-based measurements at long-term climatological validation sites.
- Participated in targeted field campaigns to validate and advance satellite retrievals.
- Advanced data fusion techniques to increase the temporal and spatial resolution of satellite soundings and established their impact in forecast models.
- Researched and implemented new methods for mitigating the GOES-17 Loop Heat Pipe (LHP) anomaly.
- Applied revolutionary Artificial Intelligence/Machine Learning (AI/ML) approaches to maximize the benefits of NOAA environmental satellites for characterizing the physical environment.

CIMSS has leveraged expertise from its long history of developing infrared sounding sensors for both low Earth and geostationary orbits to develop new calibration methodologies and participate in a range of pre- and post-launch calibration/validation efforts for the Cross-track Infrared Sounder (CrIS) program. Our goal is to ensure that CrIS radiance products are suitable for data assimilation into NWP models, atmospheric sounding, trace gas retrievals, and atmospheric wind estimation. Working with both NOAA and NASA, CIMSS and SSEC personnel have been integral in maintaining the high quality of the observations from all five CrIS sensors.

As a recent example, NOAA-21 CrIS was launched in November 2022, had its Validated Maturity review on September 28, 2023, and was declared Operational on November 8 (Figure 4.5). CIMSS played an important role in this process by developing and applying novel techniques for establishing on-orbit spectral calibration parameters, on-orbit radiometric nonlinearity parameters, and deriving the on-orbit polarization correction parameters. The spectral analysis uses Earth view data to assess and refine the knowledge of the focal plane array and metrology laser parameters; the nonlinearity work involves the use of special Diagnostic Mode data collected on-orbit to assess nonlinear harmonics and Earth view data, and the polarization analysis is based on pitch maneuver data where the sensor can view Deep Space with all scan angles. These parameters were included in the updated Engineering Packet uploaded to the sensor to improve the calibration of the data and suitability for NWP and retrieval use.

CIMSS research also demonstrated that the quality of the NOAA-21 CrIS data is as good or better than that from the CrIS sensors aboard SNPP and NOAA-20. In particular, the radiometric nonlinearity and associated radiometric calibration uncertainty is negligible. However, CIMSS identified a calibration artifact associated with rapid changes to the sensor responsivity and phase when exiting eclipse. Research is underway to determine the root cause but, after carefully studying this effect, CIMSS researchers developed a method to use single scan line (every 8 seconds) calibration combined with a random noise filter to remove the associated calibration artifacts. CIMSS is now analyzing Thermal Vacuum test data for the fifth and final CrIS that is scheduled to launch on JPSS-4 in 2028.

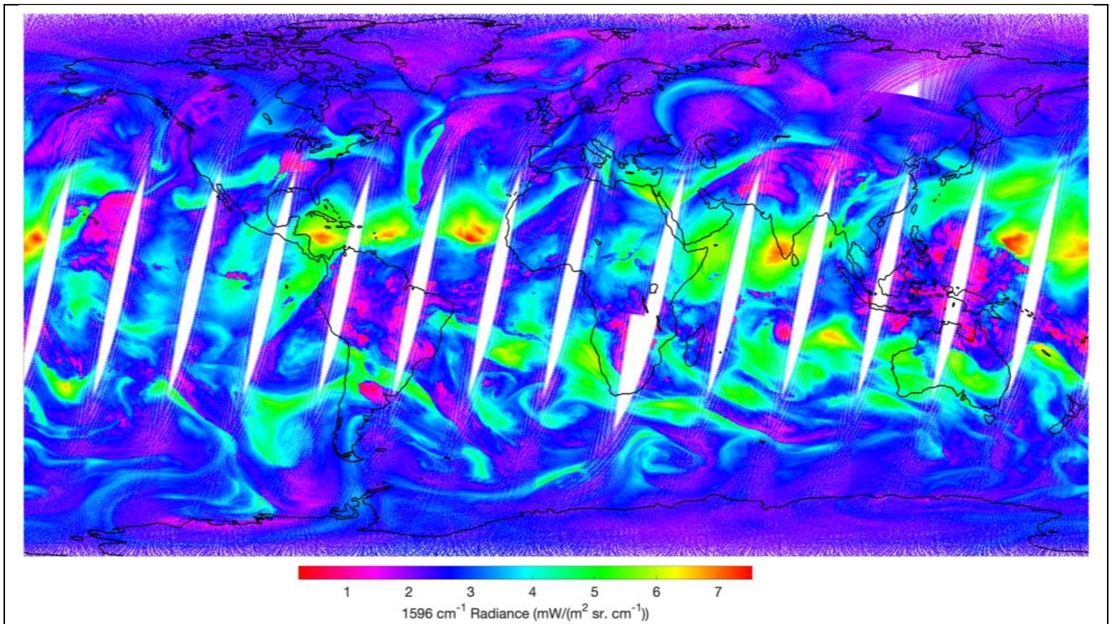

FIGURE 4.5: First light image from NOAA-21 CrIS showing descending pass radiances from the 1596 cm^{-1} channel that is sensitive to upper-level water vapor and clouds on 16 February, 2023.

A second example of CIMSS progress in Satellite Sensors and Measurement Techniques is establishing the ongoing calibration performance of the Visible Infrared Imaging Radiometer Suite (VIIRS) with the JPSS program calibration teams at NOAA STAR and NASA. These efforts are critical for establishing a multi-decadal CDR that began with the Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) instruments in 2000. CIMSS played an important role in pre-launch characterization and on-orbit calibration for MODIS and has the institutional knowledge to provide the continuity essential for producing high quality CDRs. CIMSS is researching new methods for comparing pre-launch and post-launch characteristics of the full complement of VIIRS instruments (NOAA-20, NOAA-21, JPSS-3, and JPSS-4) to allow the datasets to be combined avoiding artifacts owing to calibration differences.

Independent comparisons of VIIRS observations against other sensors (e.g., CrIS, IASI) and more than 20 fixed ground-based validation sites provide an additional test of sensor performance to identify calibration drifts and biases and their dependence on scene temperature, scan angle, and spectral response. Performing time series analysis over validation sites is complicated by cloud-contamination and the fact that these studies typically focus on nadir measurements. CIMSS has researched new approaches that address both limitations. CIMSS developed a machine learning-based algorithm that significantly improves confidence in identifying clear pixels and analyzed data from the Salton Sea in California to develop view-angle corrections to remove the angular variations of the reflectance and brightness temperatures. A key result from this analysis is that that the VIIRS on SNPP is radiometrically very stable for not only nadir but also off-nadir measurements. These evaluations serve as a baseline from which adjustments to VIIRS calibration can be made to maintain performance needed to support climate research. In the coming years, CIMSS will conduct similar studies of VIIRS on JPSS-3 and JPSS-4 once they are launched and continue researching new methods for analyzing existing time series to ensure long-term radiometric stability for climate research.

CIMSS and SSEC scientists, engineers, and students are also actively involved in many field campaigns that support both NOAA satellite sensor calibration as well as general atmospheric science research. CIMSS contributes instrument teams, product algorithm developers, calibration specialists, forecasters, and mission managers. The Scanning High-resolution Interferometer Sounder (S-HIS) is a key resource enabling this participation. S-HIS is an airborne hyperspectral infrared sounder developed at the SSEC, with support from NOAA, NASA, and the DOE. Since 1998, the S-HIS has participated in 37 field campaigns on five different aircraft and has been critical for very accurate and directly traceable calibration of satellite infrared sensors, including CrIS and the Advanced Baseline Imager (ABI) (Taylor 2023). S-HIS observations and derived temperature and water vapor soundings, clouds, surface emissivity, and trace gas retrievals have also played a central role in science investigations including air quality research and studying extreme weather phenomena like hurricanes and severe storms.

S-HIS was most recently deployed on the NASA DC-8 for the AEROMMA (Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas) and ecoDemonstrator campaigns. AEROMMA was a comprehensive field experiment led by NOAA's Chemical Sciences Laboratory to address emerging research needs in urban air quality, marine emissions, climate feedbacks, atmospheric interactions at the marine-urban interface, and future satellite capabilities for monitoring atmospheric composition over North America. AEROMMA observations are being used to evaluate the NASA TEMPO and NOAA JPSS trace gas and aerosol products and to inform the future NOAA GeoXO and NEON hyperspectral infrared sensors. A single footprint of S-HIS observations from a flight on August 9, 2023 is shown in Figure 4.6 highlighting the spectral regions of interest for some trace gas applications. The S-HIS high spatial and spectral resolution infrared radiance measurements and corresponding temperature, water vapor, and trace gas retrievals are being used to assess and refine the infrared retrieval products and evaluate the fidelity of the regional air quality predictions during AEROMMA.

Recognizing the important role the S-HIS is likely to play in the formulation and preparation for future NOAA missions including GeoXO and NEON due to its reliability, small spatial footprints, broad spectral coverage, and calibration accuracy, NOAA is supporting the first steps to upgrading the now 25-year-old system. Initial breadboard level research and testing of the primary subsystems for the next-generation S-HIS instrument is underway, and the team is hoping this support will continue to allow necessary upgrades to be realized.

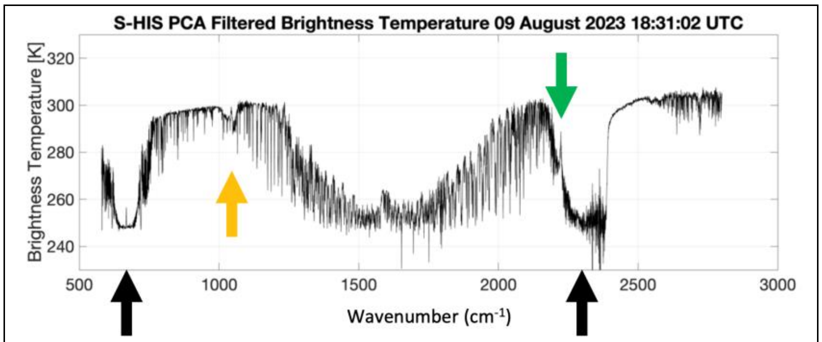

FIGURE 4.6: A single S-HIS spectrum obtained over Pennsylvania on August 9, 2023. The black arrows identify spectral regions with CO_2 absorption. The orange arrow indicates a faint O_3 feature, and the green arrow identifies a spectral region with CO absorption.

Satellite Research and Applications

This theme comprises the largest component of the CIMSS research portfolio. Our work contributes to a better characterization of the Earth’s atmosphere, oceans, and cryosphere, faster and more complete identification of weather hazards, and a more complete understanding of the climate system and how it is changing. CIMSS researchers have blended theory with modern computational methods to develop new algorithms for quantifying aspects of our environment that could not previously be observed from space (e.g., winds and turbulence). We have pioneered new methods like machine learning for distilling vast quantities of satellite data (petabytes per day) into actionable information accessible to forecasters, decision makers, and the public. We have also developed new frameworks for establishing the accuracy of satellite data products and quantifying their implications for interpreting research findings. Our research has led to a deeper understanding of the impacts of observing system changes on climate records, supplied methods for homogenizing these records, and extracted useful climate information from the resulting CDRs. Some highlights of progress toward CIMSS' Satellite Research and Applications theme that capture the breadth and interconnectedness of the CIMSS research program include:

- Developed and tested new retrieval algorithms for application to significant weather events.
- Provided operational upgrades for Joint Polar Satellite System (JPSS) and Geostationary Operational Environmental Satellite (GOES)-R series atmospheric motion vector (AMV) products.
- Researched, developed, and optimized objective methods for incorporating data from multiple satellite platforms to analyze tropical cyclone intensity and structure more accurately.
- Supported global aviation with advanced satellite-based volcanic ash and turbulence products.
- Implemented a global geostationary fire monitoring system.
- Evaluated and enhanced satellite-based estimates of cryosphere properties including sea ice cover, snow cover, and sea ice thickness.
- Researched new methods for detecting clouds and estimating their properties from satellite observations.
- Analyzed multi-platform fused cloud, fire, and sea/lake ice climate data records (CDRs) to diagnose climate change signatures.
- Applied innovative machine learning methods to improve the accuracy and increase lead time of satellite-based hail, wind, heavy rain, lightning, and tornado warnings.
- Engaged partners at the Aviation Weather Center, National Hurricane Center, and the National Weather Service to increase the use of satellite products and understand their performance.
- Researched new methods for characterizing retrieval uncertainties to increase satellite data assimilation into forecast models.

Some of these highlights are discussed in more detail below.

Clouds and Climate

Characterizing the location and properties of clouds is essential for many applications ranging from accurately retrieving other atmospheric and surface properties, data assimilation, solar energy, aviation safety, and climate monitoring. CIMSS scientists work alongside NESDIS scientists to research and implement new cloud retrieval techniques and algorithms. Five cloud property algorithms were developed at CIMSS as part of the GOES-R and JPSS Cloud Algorithm Working Group (hereafter, the Cloud AWG). These algorithms generate fourteen independent cloud products, including a clear sky mask, cloud type and phase, cloud top height, cloud top pressure, cloud top temperature, and both day and nighttime cloud microphysical properties. The scientific goal of the algorithm development was to perform similar retrievals from multiple satellite imagers, regardless of differences in sensor footprint, radiometric channel availability, scanning methods, and temporal and spectral resolution.

Figure 4.7 shows an example of cloud top temperature retrievals from coincident GOES-16 and NOAA-20 satellite observations. Though the ABI and VIIRS imagers on these satellites differ in many ways, the retrieval produces very similar results, essential for supporting both forecasting and climate research applications. Table 4.1 lists the satellite platforms and sensors to which the CIMSS cloud retrievals can currently be applied to yield similar results. Imagery from VIIRS, ABI, and AHI sensors at daily, weekly, monthly, and seasonal time periods are routinely published on the CLAVR-x website with the goal of identifying quality issues either with the cloud mask or cloud properties.

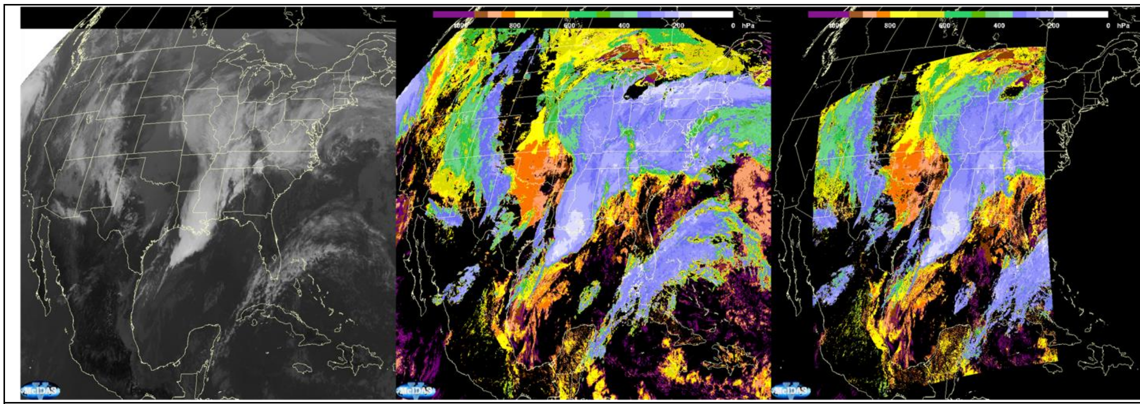

FIGURE 4.7: Infrared brightness temperature (left) and CIMSS-derived cloud top temperature retrievals from GOES/ABI (center) and JPSS/VIIRS (right) for the same scene.

TABLE 4.1: Satellite platforms and sensors supported by the CIMSS cloud retrieval algorithms.

Satellite(s)	Type	Sensor
NOAA-5 through NOAA-19	Polar-orbiting	Advanced Very High Resolution Radiometer (AVHRR)
FY-3D	Polar-orbiting	Medium Resolution Spectral Imager-II (MERSI-2)
AQUA and TERRA	Polar-orbiting	Moderate Resolution Imaging Spectroradiometer (MODIS)
Suomi-NPP, NOAA-20, NOAA-21	Polar-orbiting	Visible Infrared Imaging Radiometer Suite (VIIRS)
GOES-16 through GOES-18	Geostationary	Advanced Baseline Imager (ABI)
FY-4A	Geostationary	Advanced Geostationary Radiation Imager (AGRI)
Himawari-8 and Himawari-9	Geostationary	Advanced Himawari Imager (AHI)
COMS	Geostationary	Meteorological Imager (MI)
GOES-8 through GOES-15	Geostationary	Imager
Meteosat-8 through Meteosat-11	Geostationary	Spinning Enhanced Visible and Infrared Imager (SEVERI)
MTSAT-1R and MTSAT-2	Geostationary	Imager
Meteosat Third Generation	Geostationary	Flexible Combined Imager (FCI)

AI/ML also plays a prominent role in CIMSS Cloud AWG research. Machine learning is being applied to improve cloud classifiers within the Enterprise Cloud Mask (ECM) that establish probabilities of cloud amount and phase. These methods are particularly useful to improve cloud detection under challenging conditions (e.g., daytime clouds over ice and snow surfaces or nighttime clouds embedded in temperature inversions). For example, one new algorithm uses a gradient boosting machine cloud masking algorithm to substantially increase the accuracy of polar cloud detection, greatly enhancing the fidelity of associated Atmospheric Motion Vectors (AMVs). Likewise, a generative adversarial network has been trained using 250m or 125m reflectances from ABI/AHI to generate high-resolution cloud scenes from Sentinel-2 images.

In addition to fundamental research in cloud remote sensing, CIMSS also ensures consistent retrievals during transition to a new generation of satellites. CIMSS researchers are adapting cloud products from the Aqua and Terra satellites (which use the MODIS imager) to SNPP, NOAA-20, and NOAA-21 (which use the VIIRS imager) to produce consistent, long-term, cloud presence, cloud top pressure, and cloud phase CDRs. The resulting MODIS-VIIRS Cloud Mask (MVCM) is designed to run in the MODAPS (the MODIS Adaptive Processing System) on both MODIS and VIIRS data to obtain a CDR spanning more than 2 decades.

The Cryosphere

Accurately discriminating clear and cloudy scenes supports many other products and applications, including a branch of CIMSS devoted to studying the cryosphere. Prompt and correct global characterizations of snow and ice cover, including sea, lake, and river ice, ice sheets, glaciers, and seasonally frozen ground, are critical for marine transportation, fishery, environment protection, accurate weather forecasts, and climate studies. Changing snow and ice conditions can have profound socio-economic impacts making them a high priority focus area of several national agencies, including NOAA, NASA, and DOE. NOAA's polar and geostationary satellites provide a means to routinely monitor ice and snow cover with unprecedented temporal and spatial resolutions. CIMSS is pioneering new ways to identify ice and snow, retrieve ice surface temperature and ice concentration, estimate ice thickness and age, derive ice motion, and detect snow cover. The examples of NCEI's current operational ice products from JPSS and GOES presented in Figure 4.8 are generated by the algorithms developed at CIMSS in close collaboration with NESDIS scientists stationed here.

CIMSS researchers are actively engaged in refining NOAA's cryosphere algorithms, validating the products to ensure they meet the needs of the forecasting and research communities, developing new products, and providing technical support for users including the Alaska Sea Ice Program (ASIP) and U.S. National Ice Center (USNIC) who supply sea ice analyses and forecasts to the U.S. Navy and Coast Guard, among other users. International satellites (e.g., Himawari and MTG) are being used to extend the coverage globally and researchers are applying similar methods as the Cloud AWG to establish continuity across platforms and generate long-term ice and snow CDRs to study trends and identify feedback mechanisms. For example, the CIMSS extended AVHRR Polar Pathfinder (APP-x) CDR is being used to address the critical climate question: How are sea ice concentration, ice extent, ice thickness, and ice volume in the Arctic changing? Wang et al. (2022) showed that the Arctic has been losing ice, both in coverage and thickness, during all seasons, but especially in summer and autumn. At the current rate of sea ice changes, the Arctic will have ice-free summers by the early 2060s. CIMSS researchers have also shown that changes in ice concentration and cloud cover played important roles in Arctic surface temperature trends. Surface warming associated with sea ice loss accounts for most of the observed warming rends in autumn but, in spring, half of Arctic Ocean warming is attributed to trends in cloud cover.

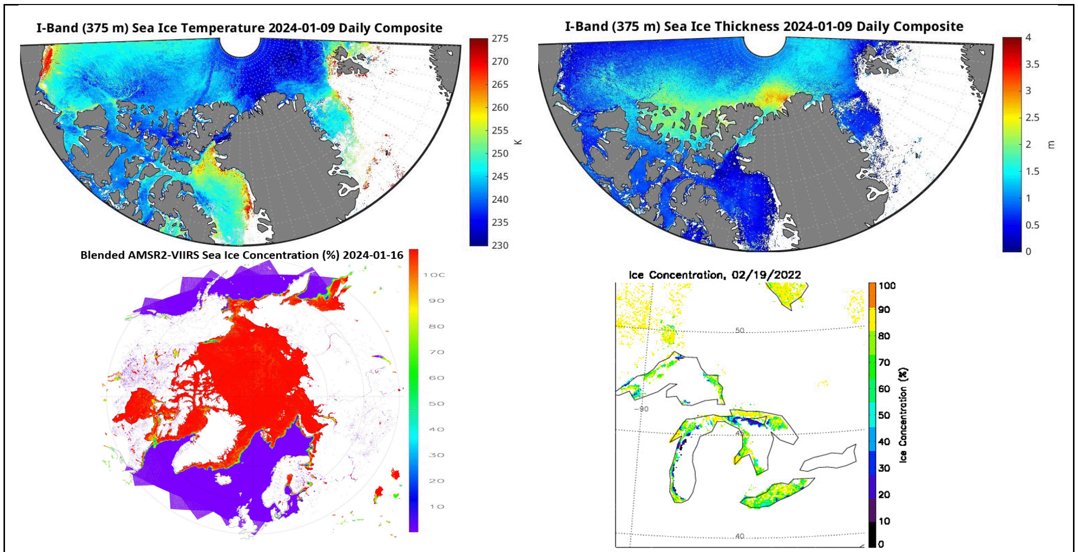

FIGURE 4.8: VIIRS very high resolution (375-m) ice surface temperature (top-left) and thickness (top-right) from NOAA-20 on 09 January 2024, blended AMSR2-VIIRS ice concentration daily composite from 16 January 2024 (bottom-left) and GOES-R ice concentration from 19 February 2022 (bottom-right), all generated with CIMSS algorithms.

Atmospheric Motion Vectors (Winds)

At first, satellites may not seem like the ideal platform for measuring the wind. However, deriving tropospheric winds provides a good example of the revolutionary and evolutionary research CIMSS conducts in the field of satellite meteorology. What started as a novel concept of Prof. Verner Suomi in the late 1970s has been transformed into an important contribution to NOAA and meteorology communities across the globe (Menzel, 2001). In collaboration with colleagues at NESDIS, CIMSS has refined algorithms that produce global, near real-time atmospheric motion vector (AMV) datasets from multiple geostationary satellites. These data are used by a wide range of users that include the U.S. Navy/Department of Defense, researchers studying specific weather events, and data assimilation into NCEP and other agencies' numerical weather prediction models.

The new GOES-R observing capabilities have given rise to new innovations in observing wind structures within tropical cyclones and other mesoscale phenomena. The high spatial and temporal resolution of mesoscale-sector imaging provide unprecedented potential to monitor rapidly evolving wind fields. Over the last 4 years, CIMSS researchers developed a completely new meso-sector AMV product that employs a novel optical flow tracking algorithm to retrieve winds at 1-minute intervals over the Tropical Cyclone (TC) core (Stettner et al, 2019) using GOES-16/18. An example of the resulting AMV product is presented in Figure 4.9 showing Hurricane Ian (2022) just before landfall. The CIMSS AMV team recently successfully completed a real-time end-to-end processing demonstration of the GOES-16/18 hurricane-scale AMV product during the last two hurricane seasons, demonstrating the maturity, quality, and real-time operability of the data/product. We are now exporting the methodologies to the new Himawari satellites to extend the capability to typhoons in the western North Pacific.

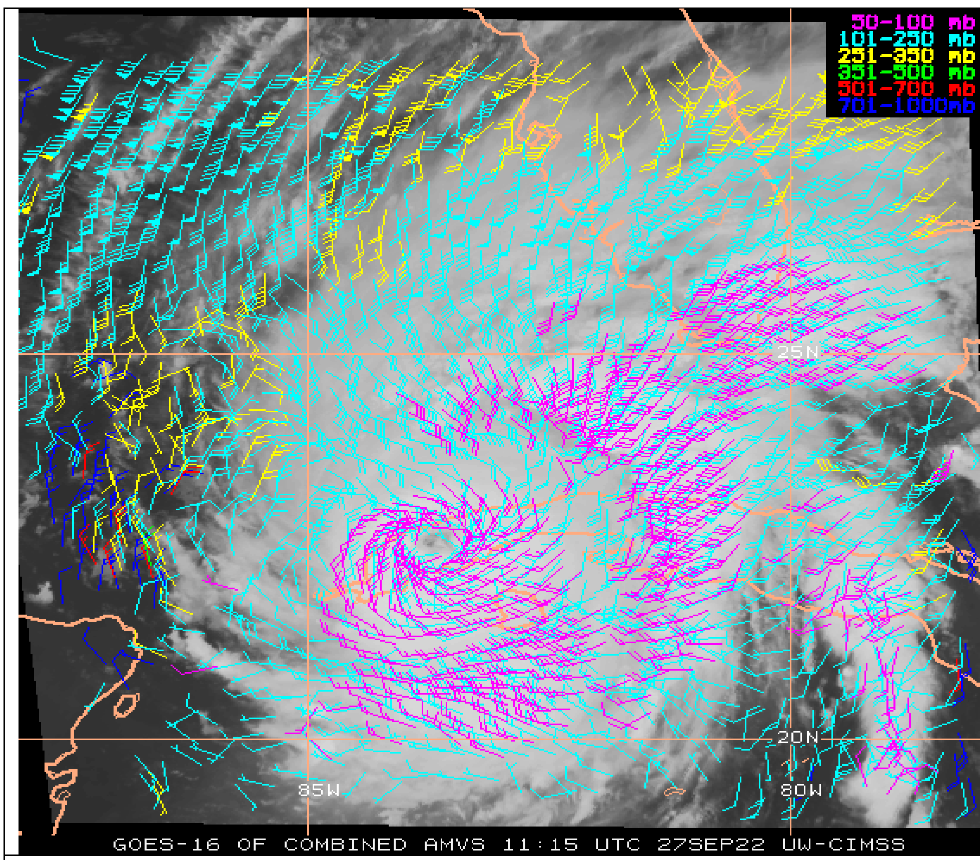

FIGURE 4.9: Winds prior to the landfall of Hurricane Ian (2022) from GOES-16 meso-sector imagery. AMVs barbs show wind speed in kts while the colors refer to the heights (mb) listed in the legend.

Through a novel adaptation of the principles behind geostationary wind algorithms, CIMSS has also worked with NOAA scientists to developed methodologies for generating wind vectors in the high latitudes using polar or low-Earth orbiting (LEO) satellite imagery (Key et al. 2003). These polar wind estimates are the only source of spatially complete wind observations across the polar regions. They were shown to have a positive impact on both the NASA Global Modeling Assimilation Office (GMAO) and European Center for Medium range Weather Forecasting (ECMWF) modeling systems and have now been adopted by over a dozen global NWP centers. Figure 4.10 shows an example of the long-term evaluation of polar AMVs being conducted at CIMSS to ensure the quality of the NESDIS operational wind products as innovations are introduced. The results show that an experimental near real-time *tandem triplet* AMV product developed at CIMSS during this reporting period offers a slight improvement over an equivalent single-satellite product.

Geostationary hyperspectral sounders will offer the next transformative advance in satellite winds, allowing complete vertical tropospheric wind profiles (hereafter, 3D AMVs) to be derived from time evolving humidity profiles. To demonstrate this capability in preparation for the launch of GEO-XO, CIMSS is developing a system to generate simulated 3D AMVs from the ECO1280 Nature Run (NR). This system will be used to perform Observing System Simulation Experiments (OSSEs) to demonstrate the impact of AMVs on forecasts of convective initiation. This information is critical for informing design decisions as NOAA develops the next generation of geostationary meteorological satellites. Through this work, CIMSS carries on a long legacy of leadership in AMV research by playing a vital role in contemporary and future geostationary and polar orbiting AMV development. CIMSS continues to build upon recent advances in extracting enhanced tropospheric wind information from current and new-generation LEO satellites and conduct the assimilation experiments needed to demonstrate and bring advanced capabilities to NOAA's operational product portfolio.

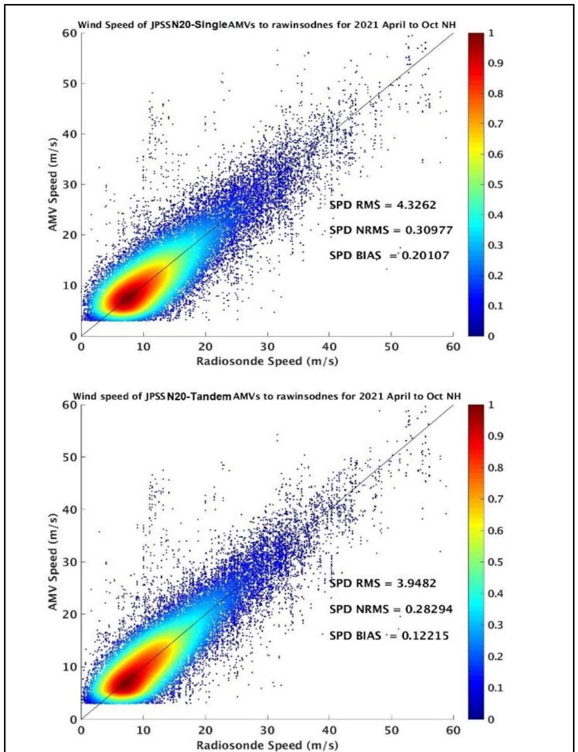

FIGURE 4.10: Arctic VIIRS AMV comparisons to collocated rawinsondes, for NOAA-20 single-satellite (top) and NOAA-20/S-NPP tandem (bottom).

Tropical Cyclones

Estimating wind structure in Tropical Cyclone (TC) cores is one example of a broader area of CIMSS research focused on improving measurements and predictions of these high-impact weather events and conveying the resulting information to the public. Accurate forecasts of the strength and motion of TCs are essential to public safety and minimizing the economic costs associated with preparation and evacuations. Though our understanding of and ability to predict TCs has considerably advanced over the past century, these storms continue to challenge researchers and forecasters alike. Most TCs occur over the ocean well removed from dense in situ surface and upper air observing networks. Aircraft reconnaissance provides valuable intensity and structure information, but these measurements are infrequent and expensive. The constellation of NOAA

LEO and geostationary satellites provide critical measurements to fill in the spatial and temporal gaps in other measurement systems and cover all tropical basins.

CIMSS TC research focuses on new approaches for analyzing TCs using new satellite sensor technologies, novel computational methods, and modern display capabilities with the goal of increasing our knowledge about TCs, improving forecasts, and ensuring that this information is communicated to anyone potentially impacted by these life-threatening events. Our current research applies the new observing capabilities provided by GOES-R and JPSS to conduct research in three principal areas:

1) Innovative Algorithm Development

CIMSS researchers have developed several new methods for estimating TC intensity from multispectral sources (infrared and microwave) and satellites (GEO and LEO). Many current efforts focus on using AI/ML to estimate TC intensity such as the AI-enhanced Advanced Dvorak Technique (AiDT) technique that utilizes a neural network to improve intensity estimates (Olander et al, 2021). New machine learning models are also being trained to correlate satellite observations with future TC behavior to gain a better understanding of the processes affecting TC intensity and track changes. For example, the CIMSS Deep IR Intensity of TCs estimator (D-PRINT) and Deep Multispectral Intensity of TCs estimator (D-MINT) algorithms, predict future TC intensity and the probability of rapid intensification from observed infrared and microwave radiances (Griffin et al, 2023). CIMSS researchers also work directly with the data assimilation community to integrate TC wind estimates to improve numerical model analyses and forecasts. The theoretical basis and verification of these products are published in numerous peer-reviewed articles that appear in prominent scientific journals (Velden et al. 2020; Griffin et al. 2022; Kossin et al. 2023). Many of the product outputs are displayed through the public CIMSS TC web page, making them widely accessible to researchers, stakeholders, and the public. The products of this research are not only useful for real-time operational applications, but many are being used by the research community for TC process and climate studies, and to describe TC-environment interactions (Courtney et al. 2020; Kossin et al. 2020; Li et al, 2020; Lewis et al, 2020; Hoover and Velden, 2020; Elsberry et al. 2020).

2) Demonstrating Capabilities to Potential Users

The benefits of these new TC products will only be realized if they are adopted by the TC analysis, forecasters, meteorologists, and emergency managers who communicate hazard information to the public. The CIMSS TC group demonstrates the value of its innovations through real-time demonstrations as part of the NOAA Hurricane Proving Ground. The newest TC applications including Deep Learning models to estimate/forecast TC intensity (AiDT, AIRI, DMINT, DPRINT) are produced and displayed in near-real-time along with pre-existing products for comparison. Operational users (e.g., NHC, CPHC, JTWC) view these new products throughout TC seasons, provide feedback, and often cite them in their forecast discussions. As we communicate emerging/promising satellite data and TC applications to user groups, we assess research priorities based on feedback from those users. With that information, we partner with STAR and other CI scientists to plan research projects centered on those user priorities. When the products achieve a sufficient state of readiness, we work with NOAA to help transition the algorithms into operational environments for broader adoption across the country.

3) Researching New Products and Methodologies

As data sources and analysis techniques improve, CIMSS researchers seek new ways to extract more comprehensive TC information from them. In particular, the CIMSS TC group is investigating how AI could open new avenues of TC analysis. With a very large dataset available through SSEC's satellite data archive, we are exploring novel Deep Learning (DL) methods to tease out new signals in the data that can lead to TC applications beyond those reachable by empirical methods. For example, as shown in Fig. 4.11, DL models are being developed for estimating 2D wind patterns in TCs and intensity from JPSS microwave imagery to provide complementary information to other methods to better inform forecasters. As depicted in the schematic, a DL model is trained with JPSS imagery matched to winds measured by aircraft reconnaissance flight transects through hundreds of TCs. The model then utilizes the rich structure in the microwave imagery to produce 2D winds that capture major TC wind structures such as the eyewall and asymmetries due to storm motion.

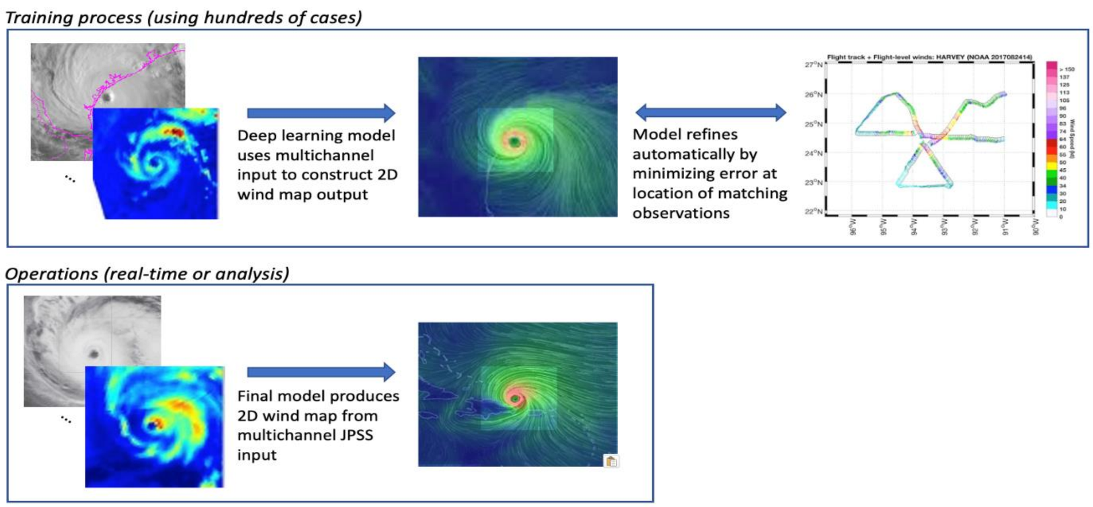

FIGURE 4.11: Using deep learning to estimate 2D surface winds in tropical cyclones. Hundreds of observed tropical cyclones are used to train a deep learning model to predict 2D wind patterns in subsequent satellite imagery.

Severe Weather

A central component of NOAA's mission is protecting society from the impacts of severe weather. Lightning, flooding, hail, wind, and tornadoes cause significant damage and result in loss of life every year. CIMSS contributes to mitigating these effects by leveraging satellite and other remotely sensed observations to help the NWS better predict convective storms and the conditions that support their intensification. CIMSS severe weather research begins by observing atmospheric instability, a precursor to storm development. In preparation for the expected GEO-XO Hyperspectral Sounder (GXS), CIMSS scientists developed an innovative approach to blend the rich spectral information from satellite infrared sounders and the high time-space resolution from geostationary imagers. The CIMSS Polar Hyperspectral Soundings and Microwave Data and ABI modeling output (PHS; Smith et al. 2020) associates JPSS sounder information with ABI observations and then propagates the information forward in time with each ABI scan to initialize a numerical model every hour. The value of PHS soundings was evident at the 2022 and 2023 NOAA Hazardous Weather Testbed (HWT) where PHS forecast output was often used in identifying regions where convective initiation was most likely to occur (or to be suppressed). Forecasters pointed out numerous examples of how the projected satellite soundings improved the mode predictions of severe weather producing environments.

To complement this satellite fusion research, a CIMSS PhD student and early career researcher led studies that used the Atmospheric Emitted Radiance Interferometer (AERI), a ground-based radiometer that measures downwelling infrared radiation in the near and thermal infrared bands, to demonstrate that high-temporal resolution soundings may accelerate identifying conditions conducive to severe weather formation. Analyzing observations from severe weather events observed over multiple seasons, demonstrated that rapidly updating boundary layer thermodynamic profiles shows tremendous promise for enhancing forecasts of where and when convection will occur (Loveless et al. 2022, Seo et al. 2022).

Once environment conditions suitable for convective development are identified, geostationary satellite cloud observations provide the earliest signs of convective initiation. CIMSS is a world-leader in utilizing modern computational methods to rapidly identify severe weather signatures in high time-resolution satellite observations. The NOAA-CIMSS Probability of Severe model (ProbSevere) leverages multi-platform multi-scale storm identification and tracking algorithms and advanced machine learning to fuse radar, satellite, lightning, and environmental data to predict the probability of hail, wind, and tornadoes up to an hour in advance, anywhere in the contiguous United States (Cintineo et al. 2014, Cintineo et al. 2018, Cintineo et al. 2020b).

ProbSevere has been shown to increase warning lead times before severe hazards and improve short term predictions. Version 3 (V3) uses gradient-boosted decision trees to include more satellite, radar, and NWP predictors and uses High-Resolution Rapid Refresh (HRRR) data to better capture the near-storm environment. Many forecasters at HWT 2021-23 noted improved forecast guidance over ProbSevere V2. An example of a storm developing in eastern New Mexico where radar coverage is poor is shown in Figure 4.12. ProbSevere's intense storm probability rapidly increased to 36% as the storm matured (top panel) as an overshooting top was identified in satellite imagery before any severe weather was apparent in radar observations. This storm subsequently produced numerous reports of large hail, severe wind, and tornadoes. The lower panel in Figure 4.12 shows the mature storm two hours after the initial identification with heavy rain and hail now evident in radar reflectivity. The ProbTor V3 (probability of tornado model) probability was 47% at this time, just prior to the first tornado report. In contrast, the ProbTor V2 probability was only 9% at the same timestep, demonstrating the value of CIMSS recent research to improve the algorithm.

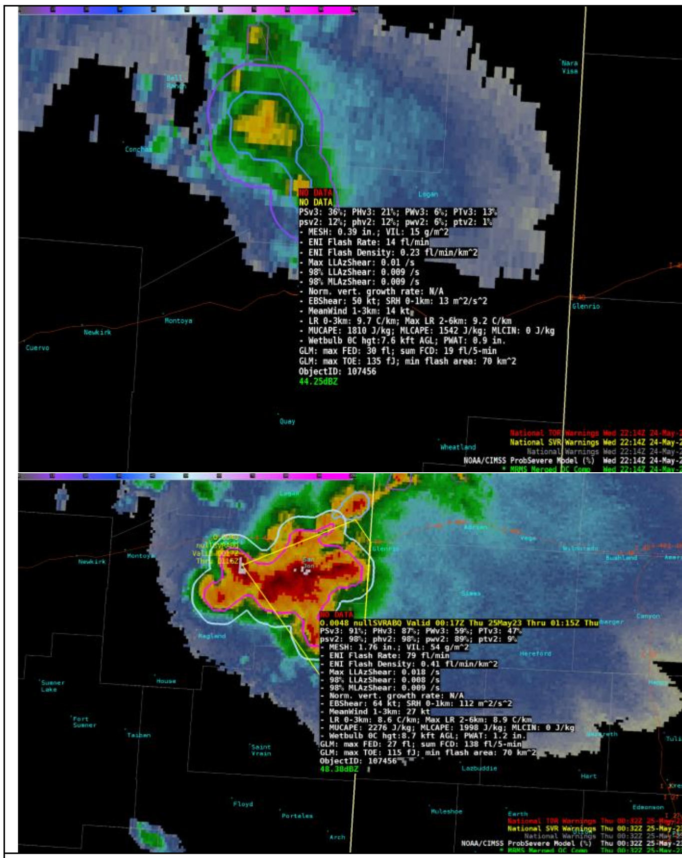

FIGURE 4.12: ProbSevere contours and Multi-Radar Multi-Sensor (MRMS) merged reflectivity observations of a storm in eastern New Mexico. Top: ProbSevere severe weather probability increases before signatures are evident in radar observations. Bottom: ProbTor V3 indicates a high probability (47%) of tornado formation in the mature storm, minutes before the first official tornado report.

CIMSS is also pioneering the use of AI/ML to forecast lightning. LightningCast is a novel deep-learning model that uses complete ABI visible, near-infrared, and longwave-infrared images at their full spatial resolutions (0.5 km to 2 km) as input to a convolutional neural network (CNN) trained using the Geostationary Lightning Mapper observations (GLM) to predict the probability of lightning in the next hour at any given location (Cintineo et al. 2022). LightningCast has proved to be very useful and popular among NWS forecasters, often providing 20 minutes or more of actionable lead time before the *first* lightning strike in a storm. This has significant benefits to society. Airports and mariners can act before storms approach. Extended lead time helps large outdoor event and venue managers (e.g., stadiums, amusement parks, festivals) make better and more timely decisions to protect people. Individuals can use this probabilistic lightning information to make decisions such as "should we go swimming today?", "when should we get off of the golf course?", "should we delay the little league baseball game?" In one specific example, on 7 April 2023, as The Masters golf tournament was taking place in Augusta, GA, LightningCast showed a rapid rise in the probability of lightning reaching 60% 25 minutes before the first flash struck within 5 miles of the Augusta Airport very close to Augusta National. It is easy to imagine how this information could help protect golfers and spectators.

To make the data accessible to forecasters, decision makers, and the public, CIMSS created an openly accessible dashboard that plots the probability of lightning and lightning flash observations over time at hundreds of airports and stadiums around the country. LightningCast was evaluated at the NOAA HWT in 2022 and 2023 and used widely for short-term lightning initiation guidance for developing convection and to inform maintenance of storms. Many NWS offices routinely use the experimental near-real time feed of LightningCast data produced by CIMSS.

CIMSS severe weather research over the past five years has encompassed everything from the pre-convective environment to mature thunderstorms and convective maintenance, infusing satellite and other remotely sensed data into all aspects. CIMSS has created novel products with this rich data and machine-learning and other advanced methods. Our cooperative institute is poised to and excited to continue trailblazing this path, ultimately benefiting society with more accurate and more timely severe weather forecasts. Recognizing CIMSS leadership in artificial intelligence applications, CIMSS scientist John Cintineo is now on the steering committee for the World Meteorological Organization (WMO) Artificial Intelligence Nowcasting Pilot Project (AINPP), where nowcasting products like LightningCast will be evaluated in underserved regions (e.g., South America, Africa, southeast Asia).

Aviation Hazards

Aviation has a significant impact on the daily lives of many U.S. citizens and contributes significantly to the economy. For example, the FAA estimated that the economic impact of U.S. aviation was 4.9% of GDP in 2019 (FAA, 2020). Beyond this economic impact, aviation safety is critically important for protecting lives and property. As part of our societally focused research, CIMSS scientists leverage satellite remote sensing data and other meteorological data to contribute to public safety, protect transported property, efficiently route aircraft, help manufacturers develop better fuel types for future aircraft, and understanding aviation impacts on climate.

Two atmospheric conditions that pose hazards for aviation are low-level clouds and fog that can impact visibility and airborne particulate matter like volcanic ash that can damage critical engine components. Either pose immediate public safety concerns, but also have significant economic impacts due to the costs of flight delays, rerouting aircraft, and repairing damaged engine components. Airlines benefit greatly from accurate depictions and forecasts of volcanic ash, fog, and stratus clouds for efficient route planning that ensures public safety. CIMSS contributes to these forecasts by leveraging NOAA's meteorological satellites and other data to automatically detect and characterize volcanic ash and low cloud.

Volcanic ash is detected in geostationary and LEO satellite observations via a multi-spectral variational retrieval of ash cloud top height, ash particle effective radius, and ash mass loading, built upon cloud-remote sense expertise (Pavolonis et al., 2013; Pavolonis et al., 2018, 2015a, 2015b). Figure 4.13 shows an example of the resulting Volcanic Cloud Analysis Toolkit (VOLCAT) detection and retrievals displayed on the VOLCAT experimental website for an eruption of the Popocatepetl volcano in Mexico from September 2023. Based on feedback from the International Civil Aviation Organization (ICAO) stakeholders, the VOLCAT system is designed to alert the community (via email or SMS messaging) of newly emergent volcanic ash clouds within five minutes. These products are used in dispersion models to more accurately forecast where volcanic ash will be in the short and medium term helping the aviation industry route flights in a manner that protect lives and safety and avoid economically costly hazardous flying conditions. The NOAA HYSPLIT dispersion modeling group has demonstrated that assimilating VOLCAT ash cloud height and mass loading information produce more accurate forecasts than those without such information (Crawford et al., 2022).

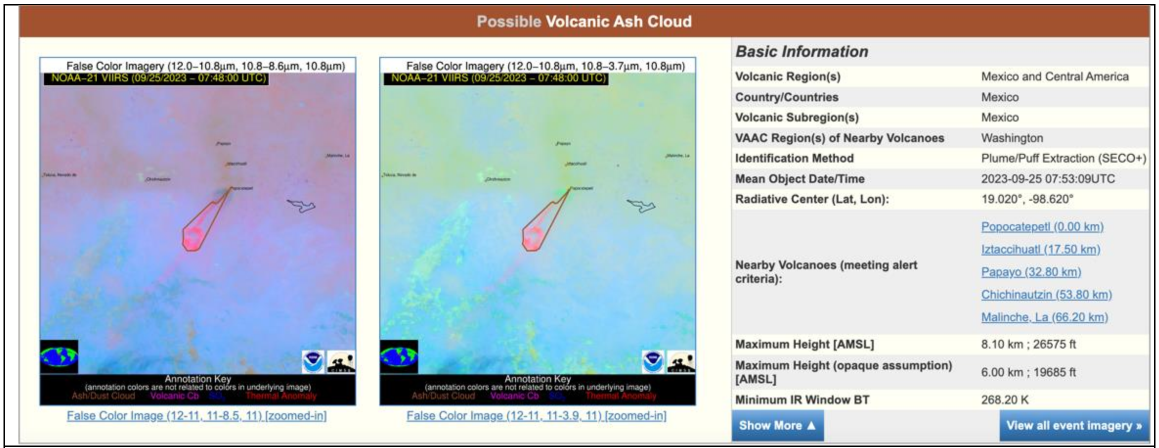

FIGURE 4.13: VOLCAT detection and characterization of a volcanic ash cloud from the Popocatepetl volcano in Mexico at 0748 UTC on September 25, 2023 using NOAA-21 VIIRS observations. The output is shown as displayed on the experimental VOLCAT website.

Fog and low stratus clouds are detected using a machine learning technique that fuses GOES ABI satellite observations, numerical weather prediction model moisture profile data, and other ancillary data to predict the cloud layer physical thickness and the probability that a satellite pixel meets aviation flight rule criteria (e.g., Instrument Flight Rule, or IFR, conditions) (Calvert and Pavolonis, 2021). The machine learning approach improves the detection of fog/low stratus during both daytime and nighttime conditions. The CIMSS fog/low stratus products developed at CIMSS are now routinely used by the NWS, Aviation Weather Center, Ocean Prediction Center, and other public and private entities for supporting public safety and efficient transportation planning.

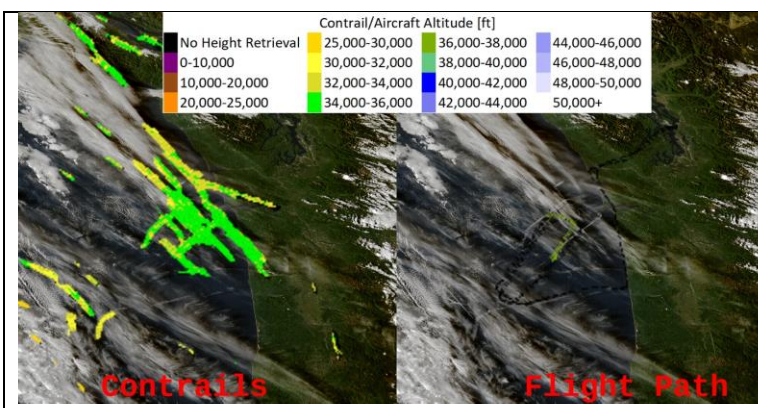

FIGURE 4.14: CIMSS participation in the 2023 ecoDemonstrator mission. Left: CIMSS AI-based contrail detections are color-coded by cloud height. Right: The flight path of the aircraft using the same color scale. Both images are overlaid on a GOES-18 true color image from October 12, 2023.

A third, and unique, example of CIMSS research on potential aviation-related hazards is jet contrails (otherwise known as aviation-induced cirrus, AIC). Under the right meteorological conditions, long-lived contrails increase the atmospheric greenhouse effect, potentially representing another human-induced source of planetary warming. However, researchers do not yet have a firm understanding on the role contrails play in the Earth's climate since they can also induce cooling during the day by reflecting solar radiation (Lee et al., 2021). In a collaboration with Boeing and the U.S. Department of Energy, CIMSS researchers are contributing to better understanding the climate impacts of contrail cirrus by using AI/ML to detect contrails and measure their lifetimes using GOES ABI imagery (Hoffman et al., 2023). The approach applies a U-Net, a type of CNN first developed at CIMSS as a methodology to detect sea ice leads (Hoffman et al., 2021), to identify jet contrails using multiple infrared channels. Output is being analyzed to determine where conditions are favorable for long-lived contrails, with a long-term goal of redirecting flights away from regions where long-lived contrail formation is likely to reduce their impact on Earth's climate.

To complement this effort, CIMSS also leveraged SSEC's airborne capabilities to collaborate with Boeing on a series of October 2023 ecoDemonstrator test flights (Boeing Company, 2024) to measure aerosol and cloud particles created by different test fuels. The CIMSS contrail detection methodology was applied to GOES ABI 1-minute mesoscale imagery to determine whether certain fuel mixtures reduced contrail formation (Figure 4.14). This university-NOAA-DOE-commercial sector collaboration showcases CIMSS' unique ability to employ cutting edge methods, multidisciplinary remote sensing expertise, and partnerships with government and industry to understand and reduce the impact of commercial aviation on Earth's climate.

Water: Too Little, Too Much, and Cascading Hazards

NOAA identifies water availability, quality, and risk as a challenge area for the next five years stating: "*too much water, too little water, or poor water quality endangers life, property, communities, economies, and ecosystems*." Flash droughts, for example, are extreme events characterized by a period of rapid intensification that leads to insufficient water to meet the needs of the natural and human environments with potentially devastating consequences (Otkin et al. 2022; Christian et al. 2024). With funding from the NOAA Climate Program Office (CPO), NSF, and NASA, CIMSS scientists have been at the forefront of flash drought research during the past decade. Otkin et al. (2021) developed the flash drought intensity index (FDII) to determine the strength of a flash drought using both the magnitude of the rate of intensification and the drought severity. Otkin et al. (2024) used the FDII to develop a multivariate flash drought climatology for the contiguous U.S. showing how flash drought occurrence and strength varies with season. CIMSS researchers also contributed to external projects that produced global flash drought inventories to benefit researchers as well as underserved communities (Christian et al. 2021).

These inventories form the basis for regression and machine learning based methods to generate probabilistic forecasts of evaporative stress index (ESI) and soil moisture on sub-seasonal time scales. Lorenz et al. (2021) found that changes in soil moisture are predictable 8–14 days in advance with more than 50% of the variance explained over most of the contiguous U.S. Machine learning and other enhancements offer potential for extending ESI and soil moisture forecasts to 15-28 days (Lorenz et al, 2024). Nonlinear machine learning methods lead to improved skill over linear methods for soil moisture but not for ESI.

Wildfires can be a direct consequence of dry conditions brought on by flash droughts dramatically compounding their impacts to life and property. Mitigating the risks of such "*cascading hazards*" is a high priority for NOAA (e.g. pages 13 – 14 of the "FY2023 – 2027 Weather, Water, and Climate Strategy"). CIMSS has researched methods for detecting fires using satellite observations since the 1990's creating the Wildfire Automated Biomass Burning Algorithm (WFABBA) that became NOAA's first operational fire detection and characterization algorithm in 2002 (Schmidt 2020). Today, CIMSS is developing and testing a new unified fire detection, characterization (e.g. size and fire radiative power, FRP), tracking, and alerting system known as the Next Generation Fire System (NGFS). The NGFS seeks to improve on earlier products by using a more robust detection method that can detect weaker thermal anomalies and has strong performance in both clear and cloudy conditions. NGFS also applies a GOES terraincorrection and a new feature-based approach to improve rendering of fires in satellite imagery, and for drawing polygons around the satellite pixels for display purposes.

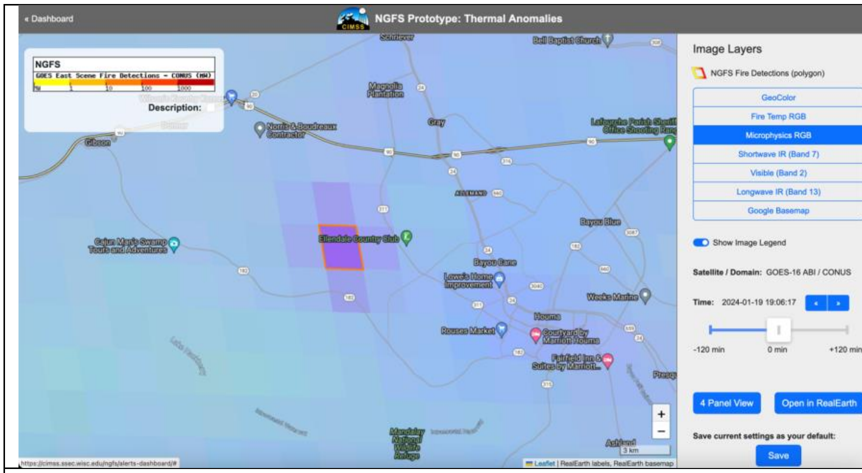

FIGURE 4.15: The NGFS streamlined satellite viewer on the prototype real-time alerts dashboard for an alert occurring in Louisiana on 19 January 2024.

The NGFS provides information critical to many front-line wildfire responders, but this will only lead to action if the data are accessible. CIMSS is working to provide the user community with NGFS detection datasets, new fire alerts, and associated satellite imagery that are informative and easy to use including generating CSV files and standardized GIS formats such as geoJSON and geoTIFF. CIMSS has also developed a customizable dashboard to display critical fire information. Figure 4.15 shows an example of the streamlined NGFS satellite viewer for an alert in Louisiana on 19 January 2024. The pixel containing the thermal anomaly is indicated by the red polygon. The user can select from several satellite image layers and then view those images over a 4-h period. Finally, CIMSS works directly with local stakeholders to customize software for specific applications. For example, the Geographic Information Network of Alaska (GINA) plans to run a local implementation of the NGFS using direct broadcast VIIRS data to rapidly detect fires in the remote Alaskan wilderness. CIMSS has worked with GINA to develop a containerized version of the NGFS code that will make it easier for external collaborators to install the NGFS on their local computing systems.

At the opposite end of the water spectrum, too much precipitation can also pose risks to life and property. CIMSS satellite expertise is also playing a critical role in validating and distributing flood information to the user community. Working with collaborators at George Mason University, CIMSS researchers use VIIRS on NOAA-20, NOAA-21, and SNPP to depict locations inundated by flood waters and estimate the depth of the water (Li et al. 2018, 2022). Figure 4.16 shows widespread flooding along the Missouri River in March 2019 identified in the VIIRS flood product. Similar flood products are produced using geostationary GOES-East, GOES-West, and Himawari data for more rapid detection of rapidly changing conditions. Direct broadcast, a dedicated RealEarth server, HTTP/FTP access, AWIPS/LDM, and GEONETcast Americas are all used to distribute the products quickly and reliably to stakeholders. CIMSS researchers frequently follow up with stakeholders to ensure that the flood products are reaching decision makers sufficiently quickly to enable rapid response to deteriorating conditions.

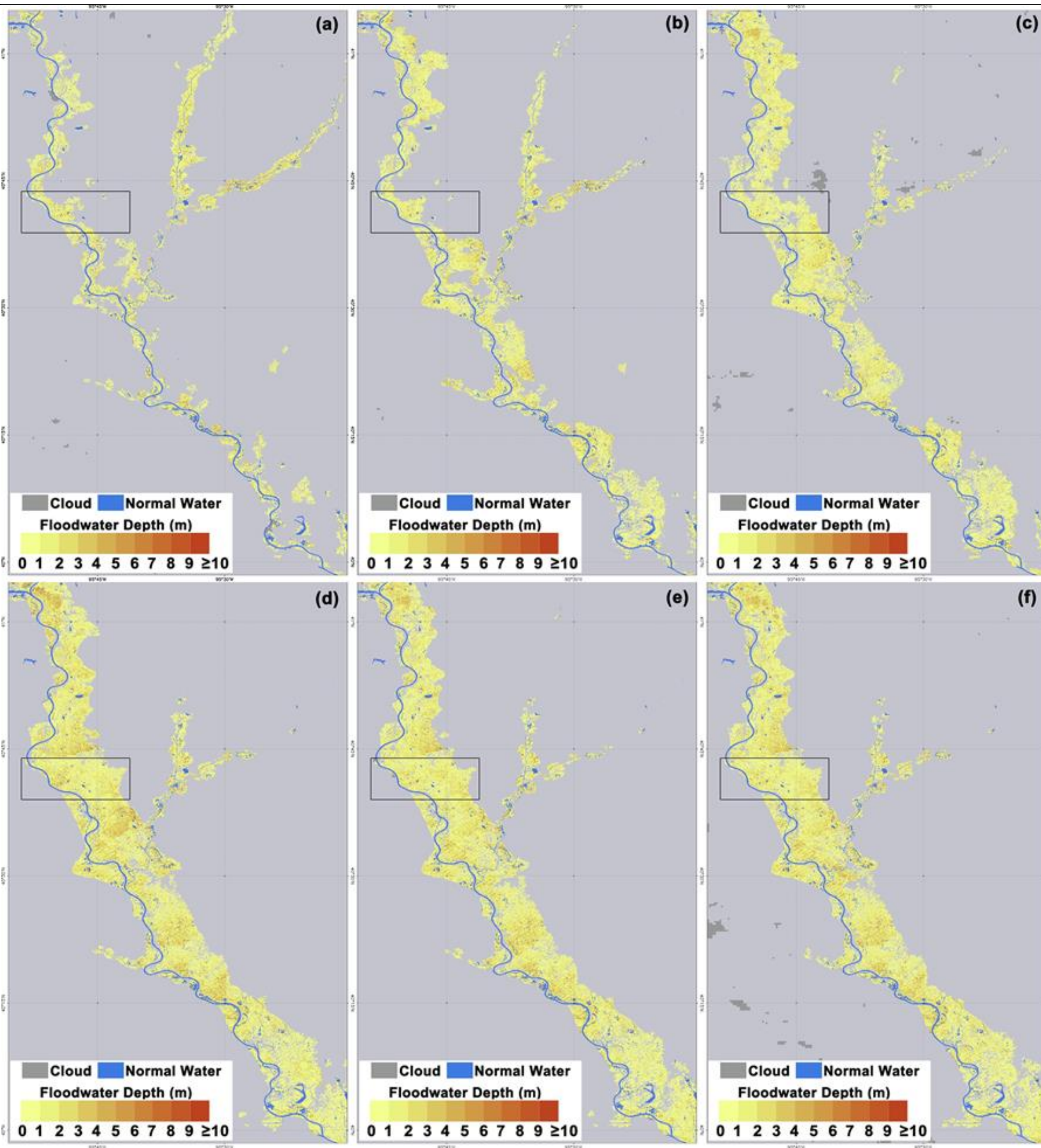

FIGURE 4.16: VIIRS downscaled 30-m floodwater depth along the Missouri River on: (a) 15 March, (b) 16 March, (c) 18 March, (d) 20 March, (e) 21 March, and (f) 22 March 2019.

Environmental Modeling and Data Assimilation

CIMSS' abundant experience in processing and analyzing environmental and meteorological satellite data equips our researchers with unique expertise to understand the advantages and limitations of various satellite products, enabling us to develop innovative methodologies to integrate satellite measurements with environmental models. CIMSS recent accomplishments in environmental modeling and data assimilation (DA) research include assimilating satellite soundings, wind vectors, and atmospheric composition, model verification, observing system simulation studies (OSSEs), and radiative transfer model development. These efforts address CIMSS' mission to "*advance the use of meteorological satellite data to enable the National Oceanic and Atmospheric Administration to meet the nation's weather and climate needs*." Ultimately, this research improves operational NWP and air quality forecasts, supporting NESDIS' mission to provide "*secure and timely access to global environmental data and information from satellites and other sources to both promote and protect the Nation's environment, security, economy and quality of life,*" and fulfilling NOAA's mission to "*understand and predict changes in climate, weather, ocean, and coasts.*"

A strength of CIMSS modeling research is the wide range of satellite measurements (LEO and geostationary, shortwave infrared/longwave infrared/microwave, radiances, and products) and the variety of different numerical prediction models (regional to global, weather forecast, reanalysis, and air quality) it addresses. This is reflected in the breadth of our recent achievements under this research theme:

- Researched and tested new approaches for assimilating thermodynamic and dynamic information provided by hyperspectral sensors and geostationary imagers.
- Developed new bias correction methods, improved observational error estimates, and advanced QC methods to increase the use of all-sky infrared brightness temperatures in data assimilation systems.
- Improved radiance assimilation over land surfaces by separating surface and atmospheric contributions.
- Explored the assimilation of satellite observations sensitive to soil moisture and vegetation properties in Numerical Weather Prediction (NWP) and land surface models.
- Extended the Realtime Air Quality Modeling System (RAQMS) Aura Reanalysis beyond 2016 using the next generation of operational trace gas retrievals.
- Advanced innovative model verification methods to support NWP model development.
- Developed a correction for non-local thermodynamic effects in the Community Radiative Transfer Model (CRTM) used in the GFS assimilation system.
- Conducted regional OSSE/OSE experiments to assess the impacts of advanced infrared sounders and imagers onboard geostationary and CubeSat satellite platforms.

Some of these highlights are discussed in more detail below.

Data Assimilation for NWP

Recent data assimilation efforts at CIMSS focus on challenging problems not addressed at major NWP centers. For example, while the assimilation of CrIS radiances has shown to reduce forecast errors, operational assimilation systems typically only use longwave infrared (LWIR) radiances in clear skies. Shortwave infrared radiances (SWIR) are more sensitive to temperature and less contaminated by water vapor and trace gases, but are affected by the non-local thermodynamic equilibrium (NLTE), which causes large discrepancies in observation minus background (OMB) biases between day and night. CIMSS has developed methodologies to correct NLTE biases in the CRTM simulation allowing CrIS SWIR radiances to be assimilated. Numerical experiments in the Global Forecast System (GFS) show that the assimilation of SWIR radiances improves the temperature field for either daytime or nighttime (Lim and Li 2024; Li et al. 2023a and 2023b).

Likewise, all-sky infrared radiance assimilation offers significant potential for increasing the value of satellite observations in areas with broken clouds. This is particularly important since forecast errors tend to be larger in cloudy regions than clear regions. To resolve this problem CIMSS has pioneered new methods for assimilating cloud cleared radiances (CCR), the clear-sky equivalent radiances assuming partially cloud covered fields of view are cloud free. Our research demonstrates that CCRs can be estimated from geostationary hyperspectral infrared sounder observations in cloudy skies using machine learning techniques without the need for collocated imager or microwave sounder data paving the way for assimilation into NWP models (Di et al., 2024). CIMSS is also developing observation operators to assimilate cloud liquid water path (LWP) and ice water path (IWP) directly. Initial experiments demonstrated that IWP/LWP assimilation improves the water vapor and consequently improve the hurricane track forecast for Hurricane Irma (2017) and Maria (2017) (Meng et al. 2021, 2022).

The current NCEP 4DEnVar assimilation system may also miss information contained in the high temporal resolution GOES-R observations by only ingesting hourly radiance measurements. CIMSS has developed new methods to increase the temporal information assimilated by assimilating the radiance tendencies (i.e., temporal variations) of ABI and AHI clear sky radiances (CSR). This also has the advantage of eliminating the need for radiance bias corrections, which generally reduce observation impacts. Numerical experiments using GFS Finite Volume Cubed-Sphere dynamical core (GFSFV3) show that assimilating window and CO_2 band tendencies improve in 500 and 1000 hPa geopotential height anomaly correlations in the Southern Hemisphere and significantly reduce temperature biases at 700 and 850hPa for all regions (Lim et al. 2022, 2023, 2024).

CIMSS atmospheric motion vector products have been demonstrated to exert a consistent positive impact on forecasts when assimilated into NWP models. In addition to playing a key role in developing AMV products, CIMSS researchers have pioneered their application to NWP models. For example, while the new era of JPSS satellites has allowed new global AMVs to be computed from the overlaps between SNPP, NOAA-20, and NOAA-21, using multiple satellites for AMVs can introduce systematic biases in AMV speed. Such biases were revealed by recent assimilation experiments using GFSFV3 conducted by the CIMSS modeling research team. The speed bias is likely due to systematic biases between sensors on different platforms that do not occur if a single sensor (e.g. geostationary) is used. CIMSS researchers have also demonstrated the value of a new AMV product based on feature tracking of ATMS moisture retrievals using the microwave integrated retrieval system (MiRS) algorithm. Microwave observations are much less affected by clouds, making it possible to provide AMVs beneath clouds where NWP models exhibit more forecast errors than in clear skies.

CIMSS researchers have also successfully demonstrated the value of tropical cyclone AMVs derived from GOES meso-sector 1-minute imagery. Numerical experiments using the Hurricane Weather Research and Forecasting (HWRF) model show that both tropical cyclone track and intensity forecasts can be improved by assimilating these enhanced high time-resolution AMVs (Li et al. 2020). Preparing for the future capabilities of the GEO-XO hyperspectral infrared sounder, CIMSS is collaborating on research to generate three-dimensional AMVs from GXS observations using machine learning. Analysis of data from the Geostationary Interferometric Infrared Sounder (GIIRS) on Feng-Yun 4B indicate that accurate AMVs can be derived from the high temporal resolution GEO hyperspectral infrared sounder data (Ma et al., 2021 and 2024). Subsequent numerical experiments suggest that assimilating these 3D AMVs offers significant benefits for NWP provided high temporal resolution observations (~15 minutes) can be achieved (Ma et al., 2021 and 2024).

Atmospheric Composition

A distinct branch of CIMSS modeling and DA research focuses on improving models of atmospheric composition. Aerosols and trace gases have implications for public health and affect the weather through radiative process, and by modifying clouds and precipitation. CIMSS researchers have developed the capability to assimilate JPSS atmospheric composition products within a Unified Forecast System (UFS) stratospheric/tropospheric chemistry model called the UFS Regional Air Quality Modeling System (UFS-RAQMS), a version of the Next Generation Global Prediction System (NGGPS). Long term experiments show that assimilating aerosol optical depth, ozone, and CO improves atmospheric composition models when compared with measurements from Aeronet, ozonesondes, and airborne in situ measurements. In addition, the assimilation improves lateral and upper boundary conditions for regional air quality predictions, providing information for air quality management, health applications, environmental policy making, climate science, and renewable energy planning (Pierce et al. 2022). These studies will provide useful information for air quality forecasts, benefiting the broader scientific community and regional air quality assessment.

Another way CIMSS is using satellite data to improve air quality modeling is to constrain the meteorological modeling systems. Weather Research and Forecasting (WRF) model simulations show that high resolution satellite-derived surface datasets and alternative parameterization schemes can produce more accurate simulations of near-surface meteorological conditions and energy fluxes (Otkin et al. 2023). The more accurate meteorological simulations are used as input to the Environmental Protection Agency (EPA) Community Multiscale Air Quality (CMAQ) model to assess the impact of these model changes on ozone forecasts in the Lake Michigan region (Pierce et al. 2023). These studies help find a model configuration that can better characterize the spatial and temporal variability in ozone and its precursors. This is particularly important for locations where lake breezes commonly affect local air quality along the lake shoreline.

Observing System Simulation Experiments

Before investing billions of dollars of taxpayer money in new global observing systems, it is essential to thoroughly demonstrate that their capabilities will meet societal needs. CIMSS contributes to the design of new observing systems by conducting Observing System Simulation Experiment (OSSEs) to assess the value of proposed sensors or sensor improvements. CIMSS has developed both a global OSSE system that uses the operational GFS model with the GEOS-5 Nature Run (G5NR), and a regional OSSE system that uses the WRF-ARM model with the high-resolution nature run (HRNR). Collaborating with the NOAA Quantitative Observing System Assessment Program (QOSAP), Lim et al. (2024) carried out global OSSE projects using the NOAA global OSSE package to contrast the impacts of various wind products, including lidar winds and AMVs from moisture tracking.

To reduce the computational cost of OSSE studies, CIMSS also developed a hybrid OSSE system where only future measurements are simulated, and all current measurements are derived from real observations. CIMSS global hybrid OSSE studies were used to demonstrate the impact of detector heterogeneity of hyperspectral infrared sounders (Lim et al. 2022) while regional hybrid OSSE studies demonstrated the value of geostationary hyperspectral infrared sounder observations for local severe storm forecasts (Wang et al. 2021). Currently, CIMSS is conducting a new regional hybrid OSSE to understand the potential added value of the Configurable Reflectarray for Electronic Wideband Scanning Radiometry (CREWSR), a future microwave imaging and sounding sensor compatible with small satellite systems (Wang et al. 2024).

Model Verification

CIMSS has also made extensive use of satellite observations to evaluate both regional and global models. For example, GOES ABI, GOES GLM, and WSR-88D radar data were used to assess the representation of clouds and water vapor in HRRR, RRFS, and FV3-LAM and evaluate the land surface models, microphysics schemes, planetary boundary layer, and land-atmosphere coupling of UFS S2S (Griffin and Otkin 2024 and 2022; Griffin et al., 2021 and 2020; Thompson et al., 2021). Each of these projects involved developing new verification capabilities and use-cases in the METplus verification system.

CIMSS has also used near global observations of infrared water vapor radiances from international geostationary satellites to evaluate upper tropospheric humidity (UTH) in reanalyses. Correcting for differences in spectral coverage and observing angles among different sensors, we found that all the reanalysis datasets evaluated (ECMWF-interim, ERA5, CFSR, MERRA-2, JRA-55, CRA) capture the main wave-like diurnal variations of UTH but the magnitudes are not as strong as the measurements and peak later in the day. All reanalyses exhibit a dominant wet bias, although some are better than others. For extreme climate events like El Niño, reanalyses capture the pattern of UTH well but underestimate the UTH gradient over the tropical Pacific in the decay year (Xue et al. 2020a and 2020b). These studies provide valuable insights to modeling centers for improving convection and cloud parameterization schemes and/or assimilation systems.

4.2.b Social Sciences/Human Dimensions

i. How are social science questions or topics included in CI funded research?

While social science did not explicitly appear in the Federal Funding Opportunity under which CIMSS was awarded, our researchers recognize that societal behaviors play a critical role in realizing our vision "*a more informed society, prepared for and resilient to weather and climate changes through the effective use of meteorological satellite observations*." In response to this need, we incorporate community engagement, science communications studies, and social science research into many of our public facing projects. Many of these efforts are conducted as supplemental elements of funded projects based on a need for understanding stakeholder and public perceptions of CIMSS research products without explicit funding associated with them.

CIMSS flash drought research described in Section 4.1.a provides a specific example. Working with domestic and international collaborators, CIMSS research is quantifying the impacts of flash droughts on vulnerable stakeholders. Flash drought leads to vegetation stress, reduced crop yields, ecological degradation, and an enhanced risk of wildland fires. The rapid intensification amplifies the societal impact of these effects by causing them to emerge more quickly than can be effectively managed. Focus group meetings with Midwestern specialty crop growers showed that extreme heat and low rainfall during flash drought may increase demand for water from irrigation systems more quickly than managers are able to respond, leading to reduced crop yields and quality (Haigh et al. 2022). Participant feedback from the focus group meetings led to the development of several crop calendars depicting when management decisions are made, and which drought and climate datasets are useful when making those decisions. The crop calendar for Midwest apple growers is shown in Fig. 4.17.

ii. Is there an explicit social science agenda in ongoing research?

Other than stakeholder engagement, there is no explicit social science agenda in CIMSS ongoing research projects. CIMSS proposed to extensively survey users of data products and incorporate feedback to improve satellite data products. While this is not explicitly social science, the lessons learned from the wide range of stakeholders and public users include information regarding how different individuals interpret environmental data and what actions they take to respond to the information it provides.

CIMSS researchers do, however, leverage the CIs position within SSEC to engage in social science through projects funded by other agencies. For example, to help realize NWS mission to "*protect life and property,*" CIMSS leverages its data, products, and expertise in geospatial modeling to engage communities throughout the U.S. and world to develop strategies for modeling their risks and vulnerabilities to natural disasters. As changes to our climate increases the impacts of severe weather on people, infrastructure, and local economies, communities are struggling to adapt to the new challenges they are facing. In 1980 the United States averaged three disasters per year that exceeded one billion dollars (CPI-adjusted), but today, that number exceeds 13 per year. Building strategies that make communities more resilient to these disasters is a priority but requires careful consideration of how people interpret and act on the information they receive.

To strengthen the pathway for CIMSS data to impact local communities, Dr. Shane Hubbard works with states and local governments to identify hazard risks before, during and after storm events and then collaborates to design strategies that mitigate against those risk. These agencies work together leveraging mitigation grant programs that are offered by the Federal Emergency Management Agency (FEMA). Recently, Hubbard and his team modeled the potential impacts from Hurricane Dorian as it was forecasted to make landfall. They relayed information regarding the potential damages and dollar losses from Dorian to South Carolina Emergency Management Division and Florida's Division of Emergency Management. These analyses are critical in determining affected populations and understanding the spatiotemporal evolution of the areas that will require the most assistance after a hurricane's landfall. As evidence of Dr. Hubbard's long-term commitment to community engagement, in January 2017, Hubbard worked with a collaboration of private sector, public sector, and academic institutions in San Juan, Puerto Rico modeling the potential impacts from a major hurricane. This work was used by the communities to lobby the municipal government to make changes to their stormwater system. This data was also instrumental in guiding the evacuations of 100 families just prior to Maria's landfall.

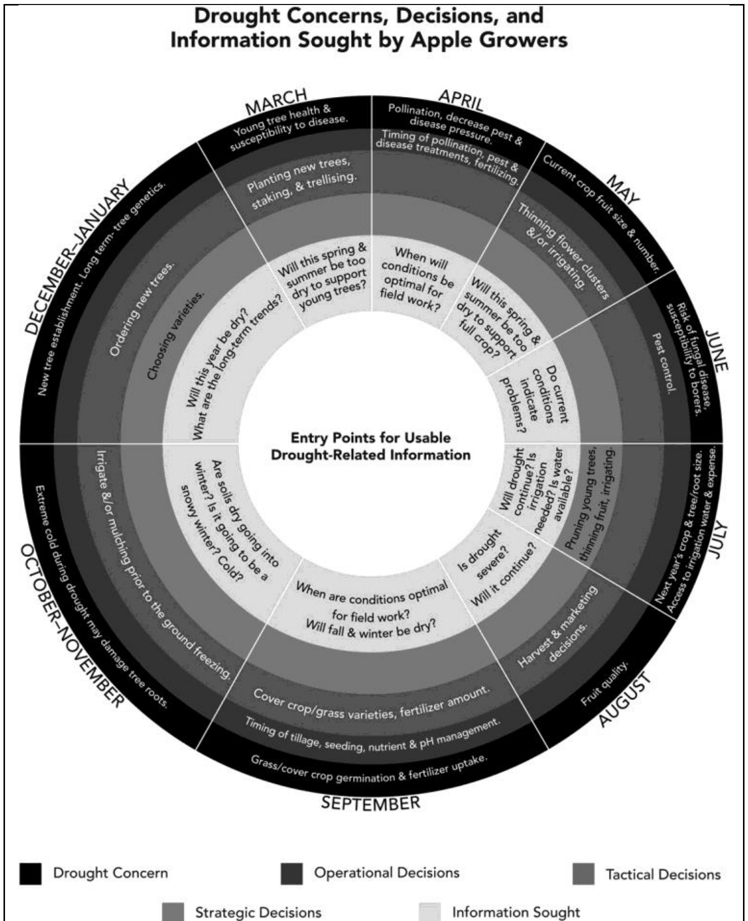

FIGURE 4.17: Graphical decision calendar for Midwest U.S. apple production during a drought year. Reproduced from Haigh et al. (2022).

iii. How much social science does the CI currently fund?

CIMSS leadership hopes to increase the emphasis on social science in our research. Social science currently represents about 40% of the CIMSS Task 1 budget for administration, education, and outreach and most of our UW Cost Share (see Section 6.4.a). We utilize these funds to partially support four people (2 FTE total) working on communications and community engagement. CIMSS also supports a PhD student, Rena Sletten, in the UW Nelson Institute for Environmental Studies who is conducting interdisciplinary research to understand barriers to communicating science to the public. CIMSS Task 2 support for social science is much more limited. Elements of our satellite product training program, particularly those targeting underserved or frontline communities (see Section 4.3.b), apply best practices for engaging non-experts in satellite remote sensing and computational methods.

iv. What are the major roadblocks to expanding social science in the research plan or portfolio?

Our presence on the UW-Madison campus furnishes CIMSS with enormous potential to expand its social science portfolio through other campus entities as well as external partnerships. The primary roadblocks to realizing this potential include the lack of social scientists on the CIMSS staff and a lack of opportunities to explicitly propose social science projects to augment NESDIS/STAR's portfolio of satellite products and services. To address the first roadblock, CIMSS leadership has identified and engaged several professors at UW-Madison with strong track records in social science research who could be entrained into CIMSS projects; CIMSS has committed to supporting students interested in studying Science Communications in the context of NOAA research. There has arguably never been a more pressing need for scientists to communicate research findings in a way that balances accuracy with accessibility to a broad audience. The UW Department of Life Science Communications (LSC) studies barriers to effective science communication and associated solutions with a particular emphasis on climate and the role political affiliation, background, and social media play in how individuals perceive climate information. Despite a lack of a funded research project on this topic, CIMSS has cultivated collaborations with two professors in LSC resulting in a research partnership that paves the way for working on NOAA projects in the future. These relationships are currently maintained through a student supported on CIMSS Task 1 funding, but this model is not sustainable due to other demands on those funds.

v. What is the CIs plan for addressing social science issues?

To address social science issues in the coming years, CIMSS will continue to leverage connections to other departments on campus, external partners, and seek opportunities through NOAA and other agencies to explore social science problems related to conveying and acting on meteorological satellite data and associated climate records. Social science-focused funding from NOAA to support students working across disciplines, such as the AOS-LSC collaboration described above, would be a welcome catalyst for advancing our social science research portfolio. Other potential avenues for collaborating include working with the Department of Civil and Environmental Engineering to incorporate satellite data into agent-based models and the School of Business to assess the economic risks of climate change and quantify the economic benefits of NOAA satellite assets, to name a few. In lieu of hiring a full-time social scientist as we seek to develop a more robust social science portfolio, CIMSS is exploring the possibility of creating affiliate positions to formalize the relationships with social scientists in other departments to stimulate proposals with current staff. Ultimately, our goal is to hire a full-time social scientist who can coordinate proposals, conduct social science research, co-advise students, and build a true social science program at CIMSS.

Another mechanism for increasing social science in CIMSS research, is our recent leadership in establishing an Industry-University Cooperative Research Center (IUCRC) at UW-Madison. In spring 2023, NOAA Chief Scientist Dr. Sarah Kapnick announced (see story here) to CI directors that NOAA was partnering with NSF to create an IUCRC focusing on climate change risk assessment to support the needs of the insurance and re-insurance sectors. The CIMSS director and researchers teamed with researchers at Northern Illinois University and the University of Illinois, Urbana – Champaign to win a Step 1 grant to develop the industry partnerships that will form the basis of this center. In addition to understanding how hazards may change in a warming climate, an important element in the research is understanding and modeling "*the role of human behavior in affecting and responding to these changes*" to adapt insurance and reinsurance policies appropriately.

CIMSS will also continue to leverage connections to other federal, state, and local agencies to address social science issues. Existing relationships with the Wisconsin Initiative on Climate Change Impacts (WICCI), FEMA, and the NOAA Cooperative Science Centers (CSCs) provide conduits to social scientists that have yet to be fully explored.

4.3 Education and Outreach

By residing at UW, the birthplace of satellite meteorology, CIMSS maximizes NOAA's potential to maintain and grow an exceptional workforce trained in science, technology, engineering, and mathematics (STEM). The UW is renowned for educational excellence and regularly places among the top ten in national research rankings for public and private universities. CIMSS leverages the educational resources at UW to provide formal education, informal education, and professional training activities that advance NOAA's education and outreach goals and help to develop NOAA's future workforce. CIMSS infrastructure enables multi-tiered activities, trainings, and collaborations that align with NOAA's mission as well as NOAA's Education Strategic Plan. Highlights of CIMSS education and outreach efforts since 2020 include:

- Developed new educational activities that facilitate the use of satellite observations from all NOAA missions in K-12 Earth science education.
- Expanded access and usage of the community Climate Digest.
- Engaged and nurtured a diverse pool of prospective STEM students by expanding the highly successful satellite virtual science fair to include all NOAA and NASA missions.
- Created dynamic content for the CIMSS website and CIMSS Satellite Blog to convey CIMSS research to wide audiences.
- Conducted in-person training visits to NWS forecast offices and ran remote sensing schools.
- Conducted satellite education programs for students jointly with STAR's CESSRST.
- Developed new distance learning modules aimed at helping to prepare tomorrow's forecasters for the next generation of meteorological satellites.
- Increased the societal benefits of satellite and weather information through communication, social science, public engagement, and collaboration with other agencies.

4.3.a What types of educational activities/opportunities does the institute offer on an ongoing basis?

<u>K-12 Education</u>

CIMSS has engaged hundreds of science teachers and thousands of middle and high school students around the GOES-R satellite series. This included a workshop at the historic GOES-R launch and plans to organize a GOES-U Teacher Workshop at Kennedy Space Center (KSC) in conjunction with the launch of the last satellite in the GOES-R series. CIMSS also co-conducts annual teacher workshops in collaboration with the Earth Science Information Partners (ESIP). Space is limited due to KSC fire codes, but 44 fortunate educators will have the chance to attend the workshop, watch the launch, and learn more about incorporating satellite data into their classrooms.

CIMSS has been a leader in educational software design for decades, pioneering distance learning software and computer-based education tools like the popular HTML5 web apps that allow users to explore physical processes like tornadoes, thunderstorms, rainbows, snowflakes and, more recently, imagery from the GOES-R Advanced Baseline Imager. NOAA SciJinks has adapted seven CIMSS WebApps to its online resources including: Grow Snow Crystals, Hurricane Simulation, Tornado Simulator, Precipitation Simulator, Rainbow Simulator, Lightning Simulator and Contrail Simulator.

CIMSS also developed and maintains an on-line course for students titled "Satellite Meteorology for Grades 7-12" and an on-line course for middle and high school teachers titled "Global and Regional Climate Change" that is being updated to reflect the most recent Intergovernmental Panel on Climate Change (IPCC) and National Climate Assessment (NCA) reports. Examples of these courses can be found on the CIMSS Education page.

In 2019, CIMSS debuted a Virtual Science Fair (VSF) as part of its GOES-R Education Proving Ground program and CIMSS has run the VSF every school year since. Middle and high school students submit projects of their own design individually or in small teams by presenting their results in a poster format. The primary requirement is using GOES-R satellite imagery. High school students are further tasked to upload videos where they describe their project, emulating a poster session at a professional conference. Top projects garner $25 gift cards. All participating students gain valuable research experience for college or future careers. Building on the overwhelming success of this program, a JPSS VSF was started in 2021, prompting the development of a new platform for JPSS imagery over North America in all 22 VIIRS channels. The VIIRS Imagery Viewer (https://cimss.ssec.wisc.edu/viirs/imagery-viewer/) has since gained considerable traction through social media, especially for acquiring Day Night Band imagery by space weather enthusiasts.

Among the more influential K-12 educational experiences offered by CIMSS is an in-person residential science camp on the UW campus each summer called the CIMSS Student Workshop on Atmospheric, Satellite and Earth Sciences, a time-honored program for high school students that has been offered every summer since 1991, except for a 3-year hiatus due to the COVID-19 pandemic. Participating students experience science education, research, and modern technology firsthand. Students work with data via activities that further their interest in careers in the physical sciences. They also take multiple field trips on and off campus.

FIGURE 4.18: CIMSS Student Workshop Participants in 2019.

Seeking to find a way to have a positive impact amidst the unprecedented challenges of a global pandemic, CIMSS developed a new on-line Weather Camp in 2020. This new program was an instant success, engaging more than 50 high school students across the country in a highly interactive on-line agenda. Originally intended as a temporary event, CIMSS responded to the overwhelming positive feedback from participants by turning this online opportunity into an annual summer event, in addition to the residential camp. Beyond introducing students to satellite meteorology, the online Weather Camp provides an early opportunity to introduce high school students to careers in weather and satellite meteorology. Participants learn about a different "weather job" daily, including an introduction to jobs at NOAA's National Weather Service. Numerous researchers share their expertise throughout the week and, to 'graduate' from the program, students are tasked to present their favorite weather using new tools or concepts that they learned in the camp.

Undergraduate Education

Educating a diverse cohort of undergraduate and graduate students that represents all demographic groups is a cornerstone of the CIMSS mission. The strong relationship between CIMSS and AOS provides a direct conduit for undergraduate and graduate education in NOAA-related fields. This relationship is cemented by a requirement that the CIMSS Director also serves on the AOS faculty, starting with CIMSS founder, Professor Verner Suomi and continuing through the present director, Professor Tristan L'Ecuyer.

Each year CIMSS awards three Verner E. Suomi Scholarships to graduating high school seniors who have demonstrated excellence in the physical sciences. This one-time award is applied toward their first year at any University of Wisconsin system school to begin studies in a field related that aligns with Suomi's vision. Very often, our Suomi scholars choose to study atmospheric science at the UW-Madison and work part-time at CIMSS exposing them to potential career paths at NOAA. When possible, CIMSS utilizes these scholarships to assist students from underrepresented and underserved communities to broaden participation in STEM majors and careers.

CIMSS typically employs three to five undergraduate students majoring in atmospheric science or a related field who express interest in pursuing advanced degrees. Participation in a CIMSS research project helps prepare an undergraduate to conduct future independent research and to experience collaborative thinking while engaged with other scientists. CIMSS also partners with the UW Department of Atmospheric and Oceanic Sciences (AOS) to mentor undergraduates in the NSF-funded STORM REU (Student Training in Oceanography Remote Sensing and Meteorology). In addition, CIMSS hosts NOAA Hollings undergraduate scholars to conduct summer research projects on-site. CIMSS has had several discussions with Wisconsin Sea Grant (collocated at the UW) about a collaborative Sea Grant-CIMSS opportunity for future Hollings scholars.

Finally, CIMSS contributes to AOS course offerings in support of undergraduate education and training, especially around satellite meteorology and remote sensing. Our research forms the backbone of the undergraduate major course "AOS 441: Radar and Satellite Meteorology" and the advanced graduate course "AOS 745: Meteorological Satellite Applications," both of which have been taught by the current CIMSS director, Prof. Tristan L'Ecuyer. In addition, AOS 102 on "Climate and Climate Change" was developed with funding that CIMSS procured from NASA in 2013. This course has educated hundreds on this important topic and has resulted in two publications in the Bulletin of the American Meteorological Society (BAMS).

Higher Education

Graduate Education: CIMSS strives to support a skilled workforce representative of national demographics, to meet NOAA and our nation's meteorological satellite needs. In collaboration with the faculty in AOS, our researchers have mentored 136 M.S. and 64 Ph.D. graduate students since 1980, the majority through collaborative research efforts and financial support from NOAA. CIMSS currently supports 8 graduate students working on subjects ranging from diagnosing climate trends in long-term satellite data records to using artificial intelligence to increase lead time for severe weather warnings. All CIMSS graduate students have an AOS academic advisor and a science advisor in CIMSS, fostering tight collaboration between researchers and faculty. By working directly with CIMSS research teams, students receive valuable real-world experience for their future careers as well as exposure to NOAA.

To provide additional opportunities for exceptional students to pursue research aligning with NOAA objectives, CIMSS also created a graduate scholarship. The William L. Smith Graduate Scholarship was established in partnership with NOAA to support graduate studies to improve public safety through more accurate weather prediction. Dr. William Smith, for whom the scholarship is named, is an emeritus AOS professor and former CIMSS director known worldwide for his leadership in pioneering satellite sounding capabilities. The award provides up to three years of financial support toward the completion of an advanced degree and an additional travel stipend to attend a relevant professional meeting, conference, or workshop. CIMSS selected and awarded Nuo Chen as the first recipient of the Smith Graduate Scholarship. She defended her PhD in 2023 in a presentation titled "*Adjoint sensitivity to potential vorticity and geostrophic imbalance,*" explaining a tool to help diagnose how specific attributes of a numerical weather prediction model can contribute to high-impact synoptic weather events.

The CIMSS graduate education program is augmented through collaborations with STAR's institutes, including two other CIs and NOAA's Cooperative Science Centers (CSCs). These collaborations enhance and advance research in support of STAR's science and education missions. The annual STAR Student Symposium (formerly Cooperative Research Program, CoRP, Symposium) is key to these collaborations. With themes focusing on professional development, NOAA careers, applied science, social science, and public engagement, the Symposium rotates between CIs and CSCs providing an opportunity for the NESDIS CIs and CESSRST (the Center for Earth System Sciences & Remote Sensing Technologies) to share their research and showcase the work of students, post-docs, and early career scientists. CIMSS graduate students unanimously express their enthusiasm for the Symposium and the quality of their work is reflected by the fact that CIMSS students have been voted best student presenter at the last two Symposia. While CoRP was officially dissolved when STAR reorganized in fall 2023, CIMSS is committed to sustaining this important venue for fostering interactions between STAR leadership and students and early career scientists. We are working with STAR leadership to organize a similar Symposium in fall 2024 and will send students and early career scientists to experience the unique research exchanges and networking opportunities the Symposium provides.

The Symposium also provides an opportunity to strengthen collaborations with CESSRST, a multidisciplinary center led by the City College of the City University of New York (CUNY), to increase diversity in the AOS graduate program. CIMSS has a formal collaboration through a Memorandum of Understanding (MOU) with two CESSRST members, CUNY and Hampton University, a Minority Serving Institution (MSI), and has leveraged these connections to advise two Hollings Scholars and a NOAA Experiential Research and Training Opportunities (NERTO) student. Through new AOS Prof. Mayra Oyola-Merced, a graduate of Hampton University and the University of Puerto Rico, Mayagüez, with strong scientific connections in the Latinx community, CIMSS is now pursuing new educational opportunities for individuals from underrepresented communities.

4.3.b What are the current and planned outreach efforts?

Public Outreach

Located in Madison Wisconsin, the birthplace of satellite meteorology, CIMSS embraces the "Wisconsin Idea" that education should influence and benefit lives beyond the boundaries of the University. This has become a guiding philosophy for CIMSS outreach, both for in-person and remote events. It is a philosophy enthusiastically shared by CIMSS Director Tristan L'Ecuyer who wrote an essay in a special section of the Wisconsin State Journal titled "Fueling Discovery; Taking Earth's Temperature" in 2022 sharing his passion for research and education and discussing his plans to study the Arctic's changing climate in plain language to the broad WSJ readership.

In coordination with campus outreach programs, CIMSS staff regularly conduct tours of our facilities for school groups, give public lectures, and frequent remote talks, as well as participate in regular campus activities. For example, we lead the UW-Madison "Meteorology Major" at "Grandparents University" each summer where alumni and their grandchildren attend a 2-day workshop learning everything weather – especially satellite meteorology. They also learn about NOAA and NOAA satellites directly from NOAA scientists co-located at CIMSS. In 2022, CIMSS collaborated with SSEC visualization experts to co-produce a new movie for NOAA Science on a Sphere (SOS) on the Hunga Tonga-Hunga Volcano Eruption featuring geostationary imagery from

GOES-16, GOES-17, Himawari-8, Meteosat-8, and Meteosat-11. More information and a link to a three-minute video can be found online in the SOS catalog here.

The global nature of satellite data combined with 21st century communication capabilities enable successful local, national, and international outreach. A popular informal education component of our outreach mission is the CIMSS Satellite Blog launched in 2006. The Blog, which has multiple contributing authors and averages over 100,000 visits a month, is frequently referenced in national news stories. CIMSS is also active in social media with two X feeds (formally Twitter) and a Facebook page. The CIMSS Satellite Blog (@CIMSS_Satellite) has over 44K followers on X. Our Facebook page has over 26,000 fans and @UWCIMSS has 23K followers reaching over 10 million people annually amplifying NOAA-sponsored research to a broad public audience. For the month of February 2022 alone, total reach topped 4 million people surrounding the GOES-T launch.

In all outreach activities, CIMSS promote NOAA, the value of NOAA CIs, and NOAA's many contributions to our nation and the world. CIMSS frequently works with NOAA Communications to post stories through NOAA social media or adapt material to serve as news stories.

Professional Training

Increasing literacy in the use of meteorological satellite products among atmospheric scientists and the public is central to the CIMSS mission, and aspects of training touch many CIMSS-developed products and programs. These activities include targeted on-site training for Direct Broadcast data users; training material as requested by the Office of the Chief Learning Officer (OCLO) Forecast Decision Training Division (FDTD); in-person training (GEO and LEO data, visible, infrared, and microwave) as requested; and satellite-related training modules developed for the VISIT and SHyMet programs for National Weather Service forecasters. We have developed training for our products as well, including Morphed Integrated Microwave Imagery at CIMSS (MIMIC) TPW, NOAA/CIMSS ProbSevere, GOES-R IFR Probability, CIMSS Turbulence Probability, LightningCast Probability and for various derived products. This training is available online and, where appropriate, has been made available to Storm Prediction Center (SPC)'s Hazardous Weather Testbed (HWT).

As a specific example, CIMSS scientists routinely engage in efforts to expand awareness of the availability and utility of the NGFS. Training sessions have been given to NWS Incident Meteorologists (IMETs) at the National Interagency Fire Center, and briefings have been given to the Tactical Fire Remote Sensing Advisory Committee and FEMA Region IX's Disaster Innovation Forum, among others. NGFS training material has been developed describing its capabilities, illustrating fire detections using different types of satellite imagery, and showing how to use the prototype alerts dashboard to display information about real-time NGFS alerts. Short courses focused on GOES-R products have also provided information to diverse groups, such as researchers, policy makers, emergency managers, Federal agencies, and broadcasters about GOES fire detection capabilities (Schmidt 2023b).

In addition, CIMSS has developed multiple display systems that are useful for both Geostationary (GOES-R, Himawari, GEOKOMPSAT-2, FY-4A) and for JPSS Infrared and Microwave Data. Software display systems include HYDRA, SIFT, McIDAS-V, Polar2Grid and Geo2Grid (the latter two being shell scripts that manipulate Satpy software). Some of these training materials are used in generating the CIMSS Satellite blog: from 2019-2023, more than 1600 blog posts on a variety of satellite topics, including multiple case studies, comprise this beneficial resource; other training material is incorporated into on-site training visits to direct broadcast sites. A partial list of these is at the CIMSS Direct Broadcast Workshop page.

CIMSS also supports the global satellite direct broadcast community by distributing software that allows users to create calibrated and geolocated science products from locally received data in real-time. NOAA has funded the Community Satellite Processing Package (CSPP) for Low Earth Orbiter (LEO) satellites since 2012; included in this funding is support for educating environmental decision-makers on the utility of the software and products. Over a span of 15 years, CIMSS scientists have taught more than 15 global direct broadcast applications workshops with students from more than 60 countries and 5 continents participating. The CSPP team has taught workshops for US National Weather Service forecasters in Miami, Puerto Rico, Hawaii and Guam Offices; CIMSS manages a deployment of direct-broadcast antennas at these locations (co-located with a National Weather Service forecast office). Each workshop was focused on training forecasters how they might use the direct broadcast products to assist in local forecast challenges. The CSPP team plans to continue to promote the use of real-time locally received satellite data as well as foster the next generation of scientists through these workshops.

CIMSS also routinely participates in Satellite-related Short Courses that occur at scientific meetings, such as the AMS Annual Meetings. These short courses are increasingly more hands-on and less lecture driven. In addition, CIMSS scientists have developed numerous webapps and case studies, that can be used to help participants understand satellite data and why it is useful. CIMSS scientists have also recently provided in-person training to meteorologists in Myanmar, Malaysia, Indonesia, Korea, and Oman.

CIMSS is currently expanding its development of timely and operationally relevant satellite training materials to the GeoXO and future JPSS satellites to assist end users (NWS, broadcast media, academia) in maximizing the value of their new capabilities. The vast subject matter expertise at CIMSS allows training to be updated to cover new science products (or advances in satellite technology) as soon as the products become available in the WFOs for the National Weather Service user, or online for the more general user.

Specific Outreach and Training Activities

These highlights capture select examples from a broad portfolio of CIMSS education and outreach activities conducted under NOAA funding to support NOAA's education and outreach goals. Other accomplishments in this portfolio include:

- Developed new and innovative methods of online training in support of professional development of weather forecasters and K-12 teachers.
- Refined educational activities that facilitate the use of satellite observations from all NOAA missions in K-12 Earth science education.
- Created dynamic content for the CIMSS website and continued to distribute data products on tropical cyclones, volcanic eruptions, clouds, winds, sea ice, and other topics.
- Conducted in-person training visits to NWS forecast offices as requested.
- Offered remote sensing schools to the international community annually.
- Expanded the number of distance learning modules aimed at helping to prepare tomorrow's forecasters for the next generation of meteorological satellites including modifying/updating existing training modules with guidance from Science and Operations Officers (SOOs) at NWS WFOs and the NWS Forecast Decision Training Division (FDTD).
- Continued participation in the Virtual Institute for Satellite Integration Training (VISIT) program in the form of live training on a variety of topics, including NUCAPS and Gridded NUCAPS data, GOES-R IFR Probability fields, Above-Anvil Cirrus Plumes (AACP), Mesoscale Convective Vortices, NOAA/CIMSS ProbSevere (v.2 and v.3), LightningCast Probabilities, Troughs of Warm Air Aloft (TROWALs).
- Produced timely blog posts focused on satellite data and products. A subset of the nearly 1600 CIMSS blog posts since 2020 were forwarded to the forecast office(s) that fall within the geographic region of the event discussed to enable just-in-time training for forecasters while events are fresh in mind.
- Demonstrated new CIMSS products at the Hazardous Weather Testbed.

- Developed Peer-to-Peer training in the form of NWS Forecaster-led training webinars, in which the forecaster describes how satellite data helped in their decision making. These webinars are outlined at this CIRA-sponsored link.
- Created imagery for WMO training events co-sponsored by NOAA/GOES-R, mostly for WMO Regions RA-III and RA-IV.
- Participated in AMS Satellite Meteorology Oceanography and Climatology (SATMOC) committee Short Courses.
- Trained US and international stakeholders on NOAA Flood Products, including vital engagement with stakeholders as floods are occurring.

Several other activities specifically target underserved and frontline communities:

- Engaged and nurtured a diverse pool of prospective STEM students by expanding the highly successful satellite virtual science fairs to include all NOAA and NASA missions.
- Waived registration fees to attend the CIMSS satellite summer camp for members of underserved communities.
- Conducted joint education activities with MSIs through our collaboration with STAR's CESSRST.
- Generated and disseminated the MIMIC-TPW2 real-time water vapor imagery through the CIMSS website to support forecasters in the Gulf of Mexico, including predominantly Latinx researchers in Puerto Rico.
- Offered a series of weekly teleconferences with the forecasters in Pago Pago to discuss satellite applications to forecast problems at that office.
- Participated (in-person) in international training courses to increase access to NOAA satellite data and products in developing countries.
- Supplied training in the interpretation of sea ice and polar wind vector imagery to indigenous communities across the Arctic.

The CIMSS website and training materials are also extensively used by non-profit and private sector entities. While it is difficult to track all the individuals who have used freely available CIMSS training resources, two anecdotes about recently established collaborations in the aviation sector highlight the value of these resources. A few years ago, CIMSS was contacted by researchers at Boeing regarding educational materials posted on the website about how turbulence can be detected in geostationary satellite imagery. Shortly after this initial contact, CIMSS and Boeing were awarded a joint Department of Energy (DOE) Advanced Research Projects Agency-Energy (ARPA-E) grant to apply machine learning to routinely identify turbulence using satellite observations. Similarly, researchers from Google learned about CIMSS research to identify the signatures of thin cirrus clouds spawning a collaboration to detect contrail cirrus and investigate methodologies for adjusting flight paths to reduce these clouds that contribute to the atmospheric greenhouse effect.

Beyond these specific examples, CIMSS scientists frequently receive unsolicited positive feedback from private sector entities about how they have benefited from the information and training resources we provide. For example, in 2022 a NWS forecaster described the CIMSS GOES Realtime Weighting Function webpage as "*A great resource! Thanks for the new page and interface*." Likewise, in a June 2020 Forbes article about Tropical Depression Cristobal, former American Meteorological Society president Dr. Marshall Shepard noted that CIMSS "*provided some outstanding historical context on their Facebook page*." Finally, the Australian Met and Oceanic Society referred to McIDAS as "*a real game-changer in forecasting*" on page 11 of their recently published anecdotal history of weather and forecasting for the Australian tropics.

4.4 Science Management Plan

4.4.a How does the Institute identify new intellectual opportunities?

The primary mechanisms by which CIMSS identifies new intellectual opportunities are through frequent interactions with NOAA and new federal funding opportunities, including infrastructure and supplemental announcements. Internal campus resources such as those provided by the Wisconsin Alumni Research Foundation (WARF) and SSEC seed funding are also sometimes used to support innovative projects initially, with a goal of seeking external funding to continue the research. Many of these efforts subsequently lead to fully funded proposals. The AOSS library maintains a list of upcoming funding opportunities and regularly shares agency announcements with researchers.

CIMSS scientists employ a wide range of formal and informal methods to identify the specific research directions to pursue under these new opportunities. Elements of this process were articulated in Section 4.1.e and include:

Internal Brainstorming: The CIMSS Director holds monthly PI meetings to discuss new or evolving NOAA priorities for research and operations, upcoming meetings, deadlines for product delivery, and agency announcements of opportunity. PI meetings are also a forum for sharing recent research results.

Interactions with NOAA: CIMSS recognizes the importance of communication as it pursues new research opportunities and collaborations with NOAA. These conversations are critical to developing a strong research program that meets the needs of NOAA. The CIMSS Director and Executive Director attend and participate in the annual CI director's meeting and our financial administration team attends biannual administrator meetings. We frequently participate in additional side meetings at society annual meetings and host the managers of relevant programs to foster discussions and create connections. Through these activities, CIMSS seeks to enhance communication and collaborations with NOAA to help fulfill its strategic mission goals.

Meetings, Workshops, and Site Visits: CIMSS scientists travel to present papers at numerous conferences, workshops, and symposia, both nationally and internationally. These face-to-face interactions are excellent sources of new ideas and often lead to collaborations. For example, to maximize the benefit of our TC research to the public, CIMSS identifies new research directions based on priorities of the TC forecasting community identified through meetings, workshops, conference interactions, and site visits to prominent TC entities such as the NHC and JTWC.

i. What is the university's policy on licensing/patenting intellectual property?

Guidance concerning intellectual property is provided by the OVCR. UW researchers are required to disclose inventions created while carrying out research using any university funding or using university premises, supplies, or equipment. The OVCR is responsible for evaluating UW invention disclosure to determine who has rights to the invention as laid out by federal rules, contracts, or other obligations. In some cases, UW inventors may retain rights to their inventions or petition the federal government to obtain these rights. More information can be found on the invention disclosure page.

If patenting and licensing is the determined next step after invention disclosure review, researchers work with WARF to finalize efforts. WARF provides royalty payments to Madison inventors and provides generous support to the campus and its many programs.

ii. What barriers exist to successfully transition research products into commercial applications?

We have not identified any specific barriers to transitioning research products into commercial applications.

iii. How does the CI account for successful research to operations/intellectual property development activities in its financial record-keeping?

UW-Madison works with WARF, a separate, not-for-profit, patent management and licensing office, to evaluate innovations that arise out of the University's research activities. For innovations that WARF protects, they maintain financial records related to intellectual property and licensing revenue.

iv. How and when does the Institute share environmental data collected/created by PIs?

Since distributing environmental data is a core element of CIMSS mission, describing all aspects of our data distribution system consumes considerable space. We provide a brief overview and some illustrative examples here, but additional details are provided in Section 6.7.

CIMSS policies regarding data sharing reflect those of NOAA that useful data '*should be visible, accessible, and independently understandable to users except where limited by law, regulation, policy, or by security requirements.*' To realize this goal, CIMSS has access to unique end-to-end satellite data processing capabilities that include all aspects of data analysis from downlink and ingest to processing and visualization to applications and assimilation into NWP models. The on-site presence of NOAA scientists further allows CIMSS to collaborate directly with NOAA offices to transition our research products to NOAA operations and fully realize the benefits of these satellite products. Finally, the educational resources available at UW afford CIMSS the opportunity to develop high quality tools for training professionals and the public. Together, these capabilities enable CIMSS to fulfil its mission to provide timely, accurate, and reliable satellite data to support the nation's weather needs.

Examples of the many data products that emerge from CIMSS research were provided above. Access to these data is facilitated by computational resources at SSEC that include several large High-Performance Computing Clusters (HPCCs) and high-performance Lustre File Systems for the purpose of executing geophysical parameter retrievals and archiving the resulting products. These compute and storage resources are paid for in part by many projects funded by NOAA, and SSEC. This shared resource allows several groups to take advantage of idle processing cycles and maximize the use of their project funds. The largest HPCC at SSEC is called The Supercomputer for Satellite Simulations and Data Assimilation Studies (S4). S4 is the third iteration of a HPCC that was first funded by NOAA in 2012 to allow more streamlined access to compute infrastructure intended to be used for data assimilation experiments with the latest available NOAA NWP models. The latest iteration was installed in 2018 and brought into service in 2019. The 2019 S4 update consists of 2,560 processing cores, 15 TBs of memory and 4 PB of storage. Combined with the second-generation system installed in 2014, the number of processing cores available is 4,160.

SSEC/CIMSS uses these systems to distribute more than 3.5 petabytes of satellite observations and derived geophysical data products per year via several mechanisms. Data are provided to CIMSS scientists using direct filesystem access, McIDAS Abstract Data Distribution Environment (ADDE), file transfer protocol (ftp), ftps, http(s), Local Data Manager (LDM), and GRB fanout. Many ingested datasets utilize advanced message queue protocol (amqp), to provide events to data users to minimize latency and efficiently initiate data transfers. Data are distributed to the science community via the Internet Data Distribution (IDD) service which is managed by Unidata. GRB data are also relayed to Unidata using GRB fanout and made available via ADDE, and LDM.

An important element of ensuring that data remain accessible and reusable is implementing protocols to keep data secure and uncorrupted. The UW data sharing and cybersecurity policies can be found here. All UW-Madison employees are required to complete mandatory cybersecurity training annually and campus IT staff continuously monitor campus computing systems to identify fraudulent use. To ensure the security of CIMSS data products, SSEC imposes additional measures that include a firewall and a single closely monitored entry hub to gain access to compute servers.

4.4.b What are some recent examples of data sharing?

The Community Satellite Processing Package (CSPP) processes raw data streams received from low earth orbiting satellites (CSPP LEO) and geostationary satellites (CSPP Geo). Users running CSPP software can generate low-level radiance products and imagery in near real-time, and further process the data to generate higher level retrieved products. For many users, this offers reliable access to low-latency observations that could not be obtained otherwise, for use in critical applications such as NWP, environmental monitoring and nowcasting. Software is distributed as self-contained binary packages that are easy to install and run, with test datasets and user documentation also provided. Generally higher-level product packages are created using algorithms developed by NOAA-funded science teams, encapsulated by CSPP-developed logic, and bundled with supporting libraries. Dynamic ancillary data is staged on servers at CIMSS and automatically downloaded as needed. All software is publicly available and free to use.

CSPP supports a very large number of products including wildfires, flooding, volcanic ash, lightning, aerosols, volcanic ash, cloud properties, fog, winds, rainfall rate, atmospheric profiles, trace gases, stability indices, surface properties, snow and ice, and space weather. CSPP software is widely used in the U.S and abroad to process sensor data from JPSS, GOES-R series and other satellites. Users include NOAA (including the NWS), NASA, U.S. military, international meteorological and space agencies, disaster response agencies, receiving station vendors, weather services providers, aerospace contractors, aviation industry, power industry, space weather monitoring groups, and the research community. CIMSS supports this user community through multiple channels, including email and a user forum. An in-person CSPP User Group Meeting is held every two years, most recently in 2022 in Madison, Wisconsin, allowing users to exchange information on applications and research, and to connect with the CSPP team.

Another example of CIMSS data sharing is the RealEarth data discovery and visualization platform that allows quick, continuous visualization and sharing of real-time Earth observation imagery and data in a common and familiar map-based interface. The system is built with geographic information system (GIS) awareness coupled with the needs of meteorological and atmospheric scientists for real-time data and animations. It supports OGC (Open Geospatial Consortium) restful endpoints for WMS, WMTS, WFS, and GeoJSON, along with KML so that users may stream *RealEarth* content into their own applications. Many land, oceanic, and atmospheric products are available to be layered, compared, and animated in time-series loops. Several projects within CIMSS and SSEC utilize *RealEarth* in their presentation of data. These include ProbSevere, LightningCast, NGFS, GeoAquaWatch, JPSS Fire and Smoke Initiative, JPSS Floods Initiative, SAR Flood Mapping, and many others. With over 1,100 active data products, over 4,000 registered users, and over one million unique IP addresses served since 2016, RealEarth has proven value with a solid and expanding user-base.

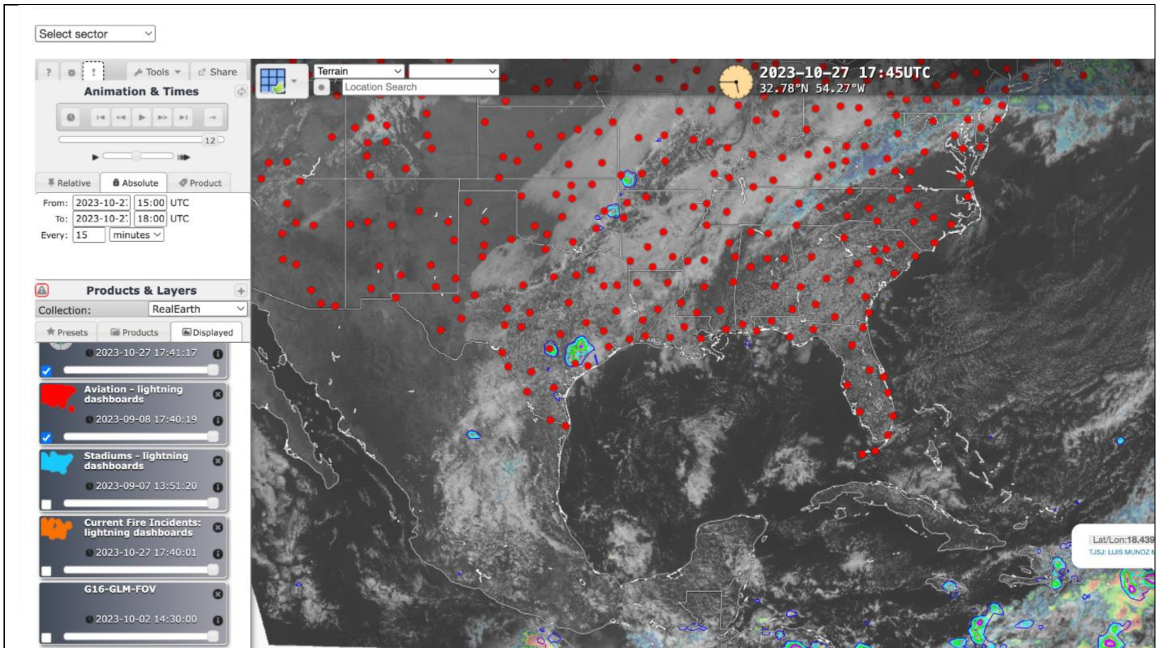

FIGURE 4.19: RealEarth visualization of ABI radiance based LightningCast probabilities (cyan contours) and U.S. airport locations (red dots).

4.4.c How does the Institute monitor and encourage compliance with public access policies and plans? Data sharing plan?

CIMSS fully supports, and enforces, NOAA and federal government policies to increase access to the results of federally funded scientific research, including both data and publications resulting from that research. CIMSS pre-award and post-award processes align with these goals of ensuring openness and transparency in publicly funded research from NOAA and all federal agencies.

Our proposal development and review process, includes educating principal investigators on their responsibility to: meet all federal data management policies, manage data according to standards and best practices, and deposit manuscripts into the appropriate federal repository and data, into the appropriate archive, where warranted. After awards are made, Atmospheric, Oceanic, and Space Sciences (AOSS) Library staff perform bi-annual checks to ensure that all publications with CIMSS lead or co-authors are deposited in the appropriate repositories. Staff also hold bi-annual workshops with researchers to discuss policy updates from common funding agencies, provide guidance regarding how to use the repositories, and answer questions. Since the use of researcher identifiers like ORCID is a best practice for meeting open science guidelines, the library also holds consultations to assist researchers in creating and updating their ORCID records.

All proposals submitted through the CIMSS Cooperative Agreement are also required to include formal data sharing and management plans. These plans ensure that all CIMSS projects strictly adhere to NOAA's latest guidance on data and publication sharing articulated here. Since CIMSS research supports several different programs, each with specific data handling and sharing requirements, data management plans for individual submissions are tailored to address the specific requirements of each program or solicitation. An outline of a standard CIMSS Data Management Plan that summarizes all the information provided to the sponsor is provided as part of the CIMSS proposal template in Appendix C below.

In short, CIMSS data stewardship practices ensure that our research data is discoverable, accessible, and reusable in the longer term. While federal policies tend to be updated frequently, CIMSS administrators and AOSS library staff ensure that the latest requirements are consistently met.

4.4.d What are your strategies to make federally funded publications, data, and other such research outputs and their metadata, are findable, accessible, interoperable, and reusable, to the American public and the scientific community in an equitable and secure manner?

Ensuring that research results are findable, accessible, interoperable, and reusable to the American public and the scientific community is a top priority at CIMSS. Open science is critical for advancing out understanding of weather and climate and maximizing the benefits of this knowledge to the public. CIMSS employs a multi-faceted strategy to ensure that our research outputs are accessible to all.

First, CIMSS provides several conduits for discovering and exploring the satellite products we produce. Most can be quickly accessed through the CIMSS website. One of the best resources for discovering new products through insightful commentary about real-world events is the CIMSS Satellite Blog. Established in 2006, the CIMSS Satellite Blog has become one of the more well-regarded sources of satellite training material, not only for operational meteorologists (its original intended target audience), but for academia and even public outreach. The blog highlights several products developed at CIMSS through attractive visuals and provides links that direct users to more general visualizations of these products and access to the data. Other examples of CIMSS resources for discovering data products include:

> *CIMSS Tropical Cyclone Site:* A website visualizing numerous tropical cyclone environment intensity and tracking products with corresponding descriptions and links to data.
> *RealEarth*: A data discovery and visualization platform developed at SSEC to allow quick, continuous visualization and sharing of real-time Earth observation imagery and data in a common and familiar map-based interface available to the public.
> *CSPP GeoSphere*: An interactive, tile-based website has been developed to display GOES-East and GOES-West imagery with very low latency available to the public. Data is acquired on antennas located on the AOSS rooftop and processed using containerized CSPP Geo software running on local cloud-equivalent infrastructure. The website and processing chain have also been demonstrated in the Amazon and Google clouds.

Enabling broad participation in weather and climate science through wide access to satellite data is a core value at CIMSS. To facilitate this process, CIMSS invests considerable effort into designing and developing software for processing, analyzing, and visualizing meteorological satellite data. Our publicly available data discovery software can ingest a wide variety of geostationary and LEO products, enabling high-quality, informative visuals to be generated quickly by users with minimal technical knowledge or computational resources.

The Man computer Interactive Data Access System (McIDAS) is a flexible software package for imaging and analyzing satellite data, comparing numerous data types within a single display, and evaluating satellite derived products. McIDAS is used worldwide in research institutes, international weather services, universities, the private sector, and government agencies, such as NASA and NOAA. Within NOAA, McIDAS is used by STAR, OSPO, ESPC, NCEI (CLASS), and NWS to support both research and operations. McIDAS can read a variety of data in netCDF or HDF format and is being enhanced to interface to Python scripts and libraries, which will enable access to data from additional satellites, improve analysis functions, and enable the use of more sophisticated scripting using Python.

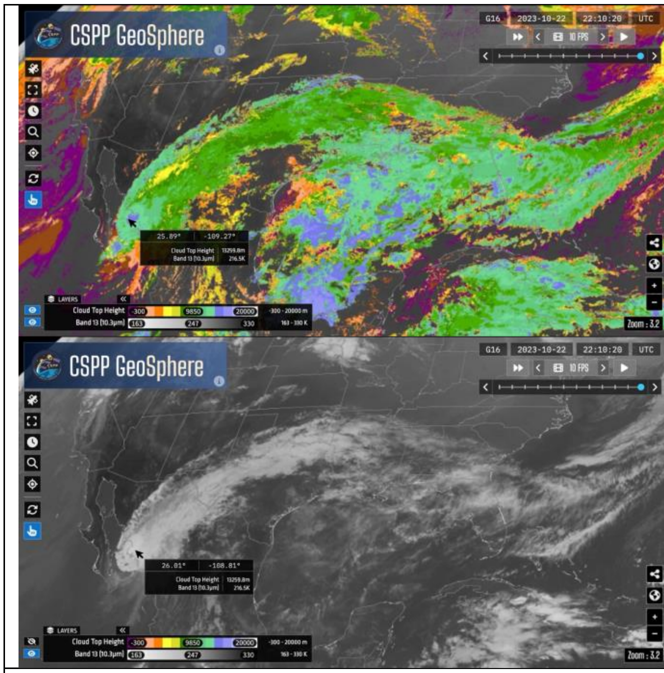

FIGURE 4.20: CSPP Geosphere visualizations of cloud top height (top) and 10.3 μm brightness temperature (bottom).

The final step in ensuring that CIMSS data are interoperable and reproducible is publishing the theoretical basis behind all algorithms, product validation, and research results in the refereed literature. In addition to depositing papers in appropriate sponsor repositories, when publishing the results of CIMSS research, our priority is to seek options that allow open access. More than half of CIMSS publications (57%) are published with what is usually termed 'gold open access' (no option to require a subscription, no waiting period or embargo, and Creative Commons license). An additional 35% are published in journals that allow green or bronze level open access (e.g., early online release or limited embargo period). Of the small remainder, most can be accessed through sponsor repositories.

Figure 4.21 shows the fraction of CIMSS papers published between 2020 and 2022 that are open access or, if not, accessible through a publication repository. 98.6% of CIMSS co-authored journal articles from 2020-2022 (2023 omitted due to the 1-year embargo period that is currently permitted before allowing public access) are available to the public one way or another. Furthermore, federal repositories require Section 508 compliance, making publications accessible to many with disabilities. While these works are findable through standard journal search applications, the AOSS Library also maintains a complete citation database of all CIMSS publications here that is accessible to the public. We are currently migrating this database to a newer, more user-friendly software that should allow for easier navigation through the database soon.

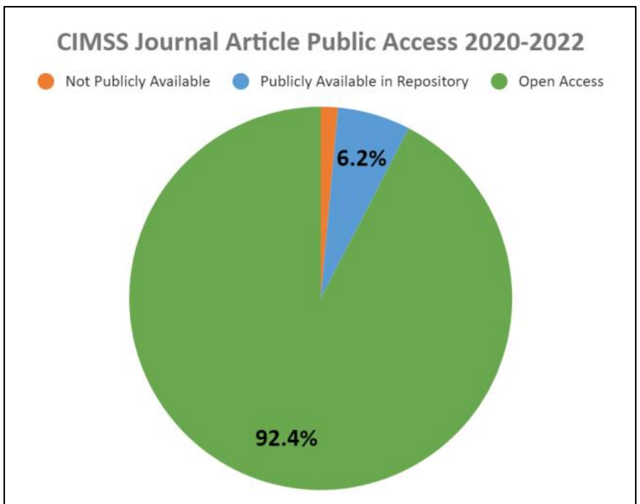

FIGURE 4.21: Public access to CIMSS publications from 2020-2022.

4.4.e What are some recent examples of intellectual opportunities?

CIMSS researchers are very successful at identifying new opportunities through workshops, extramural funding announcements, industry partnerships, and internal (campus/departmental) funding opportunities. Many of these opportunities allow us to pursue research that aligns with the emerging areas of research including AI/ML, climate studies, and next-generation satellite observing systems. Some specific examples from 2020 - 2024 include:

- Working with the aviation sector to apply AI/ML methods to identify turbulence in geostationary satellite observations trained using commercial aviation turbulence records.
- GOES Proving Ground/Risk Reduction support to explore the use of data fusion to optimally combine high-spatial resolution imager data with high vertical resolution sounder observations.
- Participation in an international research effort called the International Satellite Cloud Climatology Project – Next Generation (ISCCP-NG) to create a uniform, calibrated, geostationary satellite record and associated cloud products.
- ARPA-E investment in identifying contrails in satellite imagery, evaluating their impact on climate change, and developing mitigation strategies with NWP fields (with Boeing).
- Internal UW/SSEC funding to deploy the prototype Absolute Radiance Imager (ARI) to measure far-infrared spectral emissivities for snow and ice surfaces in two Madison winters.
- Utilizing NASA funding to adapt LEO cloud and aerosol algorithms to geostationary observations to augment the program of record (PoR) of key environmental observables to support future satellite missions.
- Successfully proposing two NASA Earth Ventures missions, the Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) and Polar Radiant Energy in the Far-Infrared Experiment (PREFIRE), that demonstrate the potential for small satellite platforms to make microwave and far-infrared measurements that may support future NOAA applications related to tropical cyclones and atmospheric soundings.

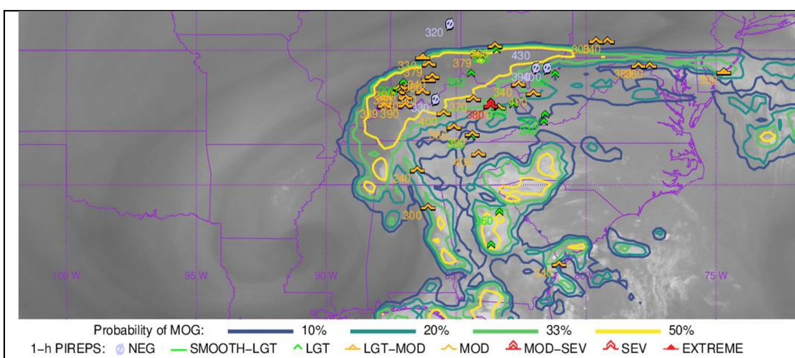

FIGURE 4.22: GOES-16 water vapor band imagery at 1720 UTC on February 15, 2021, showing moderate turbulence probability (contours) with pilot turbulence reports overlaid (symbols).

Working with the aviation sector provided a recent opportunity to develop new applications of AI/ML centering on identifying turbulence using contemporary geostationary satellite observations. Turbulence is a significant public safety risk and can lead to economic impacts through associated repair costs and flight re-routing requiring added fuel costs. Turbulence forecasting via numerical weather prediction has made progress over the past decades, however major hazards remain undetected. CIMSS research leverages geostationary satellite imagery to develop new approaches with high spatial precision and low latency to reveal structures associated with turbulence not captured by numerical models alone.

The turbulence research at CIMSS processes geostationary imagery using deep learning methods, which offer a new and *comprehensive* way to quantify the hazards posed by turbulenceforming atmospheric structures that surpasses the skill of previous heuristic methods (Wimmers et al., 2018). Our deep learning turbulence prediction model uses integrated GOES ABI imagery and National Centers for Environmental Prediction (NCEP) Global Forecasting System (GFS) fields as inputs to produce high-accuracy multi-layer nowcasts of turbulence at cruising altitude. The model clearly identifies GOES ABI-resolved deep convection and major gravity waves in their association with turbulence, whereas the GFS input fields contribute to identifying areas of significant wind shear in dry, featureless downwelling air that can be highly turbulent. The GOES ABI+GFS turbulence product began experimental real-time processing at CIMSS in February 2021 (distributed via website and AWIPS) and has been extremely successful in matching (and contextualizing) areas of real-time turbulence reports (Figure 4.22). This demonstration has resulted in a potential path to operational implementation in 2024 pending U.S. congressional budgets.

Despite being a prototype, CIMSS turbulence products already reach several stakeholders including the Honolulu Forecast Office, the Alaska Aviation Weather Unit, the Aviation Weather Center, the Central Weather Service Units that support regional airspace management, Boeing, and the major U.S. passenger air carriers represented by the Aviation for America (A4A) organization. Forecasters utilizing the experimental turbulence processing have noted the value the turbulence product adds to their forecasts and flight routing showcasing the value of AI/ML advances for better serving the aviation sector to protect public safety and maximize safe and efficient flight routing.

Another recent intellectual opportunity was stimulated by Great Lakes region conversations with the UW Center for Climatic Research and Sea Grant Institute. CIMSS researchers have created subsets of the long PATMOS-x cloud record over the Great Lakes to examine trends in cloud cover. The results suggest that cloud cover is generally decreasing over the Great Lakes but this result masks opposing trends in liquid and ice clouds in some regions (Figure 4.23). Over Lake Superior, in particular, there is strong evidence that liquid clouds are increasing at the expense of ice clouds.

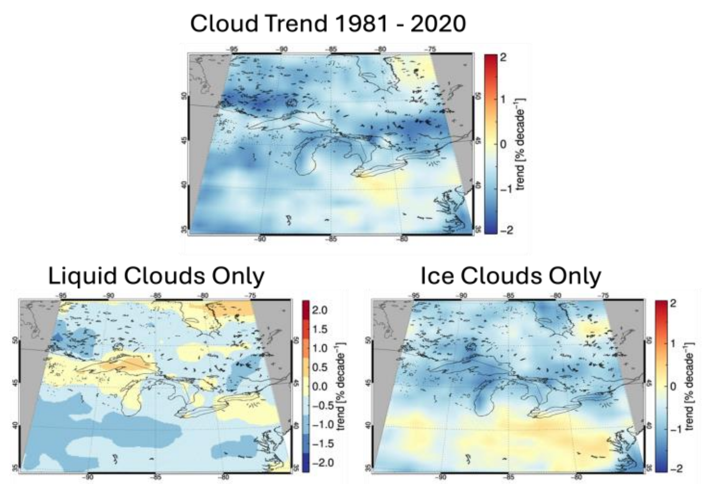

FIGURE 4.23: Cloud Trends over the Great Lakes from 1981 – 2020. Overall cloudiness is decreasing at the rate of about 1% per decade. However, liquid cloud cover is increasing in some areas (e.g. Lake Superior) at the expense of ice clouds.

As a final example, CIMSS scientists recently partnered with the Georgia Department of Natural Resources to model the impacts of flooding and hurricane winds along the 11 coastal counties. Figure 4.24 examines the potential impacts of anticipated flood changes in the late 21st century when climate change and sea level rise are included in the hazard development. For the coastline, we found the dollar losses could increase from three times higher to as much as eight times higher than today’s expected dollar losses from a hurricane. Stream and riverine flooding could see losses in some communities that are double the losses we see today.

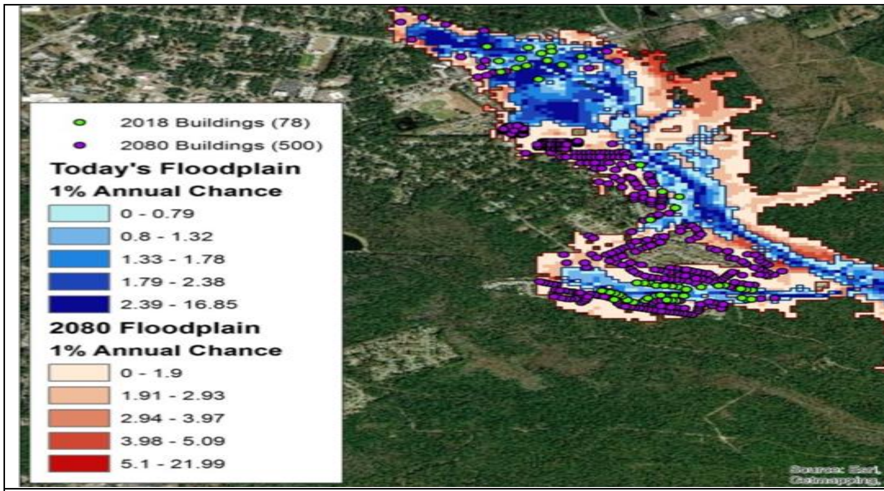

FIGURE 4.24: Changes to future floodplains in coastal Georgia and the potential impacts to future citizens.

4.4.f What is the strategy for new starts (projects, techniques, campaigns, etc.)?

CIMSS employs three mechanisms for new starts: internal seed money, articulating new ideas or offshoots of existing research to NOAA leadership, and exploring private sector partnerships.

Growth Toward Applied Research: Frequently new opportunities arise from basic research when searching for promising offshoots of existing projects. As an example, our current turbulence research program began as a small component of a NASA ROSES grant in the mid-2000s to investigate the use of meteorological satellite imagery to support aviation safety. Researchers pursued image processing methods to relate image gradients and wave patterns to aircraft turbulence reports. This work progressed slowly, but built up the necessary, related expertise in data analysis, derived product creation, and especially the basic science of aviation turbulence. They continued these efforts by adapting previous methods to the higher resolution of the GOES-R AWG program (Wimmers 2019). Around 2019, our researchers noted and applied a recent breakthrough in convolutional neural network algorithms to their existing aviation turbulence dataset. The combination of this new machine learning technique and our existing subject matter expertise created an opportunity for developing a more accurate and user-targeted turbulence estimation product. This effort was then supported by the NOAA ROSES program and has since been selected by the NESDIS for further development and eventual transition to operations.

Seeking Opportunities with Private Sector Partners: In the past several years more new projects have started with private sector partners through vehicles such as Small Business Innovation Research (SBIR) or Small Business Technology Transfer (STTR) grants. While not directly involved with NOAA, these typically help create technologies and capabilities that feed back to help our mission with NOAA. For example, in 2023 we worked with MyRadar and Boeing to develop short-term forecasting applications for 3D atmospheric visibility and contrail detection, respectively. Each of these will also lead to techniques that improve cloud height retrieval, which in turn will generate opportunities to improve the scope, accuracy, and portability of future cloud retrieval products at CIMSS.

UW Seed Funding: The UW also supports innovation, especially transformative ideas that combine expertise from multiple disciplines to solve societal problems. Some CIMSS researchers have also utilized WARF innovation grants to initiate new research. These grants offer seed funding for up to two years to develop new capabilities that attract partners to work with us. These new capabilities bring the potential for garnering extramural support from NOAA or other existing programs and helps steer CIMSS research in new directions. For example, the Cloud AWG recently teamed with civil engineers and computer scientists to develop new methods to account for uncertainty in cloud forecasts on solar power generation. Methods explored in that study are being implemented to improve surface solar flux estimates from geostationary satellites.

Center Seed Funding: Though internal resources are more limited, SSEC/CIMSS also provides smaller opportunities to investigators seeking seed money to explore new research directions, specifically targeting topics of interest to NOAA and NASA. SSEC recently concluded a large initiative called SSEC 2022 that provided seed funding for several innovative studies related to NOAA priorities. One study explored new methods for incorporating damage and loss modeling directly into hurricane forecasts to help decision makers prioritize responses. Another study developed a new CNN approach for denoising VIIRS day-night-band observations and detecting cloud layers in geostationary imager observations.

Infrastructure: In some circumstances the potential for new starts begins not just with a new idea but also with new infrastructure. For example, in 2020, in anticipation of future AI/ML-related research needs, the SSEC acquired a set of three new GPU-enabled servers to be shared on the center's science computing cluster. A community of machine learning researchers then formed at CIMSS to share ideas on new machine learning applications on meteorological satellite imagery, using the new infrastructure as a common practice ground. This informal collaboration then led to separate explorations by researchers to apply machine learning to their existing backgrounds, such as sea ice leads (Hoffman et al. 2021, 2022), tropical cyclone properties (Griffin et al. 2022, 2023; Wimmers et al. 2024), severe weather nowcasting (Cintineo et al. 2020, 2022; Ortland 2023) and contrail detection (Hoffman et al. 2023).

i. How much of the Institute's resources are reserved for new opportunities or bright ideas?

CIMSS has very little flexibility to reserve funds for new opportunities and bright ideas. In the 1980s and early 1990s, approximately 15% of the CIMSS Base Grant was allocated to support 'seed' projects that would likely lead to the development of formal proposals outside CIMSS. However, the budget for such activities has diminished considerably over the past two decades. CIMSS no longer receives Base Grant funding. Our only flexible resources are our Task 1 funds that amount to 3.7% of our research budget, most of which is consumed by administration, education, and outreach costs. Approximately 20% of CIMSS Task 1 budget (about $80k) is allocated to provide seed money for new innovations, often in the form of graduate student support to pursue a new line of research.

Instead, CIMSS researchers pursue other mechanisms to support new initiatives, though many are highly competitive. As a CI, we can leverage other federal funding opportunities such as those from NASA, NSF, DOE, and DoD. We also engage with private sector partners in R&D opportunities to support applications that may eventually find their way to NOAA (e.g., contrails). Finally, we maintain strong communication with our campus federal liaison to advocate for CIMSS and NOAA research in general.

ii. Are these activities Task I, Task II, or Task III projects?

Task 2 funding for new starts is currently very limited owing to the constrained budgets of NOAA program managers. The current emphasis on project-specific one-year proposals limits discretionary funding available for exploring innovative projects that could lead to new discoveries. There are, however, some exceptions. The CIMSS cryosphere group recently supported a PhD student to develop a novel approach for estimating sea ice thickness from passive microwave satellite observations. The GeoXO program is also funding innovative studies into using geostationary sounder observations to estimate 3D winds over the continental U.S. Other than these projects, CIMSS generally funds new innovations through Task 1 or via sources outside of NOAA such as internal seed money and private sector partnerships.

4.4.g What is the demographic structure of the Institute employees?

The UW maintains demographic information at the center level and the data provided in Table 4.1 correspond to all SSEC employees but are representative of CIMSS since more than 50% of SSEC employees work on CIMSS projects. This data does not include 7 graduate students directly supported on CIMSS projects. These students have an academic advisor in the Department of Atmospheric and Oceanic Sciences (AOS), and a science advisor within CIMSS that is part of the student's thesis committee.

As our research portfolio grows, SSEC and CIMSS have worked to recruit a talented new workforce hiring 56 new employees with a range of backgrounds. The demographic makeup of new hires in SSEC since January 2020 is as follows reflecting a shift toward a more diverse workforce across the center that we envision continuing in the future:

Male	35 (62.5%)
Female	21 (37.5%)
White	43 (76.8%)
Asian	4 (7.1%)
Not Disclosed	9 (16.1%)

Female	51	25.0%
Male	153	75.0%
Total	204	

White	159	77.9%
Black	1	0.5%
Asian	19	9.3%
Hispanic	4	2.0%
Unknown	21	10.3%
Total	204	

< 30	13	6.4%
30-49	94	46.1%
50-69	77	37.7%
>70	20	9.8%
Total	204	

TABLE 4.1: Demographic breakdown (gender, race, and age) of SSEC employees in 2023.

i. Does the CI or the university have an effective policy on underrepresented minority participation and retention?

Incorporating the experience, ideas, and opinions from a team with diverse backgrounds has profound benefits for advancing research. CIMSS is committed to increasing diversity within the CI, within the campus community, across NOAA, and in STEM fields in general. We strive to build an inclusive environment, bring new perspectives on mentoring and educating students from diverse backgrounds, and incorporate diverse perspectives into our research.

This philosophy reflects established policies of the UW that values the contributions of each person and respect the profound ways their identity, culture, background, experience, status, abilities, and opinion enrich the university commitment. UW is committed to pursuing excellence in teaching, research, outreach, and diversity as inextricably linked goals, and fulfills its public mission by creating a welcoming and inclusive community for people from every background. Specific examples of campus-wide "Diversity Issues & Accountability" are listed here.

To promote the inclusive environment required to retain underrepresented populations in AOSS building, we engage in open dialogues to recognize isolating circumstances, understand barriers to participation, and build community. Some specific examples of activities CIMSS has been involved in are:

1. Promoting a diverse population in the AOS Research Experience for Undergraduates (REU) Program
2. Contributing to startup packages for AOS faculty hiring initiatives: 9 new faculty hired in 6 years (7 of whom are women or under-represented minorities, or both)

3. AOS AGU Bridge Program Partner—provides diverse undergraduates the opportunity to have an alternate, mentored pathway to graduate school admission
4. Building-wide (multi-department) participation in Unlearning Racism in Geosciences program (URGE)
5. Developing a building-wide (multi-department) Code of Conduct, which also applies to embedded NOAA scientists
6. Encouraging all employees (and providing leave time) to attend the WISELI (Wisconsin Inclusion in Science & Engineering Leadership Institute) Breaking the Bias Habit Workshop, offered to anyone campus
7. Implementing and supporting affinity groups (i.e., SSEC Women and Non-Binary group; Women in AOS)
8. Waiving registration fees to ensure diverse attendance at the CIMSS Summer Workshop
9. Hosting undergraduate and graduate students from diverse backgrounds at the NESDIS CI Research Symposium (formerly CoRP Symposium)

ii. How does the CI integrate with minority-serving institutions and Educational Partnership Program Cooperative Science Centers (whether CI partners or not)?

CIMSS has an existing memorandum of understanding with Hampton University to engage students from diverse backgrounds through joint mentoring and internship opportunities. We establish additional partnerships with other Minority Serving Institutions across the country through our close connections with NOAA CESSRST. For example, the 2023 CoRP Symposium highlighted research presentations from the NESDIS CIs and CSCs, providing a collegial atmosphere for collaboration discussions that included representation from diverse groups. CIMSS also hosts CSC NERTO students, advised by federal employees stationed in Madison, to expand scholarship and internship opportunities for students from under-represented groups. This article, written by a recent communications student intern at CIMSS, highlights one such experience. Recent hires at AOS, particularly Prof. Mayra Oyola-Merced, a graduate from two MSIs, open additional avenues for closer engagement with these institutions in the future.

4.4.h Does the CI conduct recruitment to improve diversity? If so, provide a description of the recruitment strategy and where the CI has been successful.

i. What is provided for human resources development (recruitment, rewards, training, etc.)?

CIMSS utilizes UW tools for human resources development, including the Office of Human Resources Recruitment Toolkit and the Office of Human Resources Professional Development guide. The UW is committed to attracting, retaining, and rewarding a highly qualified and diverse workforce, both now and in the future. The university's job framework and total compensation program support and facilitate these important goals by:

- Encouraging excellence by rewarding individual contributions that support the university's mission and goals.
- Supporting competitive and equitable compensation practices through a job framework, salary structure and clear and flexible salary administrative guidelines.
- Establishing a foundation for career progression both within and across job groups and sub-groups.
- Developing a comprehensive benefit package that supports the well-being of our employees and is competitive and market informed.

UW-Madison has a market-informed title and salary structure to attract, retain, and reward employees as part of the Title and Total Compensation Project. Every university job has been assigned to a salary grade in the salary structure. More information on the Title and Total Compensation Project can be found here.

ii. How are CI employees provided training in HR issues (e.g., benefits, retirement)?

Upon hire, new employees are provided with the opportunity to attend a UW Benefits 101 class to learn more about the benefit options available as a university employee. This class is also available to current employees. Additionally, within the center there are three staff that can answer questions regarding benefits and retirement (an Administrative Director, an HR Manager, and an HR Generalist) for employees at any time. SSEC also maintains both a public *Research Support Services* and an *Employees Only* website that contains a great deal of support information for employees, including accounting information, purchasing guidelines, computing technical support, and Web information.

iii. Do CI employees participate in general NOAA HR training when appropriate?

No. CIMSS Employees are not required to participate in NOAA HR Trainings since we are not located at a NOAA facility and are not involved in the hire of NOAA employees.

iv. How are CI employees, particularly the most junior, provided with future employment training to be successful upon leaving the CI?

CIMSS works with degree granting programs at UW-Madison, such as the Department of Atmospheric and Oceanic Sciences, to be closely involved in the development of undergraduate and graduate students. By involving students in CIMSS research, the next generation of scientists receives hands-on training in the research process, from implementation to conclusion. Students working with CIMSS researchers are involved in group meetings and projects within active research teams to conduct world-class research, while also being able to connect with NOAA scientists, while completing their degrees.

Post-degree, CIMSS can continue hands on training through research internships and post-doctorate research appointments. Many post-degree trainees continue to become full-time research staff at UW, NOAA, or other research entities. Early career scientists, both post-degree trainees and new staff researchers, at CIMSS are supervised by experienced researchers who can mentor them on how to write proposals, conduct research, write publications, and present at scientific meetings and conferences.

The Atmospheric, Oceanic and Space Sciences Library also offers seminars and workshops for students and early-career scientists on skills important in the research field, such as writing workshops for developing research questions and scientific writing for publications.

v. What actions has the CI taken to ensure pay equity?

The Space Science and Engineering Center leadership reviews employee pay three times a year; this includes reviews for bonuses, performance increases, parity adjustments, equity adjustments, and market adjustments (both retention and competitive adjustments). Part of the parity review involves reviewing the salary ranges of employees in the same title to ensure an appropriate range. When applicable, SSEC will request a parity adjustment for an employee following UW-Madison's Salary Administration Guidelines.

The AOSS community, which includes CIMSS, recognizes that scientific productivity and educational success are enabled by a respectful, professional, and supportive environment. The entities within AOSS have adopted a Code of Conduct to foster an environment in which everyone may reach their full potential, whether in research, education, public outreach, administration, or academic studies. The code of conduct applies to all members of the AOSS community, including students, staff, faculty, and visitors, regardless of location when interacting with other AOSS community members or as a representative of AOSS (whether inside the AOSS building or elsewhere on or off campus).

4.4.i What is the state of the financial health of the Institute?

After a period of considerable growth from 1980 to 2010 owing to the rapid increases in NOAA and NASA's Earth observing system, CIMSS has settled into a stable financial situation despite several recent headwinds. CIMSS funding history is presented in Figure 4.25. While funding in 2022 – 24 has been relatively constant, this figure presents examples of two ongoing concerns for our staff. Dips in 2013 and 2017 reflect federal budget cuts (e.g., sequestration). The current political climate raises concerns about the stability of future NOAA budgets and the potential impact to CIMSS personnel. Since NOAA support to CIMSS consists of single year grants that are often too small to fund a single person full time, our 'soft-money' staff are particularly susceptible to year-to-year fluctuations in federal support. The fact that this annual financial support model comprises such a large fraction of our portfolio, poses a challenge for long-term planning of CIMSS' research agenda.

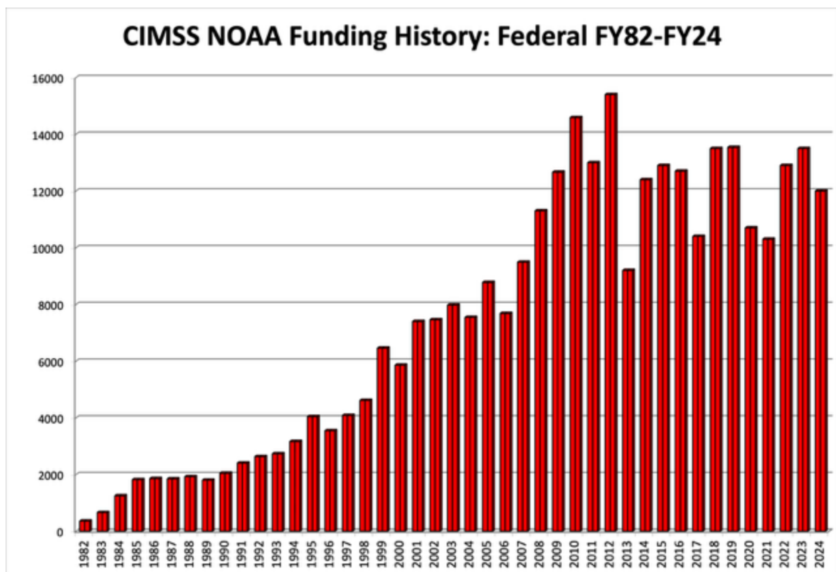

FIGURE 4.25: CIMSS spending history from FY82 to FY23 (anticipated funding for FY24 is included for completeness). Figures do not include NOAA funding obtained from infrastructure and supplemental grants.

Related to this concern is the sensitivity the annual funding model introduces to changes in NOAA's geostationary and LEO programs. CIMSS is particularly sensitive to fluctuations in research funding as programs evolve from their planning phase, through their implementation, launch, checkout, and mature phases. Dips in funding in 2020 and 2021 reflect the maturity of the GOES-R assets that resulted in deep cuts to many algorithm development activities. A multi-year funding model in which such activities transitioned to weather and climate research projects would help provide stability to staff who frequently express concerns about their funding from year to year.

The financial health of the Institute is aided by its position within SSEC, which obtains funding from a diverse set of funding sources. Current SSEC research funding by agency is shown in Figure 4.26. Approximately 40% of SSEC's annual funding derives from NOAA while NASA accounts for nearly 25%. Additional support comes from other federal agencies and a small amount of funding derives from private partnerships.

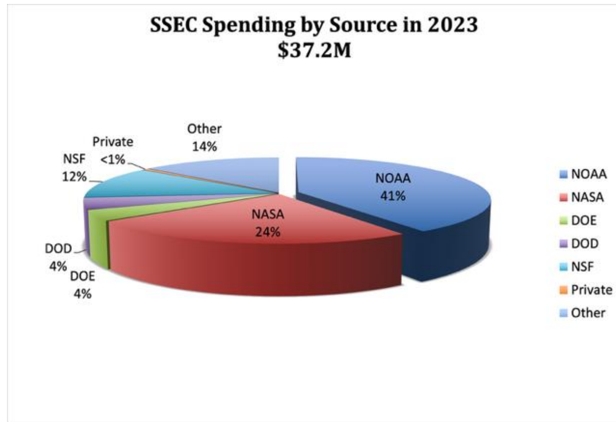

FIGURE 4.26: SSEC spending by agency in 2023.

CIMSS funding in 2024 is anticipated remain at 2022 and 2023 levels. While this is encouraging, it does not address the increasing costs of conducting research owing to salary increases necessary to keep up with increasing cost of living. The increasing costs of doing business effectively reduces the staffing that can be supported with constant budgets. We are hopeful that GeoXO and next-generation JPSS program Risk Reduction and Proving Ground activities will increase support in the coming years to offset these costs.

4.4.j How does the Institute intend to work towards accomplishing its financial goals?

CIMSS will continue to employ a combination of close interaction with NOAA, private sector engagement, and other internal extramural sources to meet its financial goals. CIMSS leadership will continue to work with NESDIS leadership and program managers to align staffing levels and expertise with NOAA strategic goals and initiatives. Several CIMSS researchers have active collaborations with private partners and the SSEC data services team have some established fee for service contracts with aviation and weather companies. We intend to continue growing these relationships as a source of additional revenue to fund innovative research projects at the Institute. Many CIMSS researchers are funded, in part, through other agencies and UW seed grants. These efforts provide additional financial stability for CIMSS research staff and often benefit NOAA interests by developing additional expertise in fields like AI/ML.

CIMSS will maintain its current balanced budget with the assistance of the SSEC administrative team. The SSEC accounting office closely monitors expenditures and staffing in relation to expected income to avoid overspending on any individual research project. The accounting system created and maintained by the SSEC administrative team has an interface that allows all CIMSS project leads and employees to review the status of their accounts monthly. The UW Shared Financial System is used to prepare formal monthly and annual CIMSS financial reports. Monthly effort reporting is reviewed quarterly to assure that spending aligns with project commitments. When hiring needs arise, we first look to see if there is someone within CIMSS available to address those needs before seeking new hires.

CIMSS can maintain financial stability for as long as the task leads continue to win grants, awards, and contracts. To avoid placing the burden of securing funding on just a few individuals, we distribute it among many Principal Investigators (PIs), each of whom lead a small number of projects and oversee a small team. Figure 4.27 shows the composition of CIMSS staff at the end of 2023. More than 30 individual PIs – amounting to about a third of the CIMSS staff – submit proposals and lead research projects. The CIMSS research staff are primarily meteorologists and programmers, but their expertise is wide ranging, providing strong support for a variety of programs. CIMSS conducts its research by building teams to accomplish program goals. The staff can move from one project to another or work on multiple projects to provide expertise and stability to the CIMSS research program. There has traditionally been strong support from the federal government to not only maintain but grow the nation's remote sensing capabilities and we anticipate this continuing as NOAA prepares to launch the next generation of geostationary and LEO meteorological satellites. CIMSS is in excellent position to continue assisting with this effort.

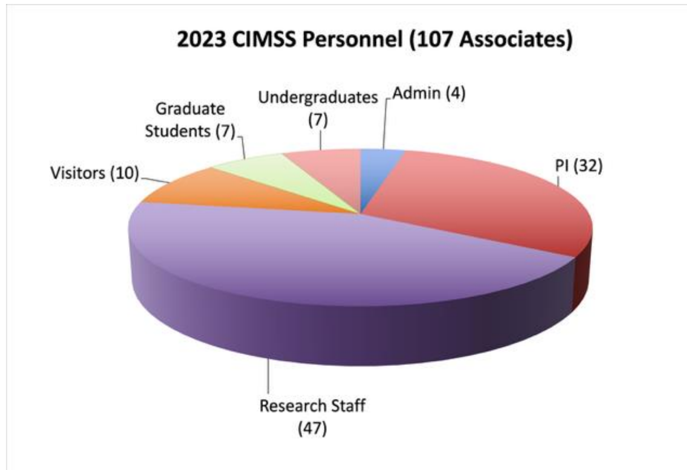

FIGURE 4.27: CIMSS personnel breakdown in 2023.

4.4.k Are there any issues in interacting with NOAA that require attention?

Communication and continuity have historically been key elements to the successful relationship between NOAA and CIMSS. While we continue to meet regularly with NOAA and STAR leadership and program managers, recent turnover in several positions has interrupted progress in some important initiatives beneficial to both NOAA and CIMSS. For example, support for student fellowships, vital to the training of the next generation of NOAA scientists and staff, has been difficult to obtain via NOAA grants that fund projects one year at a time, too short to support a graduate student. Encouraging discussions about reinstating NOAA student fellowships are paused as leadership evolves. Multi-year support for graduate students would also allow some to initiate social science or communications projects.

There is also growing concern about a possible reduced presence of NOAA federal employees stationed at UW-Madison. With no on site NOAA laboratory, CIMSS relies on communication with local federal employees to maintain communication with NOAA. Recent and upcoming retirements threaten to reduce the number of NOAA employees stationed in Madison in the absence of a concrete plan for replacing those positions.

A practical challenge posed by the annual funding model NESDIS employs to support CIMSS projects is a recurring need to submit approximately 50 proposals in the span of about 3 weeks each spring. This not only places an enormous burden on SSEC administrative staff, it makes it very difficult to satisfy NOAA's timelines for project planning and costing information. The confluence of increasingly delayed funding information and earlier proposal submission deadlines adds to the challenge of deriving stable support in an era of tight budgets and a lack of continuity of resources. The late arrival of funding in the federal fiscal year has become the norm resulting in an annual scramble to submit many small proposals over a very short period. This introduces tension between CIMSS, NOAA funding managers, and NOAA's grants division. Moving cooperative agreement funding forward in the fiscal cycle or establishing a mechanism for multi-year awards would help mitigate this situation, though we recognize this is likely a process we cannot change.

4.4.l Are there any issues in interacting with the university that require attention?

CIMSS and SSEC work closely with the Office of the Vice Chancellor for Research (OVCR) to administer the cooperative agreement. OVCR assists CIMSS in navigating any barriers with research administration, purchasing, travel, and human resources. UW-Madison policies are developed to ensure compliance with Universities of Wisconsin and State of Wisconsin statutes, as well as federal processes and regulations governing administration of grants.

CIMSS also enjoys a positive reputation with other campus units, including the Chancellor who recognizes the value of CIMSS weather and climate research. CIMSS research supports everything from individual campus events like graduation and football games to the development of campus sustainability policies. While not guaranteed, it is critical that the university be encouraged to continue to invest in CIMSS success through matching funds in the future.

4.4.m What progress was made towards the performance measures the CI uses to gauge, quantify, and/or evaluate progress on both individual projects and its overall performance?

CIMSS Progress Metrics

Quantitative Metric	2020	2021	2022	2023	Total
Peer-Reviewed Publications	86	89	93	80	348
AMS Annual Meeting Presentations (2021 – 2024)	45	48	45	56	209
AGU Annual Meeting Presentations	41	23	17	24	105
Funded Graduate Students	9	11	11	9	18
MS Degrees Conferred	3	2	2	0	7
PhD Degrees Conferred	2	2	2	2	8
Undergraduate Interns Advised	12	7	7	8	24
Unique Data Products	N/A	N/A	N/A	N/A	63
Proposal Success Rate	83%	77%	83%	94%	N/A

Selected quantitative metrics tracking CIMSS progress toward project goals and overall performance are summarized on the left. CIMSS' success as a center of excellence in satellite-related research is demonstrated through our publications and conference presentations. We frequently conduct thorough bibliometric analyses of all papers published by CIMSS researchers to quantify these metrics. CIMSS publication statistics for the years 2000–2023 are shown in Figure 4.28. From 2020 – 2023, CIMSS researchers were publishing around the highest annual rate during the period, authoring 348 peer-reviewed papers. Of these publications, 35% included a NOAA co-author reflecting positively on our productive relationship with NOAA. Comparing Figures 4.25 and 4.28, CIMSS researchers author approximately 7.5 papers per $1M of funding. A complete list of all publications for which a CIMSS researcher was first author is provided in Section 6.6.

To measure the impact of CIMSS research products, Table 4.2 lists the most highly cited papers from CIMSS researchers since 2020. Despite typical delays between a paper being published and new research that builds upon the work, 19 CIMSS papers published after 2020 had already received 50 or more citations as of January 2024. The CIMSS bibliometric analysis for the period 2020 – 2023 (available on the 5-year review website) further indicates that CIMSS authors frequently publish in journals with high impact factors (IF) including 2 papers in Science (IF 56.9), 2 papers in Nature Climate Change (IF 30.7), and 4 papers in Nature Communications (IF 16.6).

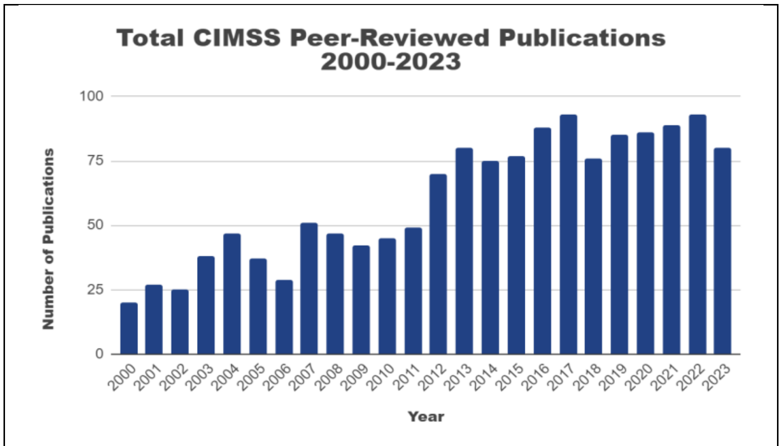

FIGURE 4.28: CIMSS publications from 2000 - 2023.

TABLE 4.2: CIMSS most highly cited publications from 2000 - 2023.

CIMSS Author(s)	Title	Journal	Year	Times Cited
James Kossin	Tropical Cyclones and Climate Change Assessment: Part II: Projected Response to Anthropogenic Warming	Bulletin of the American Meteorological Society, 101, 3	2020	526
Steven Greb	Seamless retrievals of chlorophyll-a from Sentinel-2 (MSI) and Sentinel-3 (OLCI) in inland and coastal waters: A machine-learning approach	Remote Sensing of Environment, 240	2020	223
Steven Greb	Robust algorithm for estimating total suspended solids (TSS) in inland and nearshore coastal waters	Remote Sensing of Environment, 246	2020	110
Jason Otkin	Global distribution, trends, and drivers of flash drought occurrence	Nature Communications, 12, 1	2021	105
Tristan L'Ecuyer	An overview of the ORACLES (ObseRvations of Aerosols above CLouds and their intEractionS) project: aerosol-cloud-radiation interactions in the southeast Atlantic basin	Atmospheric Chemistry and Physics, 21, 3	2021	85
Aronne Merrelli	OCO-3 early mission operations and initial (vEarly) XCO2 and SIF retrievals	Remote Sensing of Environment, 251	2020	84
Matthew Lazzara	Tropical teleconnection impacts on Antarctic climate changes	Nature Reviews Earth & Environment, 2, 10	2021	76
Bradley Pierce	Evaluating Sentinel-5P TROPOMI tropospheric NO2 column densities with airborne and Pandora spectrometers near New York City and Long Island Sound	Atmospheric Measurement Techniques, 13, 11	2020	73
Andi Walther	EUREC4A	Earth System Science Data, 13, 8	2021	70
Chris Schmidt	Australia's Black Summer pyrocumulonimbus super outbreak reveals potential for increasingly extreme stratospheric smoke events	NPJ Climate and Atmospheric Science, 4, 1	2021	69

Jun Li; Paul Menzel	Retrieval of cloud top properties from advanced geostationary satellite imager measurements based on machine learning algorithms	Remote Sensing of Environment, 239	2020	64
Jason Otkin	Flash drought development and cascading impacts associated with the 2010 Russian heatwave	Environmental Research Letters, 15, 9	2020	60
William Smith; Patrick Heck	CERES MODIS Cloud Product Retrievals for Edition 4-Part I: Algorithm Changes	IEEE Transactions on Geoscience and Remote Sensing, 59, 4	2021	59
Chris Schmidt	Satellite remote sensing of active fires: History and current status, applications and future requirements	Remote Sensing of Environment, 267	2021	57
Robert Knuteson	Thermal and near-infrared sensor for carbon observation Fourier transform spectrometer-2 (TANSO-FTS-2) on the Greenhouse gases Observing SATellite-2 (GOSAT-2) during its first year in orbit	Atmospheric Measurement Techniques, 14, 3	2021	56
James Kossin	Declining tropical cyclone frequency under global warming	Nature: Climate Change, 12, 7	2022	56
Jason Otkin	Flash drought onset over the contiguous United States: sensitivity of inventories and trends to quantitative definitions	Hydrology and Earth System Sciences, 25, 2	2021	52
Jason Otkin	A global transition to flash droughts under climate change	Science, 380, 6641	2023	51

Many CIMSS scientists give several presentations per year at venues ranging from major scientific conferences to small topical workshops. While CIMSS acknowledges each of these contributions in individual annual performance reviews, we use the regular American Meteorological Society (AMS) and American Geophysical Union (AGU) annual meetings as a metric of progress toward our goals of communicating our research/science. Table 4.3 summarizes oral and poster presentations given by CIMSS researchers and students at the AMS and AGU annual meetings from 2020 – 2024. In addition, we note that CIMSS was well represented at the August 2022 AMS Collective Madison Meeting (CMM) that featured three topical conferences (Polar, Satellite, and Clouds & Radiation) directly related to our research. CIMSS researchers presented 36 oral and 56 poster presentations at the CMM.

TABLE 4.3: CIMSS AGU and AMS presentations from 2020 – 2024. Note that the 2020 AMS meeting was outside the reporting period while the 2024 AGU meeting will not take place until December 2024. Care has been taken to avoid duplicating presentations with multiple CIMSS scientist co-authors.

	AGU			AMS		
Year	**Oral**	**Poster**	**Total**	**Oral**	**Poster**	**Total**
2020	20	21	41	N/A	N/A	N/A
2021	13	10	23	30	15	45
2022	9	8	17	37	11	48
2023	13	11	24	28	17	45
2024	N/A	N/A	N/A	31	25	56

Other indicators of a successful research center include the success rate for submitted proposals, international collaborations, awards of recognition, diversity of research products, research product utilization and adoption in operational systems, and data sharing. We closely track these activities as noted in the following examples:

- Including NOAA projects, SSEC and CIMSS scientists have collectively had a better than 80% success rate on proposals submitted since 2020 (FY20 – 83%; FY21 – 77%; FY22 – 83%; FY23 – 94%).
- CIMSS researchers maintained active collaborations with researchers from at least 30 agencies in more than 17 countries.
- CIMSS scientists and students have garnered numerous professional awards. Many CIMSS scientists have collaborated with NOAA scientists who have received NOAA's gold, silver, and bronze medals. Section 6.7 summarizes awards recognizing the accomplishments of our scientists.
- CIMSS scientists have produced environmental data products covering almost every aspect of the climate system. Since 2020, CIMSS has generated 63 unique data products. A complete list is provided in Section 6.9.
- CIMSS has also produced and distributed several data products using cutting edge AI/ML methods including tropical cyclone wind distributions, turbulence, severe weather probabilities, and cloud identification.
- Several CIMSS research algorithms have been or will soon be transferred to NOAA and other agencies with operational responsibilities. GOES-R fog and low stratus (FLS) products, Version 2 MIMIC water vapor, VOLCAT volcanic hazard products, geostationary and LEO cloud products, and the Advanced Dvorak Technique TC intensity estimates were all implemented operationally in the review period. Other algorithms such as LightningCast and AiDT TC intensity estimates will be implemented soon based on feedback from the Hazardous Weather Testbed.
- The NOAA OSPO data products page lists CIMSS-developed sounder cloud top pressure, Automated Biomass Burning Algorithm (ABBA), GOES Total Ozone, sounding products, and Clouds from AVHRR Extended (CLAVR-X) cloud properties.
- CIMSS imagery regularly appears on news websites and broadcast news and is disseminated to a wide range of stakeholders during environmental disasters such as wildfires, volcanic eruptions, and hurricanes.
- The SSEC/CIMSS data center distributed an average of 3.5 PB of data per year between 2020 and 2023.

Many CIMSS education and outreach goals are summarized in Section 4.3. Given the importance of workforce development for NOAA and weather and climate science in general, we highlight CIMSS contributions to graduate student training here. Figure 4.29 shows the number of CIMSS M.S. and Ph.D. degree recipients over its history. To date, CIMSS researchers have advised 136 M.S. and 64 Ph.D. students through the completion of their degrees, respectively. The 18 CIMSS students who graduated during the reporting period 2020 – 2023 are listed in Table 6.2 (Section 6.4). Eight of these students went on to work with NOAA either directly or at NOAA Cooperative Institutes, including CIMSS, demonstrating that the training students receive at CIMSS prepares them well for careers in weather, climate, and remote sensing fields and highlighting how studying at CIMSS promotes career opportunities at NOAA. CIMSS currently provides complete support for seven graduate students as well as partial support for several others, including providing startup funds for recent AOS hires specifically designated for student support.

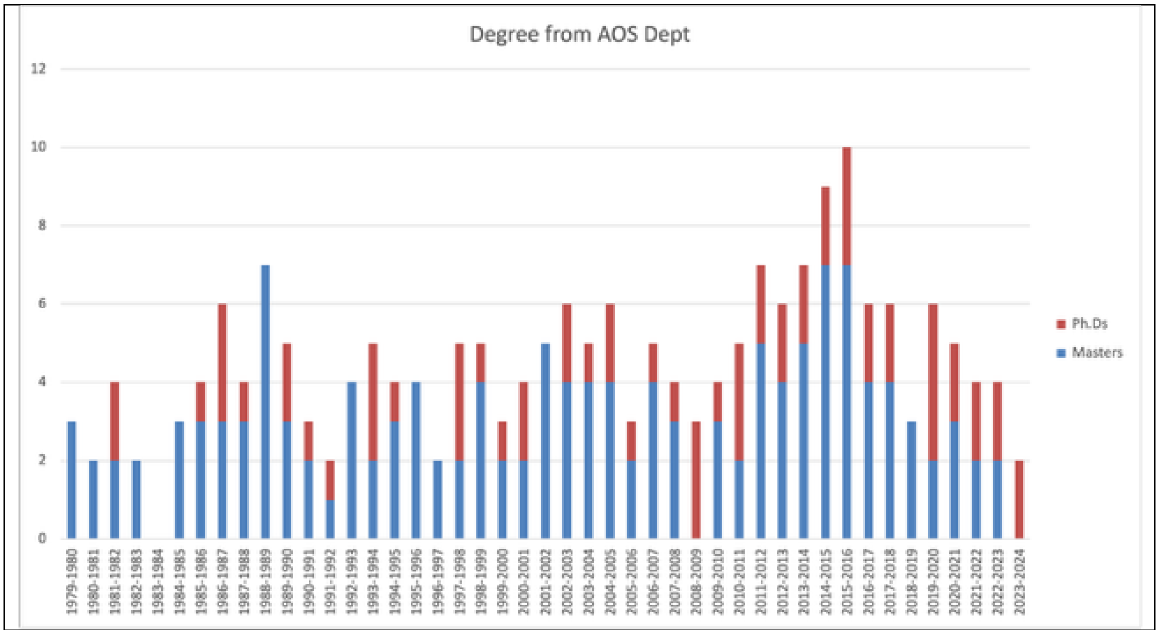

FIGURE 4.29: CIMSS-supported UW-Madison graduate degree recipients from 1980 to present.

Since 2020, the SSEC/CIMSS communications team has made 1388 blog posts and published 35 feature stories highlighting the research conducted by our scientists. Many stories feature the work of our students and early career scientists. Five of these feature stories were picked up by major national news outlets including the NY Times, CNN, Discover Magazine, Smithsonian Magazine, and CBS News. For example, in 2022 CNN published a story about the new CIMSS ADT approach for estimating hurricane intensity. Later that year, Discover Magazine published an article about CIMSS research into smoke and clouds associated with California wildfires.Our Facebook page currently has 27k followers while our X (formerly Twitter) feed has 23.7k followers.

We conclude with a final qualitative metric indicative of CIMSS progress toward fulfilling our mission and achieving our goals: a survey of the key words used to describe our research papers. The word cloud in Figure 4.30 shows the most frequently used key words in CIMSS publications from 2020 to 2023. CIMSS' strong focus on remote sensing research using satellite observations is clear. Also evident is our growing portfolio of climate research through topics like 'climate,' 'climate change,' 'climate variability,' and key climate parameters including 'drought,' 'precipitation,' and 'sea ice.'

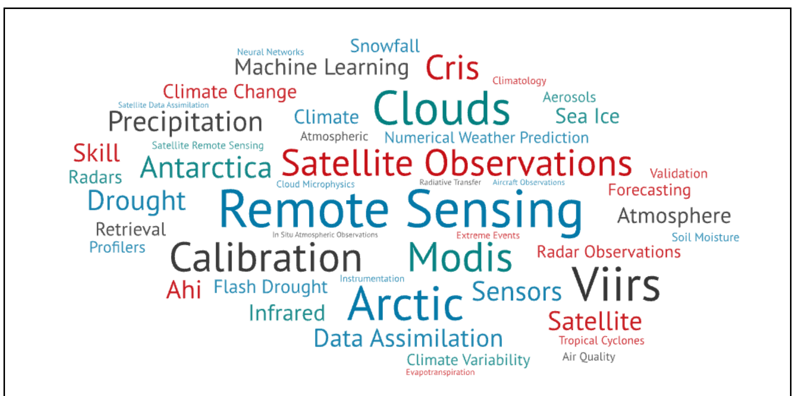

FIGURE 4.30: Key words from CIMSS publications from 2020 – 2023 indicating areas of emphasis in published work. Word size indicates the frequency with which terms occur. Keywords were simplified to remove redundancies and improve clarity and focus.

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6. Supplemental Materials

The unique research setting at CIMSS within SSEC at the UW and collocated with NESDIS/STAR personnel and AOS faculty and students has proven extremely effective in advancing research and operational applications of meteorological satellite data. This section provides more comprehensive summaries of CIMSS research programs, research staff and students, first-authored publications, university resources, and data services to support the review question responses above.

6.1 Current CIMSS Research Programs and their Evolution

CIMSS projects contribute to all aspects of satellite meteorology from instrument design through training end users in the uses and interpretation of data products derived from modern geostationary and low-Earth orbiting satellite measurements. The primary research programs conducted at CIMSS to meet the nation's needs for timely, accurate, and reliable weather and climate information are summarized in Table 6.1

TABLE 6.1: Example CIMSS research programs, including the research theme and evolution.

Project	Themes	Evolution
Atmospheric Sounding	Satellite Meteorology and Research Applications	CIMSS leadership in atmospheric sounding from space began with algorithm development for VAS in the late 1970s. Algorithms also developed for polar orbiting satellites, including TOVS, MODIS and AIRS. These algorithms are distributed to a wide variety of users through ITPP, IAPP, IMAPP and CSPP. Algorithms are modified and transitioned to operations. Most currently operate on the contemporary series of NOAA satellites. Hyperspectral research applications are currently underway with SNPP/JPSS CrIS, and Metop IASI, and leading to future geostationary advanced GeoXO IR sounder for monitoring four dimensional thermodynamics and trace gas tendencies. The measurement is crucial to monitoring of atmospheric stability, aviation weather cold air aloft monitoring, NWP data assimilation, and frontal position monitoring.
Aviation Weather	Satellite Meteorology and Research Applications	CIMSS has been exploring the use of weather satellite data directly for the purposes of providing the commercial and general aviation communities better weather decision support in the areas of volcanic hazard, low cloud/fog, icing, and atmospheric turbulence nowcasts. CIMSS science algorithms have matured – for example, VOLCAT is now being used at the Volcanic Ash Advisory Centers (VAAC) for commercial aviation advisories, GOES-R series Low/Cloud fog is now available through NOAA operations for NOAA NWS for TAF issuance usage, and satellite-based turbulence nowcasts have been made available for experimental use at NWS proving ground experiments and is under evaluation for operational transition to NOAA.
Biomass Burning	Satellite Meteorology and Research Applications/ Environmental Models and Data Assimilation	CIMSS develops algorithms to detect fires using satellite observations, beginning with the Automated Biomass Burning Algorithm (ABBA) which became NOAA's first operational fire detection and characterization algorithm in 2002. WFABBA subsequently served as the basis for the Fire Detection and Characterization Algorithm

		(FDCA) that is currently NOAA's baseline fire detection algorithm for the GOES-R series of satellites. CIMSS continues its leading role by developing and testing a new unified fire detection, characterization, tracking, and alerting system known as the Next Generation Fire System (NGFS).
Calibration and validation	Satellite Sensors and Techniques	CIMSS conducts ground-based, and aircraft-based validation field programs as well as inter-satellite calibration studies. We have participated in all GOES-R series weather satellite science check outs, including producing first light imagery from data access via SSEC's rooftop antenna reception capabilities. CIMSS has been involved with scientifically establishing, monitoring, and maintaining polar orbiting SDR performance for all CrIS and VIIRS sensors, utilizing pre-launch test characterization with on-orbit SNOs evaluation to optimize accuracy and precision of the radiance product.
Cloud Properties	Satellite Meteorology and Research Applications/ Environmental Models and Data Assimilation	Characterizing the location and properties of clouds is essential for the accurate retrieval of atmospheric and surface products, and has important implications for data assimilation, solar energy, aviation safety, and climate monitoring. A CIMSS 40+ year climatology of cloud-top pressure from polar orbiting and geostationary platforms has been assembled using an internationally recognized approach to high cloud remote sensing and expanded to produce AVHRR and the International Satellite Cloud Climatology Project - Next Generation (ISCCP-NG). CIMSS expertise in satellite remote sensing allows researchers to develop long-term satellite climate data records (CDRs) for tracking long term changes in variables such as clouds, moisture, fires, and sea/lake ice concentrations at local to global scales for climate study and data assimilation.
Cryosphere studies	Satellite Meteorology and Research Applications/ Environmental Models and Data Assimilation	CIMSS has pioneered many snow and ice retrieval algorithms, including ice and snow identification, ice surface temperature and ice concentration, ice thickness and age, ice motion, and snow cover. New projects include curating long-term ice and snow data records for cryosphere studies including trends, feedback mechanisms, data integration and assimilation using the GOES and JPSS satellite series
Data Assimilation	Environmental Models and Data Assimilation	As the birthplace of meteorological satellites, UW-CIMSS has abundant experience and expertise in processing and applying environmental and meteorological satellite data for environmental modeling and data assimilation (DA) research. These research activities span a wide range of areas, including the assimilation of satellite measurements of meteorological information and atmospheric composition, model verifications, observing system simulation studies, and radiative transfer model development. CIMSS has the capability to conduct data assimilation experiments on the NOAA funded Supercomputer for Satellite Simulations and Data Assimilation Studies (S4), which is housed and managed at SSEC. The system has running versions of the GFS, GDAS, GSI, WRF, and UFS data assimilation systems. A wide

		variety of satellite derived data sets are used including visible/IR radiances (and tendency), cloud properties, winds, aerosols, and temperature/moisture.
High-spectral resolution (HSR) infrared research	Satellite Sensors and Techniques	Beginning in the 1970s, this research program has been an area of emphasis for CIMSS. Working with SSEC, CIMSS is internationally recognized for its work with HSR observations from satellite, aircraft, and ground-based platforms. CIMSS continues making important contributions to the calibration of existing NOAA sensors, as well as helping to define sensors for future missions including, for example, GeoXO and NEON. S-HIS (aircraft based FTIR), proven to be a key capability and asset for NOAA/NASA, has been critical to highly accurate and directly traceable calibration validation of satellite infrared sensors, including the CrIS and the Advanced Baseline Imager ABI.
Satellite Derived Winds	Satellite Meteorology and Research Applications	The tracking of persistent, identifiable cloud and water vapor features in sequential geostationary satellite imagery, as an estimation of the ambient wind flow, was one of the original quantitative applications attempted with GOES and polar data and has its heritage at SSEC/CIMSS. The algorithm was automated in the late 1980s and expanded to also derive polar winds. The algorithms now are operational at NOAA, the Navy, and at European weather agencies supporting data assimilation into NCEP and other numerical forecast models. Current research involves improving the monitoring of rapidly evolving wind fields over the core of hurricanes and polar wind derivation for direct data assimilation where in situ atmospheric soundings are sparse.
Severe Weather (Convective) Studies	Satellite Meteorology and Research Applications	CIMSS is on the forefront in leveraging satellite and other remotely sensed observations to help the NWS better predict convective weather for additional awareness lead time, benefiting the public at large. Relatively new capabilities developed at CIMSS include ProbSevere and LightningCast which are a collection of machine-learning/deep learning models using satellite ABI radiances, GLM lightning detection, radar, weather model data used for short term prediction of convective hazards including (high wind, hail, tornado, and lightning threat). These capabilities have been successfully tested at NOAA Proving Ground testbeds (HWT, OPC, AWC) and have been made available to NOAA for transferring to operations.
Training	Education and Outreach	Training atmospheric scientists is a cornerstone of the UW-CIMSS mission, and aspects of training touch many CIMSS-developed products and programs. These activities include targeted on-site training for Direct Broadcast data users; training material as requested by the Office of the Chief Learning Officer (OCLO) Forecast Decision Training Division (FDTD); in-person training (GEO and LEO data, visible, infrared, and microwave) as requested; and satellite-related training modules developed for the VISIT and SHyMet programs for National Weather Service forecasters.

Tropical Cyclone Studies	Satellite Meteorology and Research Applications	Studies began in the 1980s to use satellite observations to better understand tropical cyclone formation, development, and movement. Multiple products are now used operationally by hurricane forecasters around the world. CIMSS tropical cyclones web site was pioneering in the early 1990s and continues today as a lead TC web page for real time and research satellite-derived products aimed at hurricane applications. TC science has now expanded into artificial intelligence/machine learning research for improving estimates of surface wind speed fields and TC rapid intensification forecasts.

6.2 CIMSS Organizational Structure

CIMSS resides within SSEC at the UW. SSEC is part of the Office of the Vice Chancellor for Research (OVCR), which oversees a large fraction of the campus research enterprise. CIMSS project support comprises approximately 40% of SSEC's funding portfolio.

Director: The CIMSS Director, Tristan S. L'Ecuyer is a faculty member in AOS. Prof. L'Ecuyer's appointment within AOS is required by the Memorandum of Understanding between UW–Madison and NOAA.

Executive Board and Council of Fellows: CIMSS is advised by an Executive Board (EB) and a Council of Fellows (CoF). The EC reviews the policies, research themes, and priorities of CIMSS, including budget and scientific activities. The EC is also responsible for approving the appointment of members to the CoF. The CoF advises the CIMSS Director in establishing the broad scientific content of its programs, promoting cooperation among the CI, NOAA, NASA, and other agencies, maintaining high scientific and professional standards, and preparing reports of CIMSS activities.

Staffing Structure: CIMSS Deputy Director, Wayne Feltz, oversees the day-to-day operations of CIMSS and provides management and coordination for the CIMSS research grants/contracts. As SSEC Associate Director for Science, Mr. Feltz represents CIMSS at the highest departmental administrative level.

The foundation of CIMSS is its 32 Principal Investigators (PIs). CIMSS encourages all staff to develop proposal ideas that support NOAA goals, in close coordination with the Director and Executive Director. The CIMSS Director holds monthly PI meetings to discuss new or evolving NOAA priorities for research and operations, upcoming meetings, deadlines for product delivery, and agency announcements of opportunity. PI meetings are also a forum for sharing recent research results.

CIMSS staff (107 individuals, including undergraduate and graduate students) provide the expertise that goes into its research activities. Most staff members work on multiple research projects, allowing the staff to expand their knowledge and skills. This arrangement provides a versatile core of talent and gives our institute the flexibility to apply it where and when it is needed to meet its research goals. Complete listings of CIMSS PIs, supporting scientists, visitors, staff, and students are provided in Sections 6.3 and 6.4.

6.3 CIMSS Personnel in March 2024

CIMSS	Tristan L'Ecuyer	Director
ADMINISTRATION	Wayne Feltz	Deputy Director - Science
AND TECHNICAL SUPPORT (5):	Maria Vasys	Outreach Specialist

		Leanne Avila	Editor
		Margaret Mooney	Outreach Program Manager

UNIVERSITY PRINCIPAL INVESTIGATORS: (32)

(Tristan L'Ecuyer	Professor, AOS	Clouds / Aerosols)
(Wayne Feltz	Scientist III	Aviation Weather)
Sam Batzli	Data Engineer III	GIS technologist
Eva Borbas	Scientist II	Retrieval Science
Mike Foster	Scientist II	Cloud microphysical properties
Thomas Greenwald	Scientist III	Direct Broadcast and Data Analysis
Liam Gumley	Scientist III	Direct Broadcast and Data Analysis
Mathew Gunshor	Researcher III	Calibration/Validation
Allen Huang	Scientist III – Distinguished	Retrieval Science / Hyperspectral
Shane Hubbard	Scientist I	GIS Science
Tommy Jasmin	Data Engineer III	Visualization/GIS Science
Jim Jung	Scientist III	Data Assimilation
Bob Knuteson	Scientist III	Hyperspectral Instruments / Data Analysis
Adita Kumar	Researcher II	Data Assimilation
Allen Lenzen	Data Engineer III	Data Assimilation
Zhenglong Li	Scientist I	Satellite Decision Support Training
Agnes Lim	Researcher III	Data Assimilation
Scott Lindstrom	Scientist I	Satellite Decision Support Training
Graeme Martin	Data Scientist III	Clouds and Climate / Instrumentation
Paul Menzel	Scientist III	Clouds and Climate / Instrumentation
Jason Otkin	Scientist II	Data Assimilation
Ralph Petersen	Scientist III	NWP / Nowcasting
Hank Revercomb	Scientist III	Hyperspectral Instruments/Data Analysis
Dave Santek	Scientist I	Polar Winds / Data Assimilation
Chris Schmidt	Researcher III	Biomass Burning
Kathy Strabala	Scientist I	Direct Broadcast and Data Analysis
Joe Taylor	Scientist II	Instrumentation Science
Dave Tobin	Scientist III	Radiative Transfer
Christopher Velden	Scientist III	Satellite Winds / Tropical Cyclones
Elizabeth Weisz	Scientist III	Hyperspectral Instruments/Data Analysis
Anthony Wimmers	Scientist II	Tropical Cyclones / Aviation Weather
Norman Wood	Scientist II	Microwave/Rainfall

UNIVERSITY SCIENTIFIC AND PROGRAMMING STAFF (47)	Brianne Anderson	Researcher I
	Scott Bachmeier	Researcher II
	Kevin Baggett	Software Engineer/Dev. IV
	Nick Bearson	Software Engineer/Dev. III
	Lori Borg	Researcher III
	Jessica Braun	Researcher III
	Corey Calvert	Researcher III
	John Cintineo	Researcher III
	Lee Cronce	Researcher III
	Geoff Cureton	Data Engineer I
	Alan De Smit	Software Engineer/Dev. III
	Dan DeSlover	Researcher III
	Rich Dworak	Researcher III

Joleen Feltz	Data Engineer I
Ray Garcia	Data Scientist III
Sarah Griffin	Researcher III
Derrick Herndon	Researcher III
Lena Heuscher-Stewart	Research Associate
Dave Hoese	Software Engineer/Dev. IV
Jay Hoffman	Researcher III
Jinlong Li	Scientist I
Yue Li	Researcher II
Graeme Martin	Data Scientist III
Jessica Maier	Researcher I
Scott Mindock	Software Engineer/Dev. III
Szu-Chia Moeller	Researcher II
Sharon Nebuda	Researcher II
Jim Nelson	Data Engineer I
Tim Olander	Researcher III
Erik Olson	Researcher III
Min Oo	Researcher III
Coda Phillips	Researcher II
Greg Quinn	Software Engineer/Dev. IV
Tom Rink	Data Engineer II
Alexa Ross	Researcher I
Eva Schiffer	Software Engineer/Dev. III
Justin Sieglaff	Researcher III
Dave Stettner	Researcher II
William Straka	Researcher III
Tian Tian	Researcher Associate
Kati Togliatti	Researcher II
Xuanji Wang	Scientist I
Steve Wanzong	Researcher III
Pei Wang	Researcher II
Hong Zhang	Researcher II
Yafang Zhong	Researcher III

6.4 Graduate Students and Postdocs

During the reporting period, CIMSS researchers advised 8 MS students and 10 PhD students through the successful completion of their degrees (Table 6.2). Seven of these graduates now work at NOAA Cooperative Institutes while two others work at NASA labs.

TABLE 6.2: MS and PhD graduates supported by CIMSS 2020 – 2023.

Student	Advisor	Degree	Graduation Year	Employment
James Anheuser	Menzel	MS	2020	PhD Program
Kai-Wei Chang	L’Ecuyer	PhD	2020	Texas A&M
Andrew Dzambo	L’Ecuyer	PhD	2020	CIWRO
Jerrold Acdan	Pierce	MS	2020	PhD Program
Margaret Bruckner	Pierce	MS	2021	PhD Program
David Loveless	Wagner	PhD	2021	CIMSS
Jongjin Seo	Foster	MS	2021	PhD Program
Anne Sledd	L’Ecuyer	PhD	2021	CIRES
Brianne Anderson	Pavolonis	MS	2021	CIMSS
Stephanie Ortland	Pavolonis	MS	2021	PhD Program

Charles White	Heidinger	PhD	2022	CIRA
Zoe Brooke Zibton	Martin	PhD	2022	Unknown
James Anheuser	Key	PhD	2023	CISESS
Ian Cornejo	Rowe	MS	2023	PhD Program
Cassidy Johnson	L'Ecuyer	MS	2023	CIRA
Nuo Chen	Morgan	PhD	2023	Unknown
Julia Shates	L'Ecuyer	PhD	2023	NASA JPL
Juliet Pilewskie	L'Ecuyer	PhD	2023	NASA GISS

CIMSS researchers currently advise 10 graduate students (7 of whom are directly funded through the cooperative agreement) and 4 post-docs. The following paragraphs provide brief descriptions of their research topics in their words (unedited).

Leila Gabrys, M.S.: Improving mixed-phase cloud satellite observations with an emphasis on lake-effect processes over the Great Lakes. Lake-effect clouds (often in the mixed phase) can be difficult to forecast and observe, especially given radar holes on large spatial scales such as the Great Lakes. Working with satellite products from CloudSat and CLAVR-x, it is my goal to verify observations to improve these models, as well as forecasting strong precipitation bands.

Kyle D. Obremski, M.S.: In recent decades, the Arctic has experienced a rapid decline in sea ice. This decline in sea ice and sea ice concentration (SIC) is likely to lead to increased levels of maritime activity in the region, particularly through the Northwest Passage in the Canadian Archipelago. This increased activity underscores the need for reliable SIC predictions in the region. An analysis of environmental conditions leading to late-summer SIC anomalies is being conducted to identify the best predictors of these anomalies. Using these predictors and remotely sensed SIC, a convolutional neural network is to be created that will be able to predict where SIC anomalies are likely to occur within the Canadian Archipelago to locate the best routes for maritime transit.

Katrina (Rena) Sletten, M.S.: Satellite meteorology and climate science communications. As technology advances and our resources to understand Earth's climate increase, so too must our ability to communicate all the new information. My research will focus on data visualization and communication for PREFIRE, a mission collecting measurements of the full spectral InfraRed radiation at the poles. My goal is to find the best way to interpret and communicate PREFIRE's data to a variety of audiences so that it is useful, informative, and easy to understand, and potentially use it as a case study for future climate data communication.

Natasha Vos, M.S.: "Investigating the PREFIRE intersections." Despite their large contribution to polar energy budgets, far-infrared (FIR) emissions have not been systematically constrained owing to past observational challenges. The Polar Radiant Energy in the Far-InfraRed Experiment (PREFIRE) will pioneer global moderate-resolution FIR observations from space by leveraging two CubeSats in separate sun-synchronous orbits, either of which will measure top of atmosphere radiances up to 54 microns. The dual CubeSats will give rise to so-called intersections that will be paramount to capturing local surface and atmospheric changes in the FIR, and my research investigated their anticipated spatial and temporal patterns ahead of the upcoming May launch as well as their hypothetical utility in the context of broader climate applications.

Stephanie Ortland, Ph.D.: Satellite and radar observations were used to develop a deep learning models for thunderstorm nowcasting in the United States. However, statistical analysis of semantic segmentation tasks, although useful for understanding how well a model labels images on a pixel-by-pixel basis, do not provide allowances for spatial offset unless using a Fraction Skill Score. Even so, fraction skill scores focus on how well a model performs in a spatial scale, not general regions of predictions as one might look for when forecasting thunderstorm initiation. The research for my second chapter of my Ph.D. develops an object-based evaluation technique to address this gap in model evaluation.

Doreen Mwara Anande, Ph.D.: The objective of my research is to enhance understanding of the climatological characteristics and physical causes of rapid changes in hydrological and vegetation conditions over sub-seasonal to seasonal time scales over Africa. Various remote sensing and reanalysis datasets will be used during my research. The research will include a climatological assessment of the occurrence of rapid change events, diagnosis of the atmospheric patterns that most often lead to their development, and investigation of observed and projected changes in their occurrence within an evolving climate (Funded by a CIMSS donor, Dr. George Diak).

Cameron Bertossa, Ph.D.: Radiation plays an important role in shaping the Arctic and Antarctic climates. Several Arctic expeditions have found that certain regions flip between having a very large energy deficit (‘transmissive’) to relatively small energy deficit (‘opaque’). My research uses satellite observations to understand if this behavior is consistent across the Arctic and Antarctic, uncovering the leading processes contributing to the behavior.

Margaret Bruckner, Ph.D.: “Indirect Validation of Ozone Mapping Profiler Suite (OMPS) Limb Retrievals.” Chemical re-analyses are used in investigation of ozone interannual variability and trends associated with ozone recovery. The Real-time Air Quality Modeling System (RAQMS) reanalysis has been developed using retrievals from the NASA Ozone Monitoring Instrument and Microwave Limb Sounder. These satellites are being replaced by the next generation of instruments, including OMPS. To continue this re-analysis, the re-analysis must be able to assimilate OMPS limb retrievals. In order to assimilate this data, a good estimate of the observation error is necessary. We are obtaining an estimate of observation error through indirect validation. Indirect validation does not require coincident measurements, which increases the number of data points included in the intercomparison of datasets and reduces the error in comparing the datasets. This indirect validation bias-corrects the existing RAQMS re-analysis with Atmospheric Chemistry Experiment (ACE) retrievals, validates this correction with ozonesonde observations, and evaluates the observation error in OMPS utilizing the bias-corrected re-analysis.

Jongjin Seo, Ph.D.: Clouds over the ocean at the Tropics play an essential role in regional and global climate changes due to their radiative effects. My research focuses on changes in cloud fractions and properties over this region since 1980 using PATMOS-x v6.0 which is the satellite-based climate data record and finding relationships between these changes and atmospheric drivers such as El Niño, surface temperature, humidity as well as inversion strength.

Jerrold Acdan, Ph.D.: “Air quality in the Lake Michigan region.” Provided chemical forecasting support for the summer 2023 NOAA AEROMMA and NASA STAQS field campaigns that focused on investigating urban air quality. Work seeks to understand the chemical and transport processes that create ozone pollution in the Lake Michigan region using air quality models, satellite observations, and AEROMMA-STAQS 2023 field campaign measurements.

Lena Heuscher, Postdoc: Wildfires play an important role in landscape evolution and result from interactions between surface fuels and ignition sources. Lightning, which is the leading natural cause of wildfires, also poses a safety risk to those fighting the fires. The goals of this research are: a) help characterize the land surface for lightning- and non-lightning ignited wildfires in order to help predict which lightning strikes ignite wildfires and b) improve firefighter safety by verifying lightning prediction methodologies over named wildfire incidents.

Zheng Ma, Postdoc: “Time Series Analysis of SNPP/VIIRS over Lake Michigan.” VIIRS is a key instrument carried on the JPSS satellites. It is important to understand the long-term radiometric stability of VIIRS through time series analysis. This allows improved understanding of the climate changes at certain sites such as Lake Michigan.

Kavita Mitkari, Postdoc: Two topics are being pursued. First, the depth of snow on sea ice, which is critical to the estimation of sea ice thickness, is one of the major challenges for remote sensing of the cryosphere. Emerging methods like machine learning will be evaluated and applied. Second, techniques for the detection, tracking, and characterization of icebergs will be developed as an aid to operational ice services. (JPSS)

Tian Reddy Tian, Postdoc: Remote sensing of ice motion products using the satellite imagery (GOES-R, EPS-SG, VIIRS, etc.), investigate ice kinematics by using remote sensed ice motion observations.

6.5 Cost Sharing

The UW recognizes the value and importance of institutional support for the CIMSS partnership with NOAA. The UW has supported CIMSS through a combination of formal cost sharing and leveraged resources as outlined below.

6.5.1 Formal Cost Sharing

The UW provides formal cost sharing to CIMSS with an estimated value of $865,748 through the following mechanisms:

1. Salary, Fringe, and F&A costs for the CIMSS Director and Executive Director for Science: The UW agrees to cost share 10% effort for each the CIMSS Director and the Executive Director for Science. The estimated value of this contribution totals $365,748. Note: The basis of salary and effort for the CIMSS Director is based on a 9-month faculty appointment. Salary and effort for the ED-S is a 12-month academic staff appointment.

2. The OVCR provides flexible research support funds for direct costs in the amount of $100,000 per year over the five-year award duration totaling $500,000. This funding is used to support undergraduate and graduate students, post-doctoral researchers and visiting scientists, outreach and communications, and research resources such as software or equipment.

6.5.2 Leveraged Resources

While the following is not "documented cost sharing," the services outlined below are of direct benefit to the federal government. This financial support brings significant additional capability and flexibility to the CIMSS Director and the CIMSS research teams.

In the discussion below, where possible, dollar amounts are provided for CIMSS support services based on the most recent State of Wisconsin fiscal year (SFY) costs (1 July 2023 to 30 June 2024). This support has been and continues to be an ongoing contribution throughout the CIMSS partnership with NOAA. The most recent fiscal year data provides examples of the broad support that the UW provides to the institute. The total UW contribution for SFY2024 is estimated to be $563,844 of support in addition to the formal cost-sharing outlined in Section 6.5.1. Specific components include:

1. **Physical space for NOAA staff.** The UW agrees to provide physical space for NOAA federal researchers at CIMSS to facilitate the transfer of scientific findings, tools and products to the operational users, to include office facilities, computing and other university services (e.g., access to facilities), details to be determined. The total square

footage of NOAA employee occupied office space (7 persons) will be approximately 880 square feet not including the use of conference rooms, labs, and other facilities.

2. **Technical Computing** provides a unique set of shared research computing services to meet the high-performance computing and data storage needs of the CIMSS research staff. This includes the design, construction, and maintenance of a high-performance data processing and storage facility to a customized science software application stack. These services provide the users with cost effective powerful tools they could not otherwise access while maximizing the available resources (labor and equipment). As noted above, SSEC currently has one of the largest computing clusters on campus with 4,160 cores and approximately 15 petabytes of total data storage.
3. **SSEC Satellite Data Services (SDS)** plays a key role in most CIMSS science programs, providing scientists and collaborators with low latency, high quality global satellite and other data in near real time to support research and development. SDS works closely with NOAA/NESDIS/OSPO and /NCEI to support GOES ground station, product creation and archiving activities. Several times a year SDS provides data back-up support to OSPO when data is lost.
4. **The SSEC Research Support Office** provides administrative support to CIMSS leadership and research staff in pre- and post-award management, purchasing, property control, travel, human resources, and financial ancillary systems. The Research Support Office is staffed by 13 full-time employees with extensive experience interpreting University, State, and Federal rules and regulations, as well as monthly reconciliation of expenditures, tracking of capital equipment, and resolution of personnel issues. The total SFY2024 cost of the office was $1,100,000, of which approximately 40% can be attributed to processing CIMSS projects.
5. **The Atmospheric, Oceanic, and Space Sciences Library** at SSEC/CIMSS serves as an important resource for CIMSS scientists and AOS students. SSEC provides funds to support the AOSS Library activities. In SFY2024 this cost was $51,157.
6. **Quality Assurance and Program Management.** SSEC supports experts in Quality Control, Safety, and Employee Training. This group has developed specific quality and safety procedures for SSEC/CIMSS including several documents (e.g., workplace emergencies). This team is also developing management training materials specific to SSEC/CIMSS project needs. The value to CIMSS of this support in SFY2024 was approximately $30,695.
7. **SSEC Rooftop Instrument Suite and SSEC Portable Atmospheric Research Center (SPARC).** SSEC supports an instrument validation site on the roof of its 15-story building. A UW grant funded the purchase and installation of high quality basic meteorological measurements (temperature, moisture, wind, pressure, solar radiation). NSF, NASA and NOAA have funded the purchase and installation of remote sensing instruments. To bring all this information to scientists and other users, the UW has funded the development of a data collection, management and web-based delivery system for this instrument site. SSEC also maintains a mobile research facility called the SPARC (SSEC Portable Atmospheric Research Center*)* to study the atmosphere. Several instruments are integrated into a 36-foot trailer that is configured for remote operation either by using internal generators, or by connecting to virtually any electrical power source found in the field. The current complement of instruments in the SPARC includes an Atmospheric Emitted Radiance Interferometer (AERI), High-Spectral Resolution Lidar (HSRL), a Halo Doppler Wind Lidar (DWL), a ceilometer, a meteorology surface station, a radiosonde launch receiver, and a GPS total precipitable water instrument. SSEC acquired the facility in 2013 and it

has provided great benefit to CIMSS to support field experiments and satellite cal/val activities. The SFY2024 support for the Rooftop Instrument Suite and SPARC was approximately $78,195.

8. **Start-up Funds for new ideas and projects:** The UW has provided considerable support for developing new research concepts that have a strong likelihood of leading to new proposals. These funds have supported several projects of significant benefit to both CIMSS and NOAA. SFY2024 approximate reinvestment of these programs totaled approximately $138,881. Examples include:
    a. **High spectral resolution IR interferometry:** The UW has provided important support to continuing efforts to build, operate, and demonstrate the capabilities of hyperspectral infrared sounders. While significant program funding has supported this work, gaps in funding were bridged by the UW. SSEC's work in this area has been of great benefit to NOAA instrument design planning.
    b. **Application of satellite data for energy reserve capacity optimization system:** Renewable energy sources present challenges to the electrical power grid due to the volatility created by the spatially and temporally changing weather patterns. The UW provided important seed funding support to utilize satellite data and numerical weather prediction models to address a key need for an optimized planning model for reserve capacity within a large region electrical power system.
    c. **Data compression:** The very high data rates from advanced instrumentation require data compression. The UW has provided crucial support when CIMSS has experienced gaps in funding in this area.
    d. **Visualization tools:** When a new generation of data analysis and visualization tools were needed to work with the next generation of environmental satellite data, the UW funded a design study and proof of concept to develop the goals and requirements for the project. That funding has led to current NOAA and IPO support for building the open source, freely available McIDAS-V software.
9. **Support of Visiting Scientists.** The UW–Madison has provided partial support to foreign scientists visiting our institute for extended stays to help defray their living expenses (salaries and transit costs are usually borne by the home institution). In addition, the UW supports CIMSS scientists to visit foreign laboratories for extended stays fostering stronger collaborations. Examples include the German Deutscher Wetterdienst, Japanese Meteorological Agency Satellite Division, EUMETSAT Met and Climate Division, the Taiwan Central Weather Bureau, the Australian Bureau of Meteorology, and the United Kingdom Met Office and many more international government and universities. These extended visits have cemented our strong international collaborations to the benefit of both CIMSS and NOAA.

In summary, the **UW is committed to its partnership with NOAA through this Cooperative Institute.** NOAA benefits tremendously from the support the UW provides to NOAA and SSEC/CIMSS. This financial commitment furthers the goals of both NOAA and CIMSS, supporting their science teams to provide the government with innovation and creativity in the research to operations process. This commitment from the UW also enhances NOAA's operational capability by linking with a strong university partner that can provide numerous programs and facilities that benefit NOAA as it seeks to fulfill its mission to the nation.

6.6 Publications

The following list summarizes CIMSS first-authored publications from 2020 – 2024 (note some papers from late 2023 and 2024 may be missing due to lags in updating publication databases). For completeness, publications for which a CIMSS researcher was a contributing author are also listed on the CIMSS 5-year review website: https://cimss.ssec.wisc.edu/cimss-review-2024/

1. Anheuser, J., E. Weisz, W. P. Menzel, 2020: Low earth orbit sounder retrieval products at geostationary earth orbit spatial and temporal scales. *J. Appl. Remote Sens.*, **14**, 4, 048502, https://doi.org/10.1117/1.JRS.14.048502.
2. Cintineo, J., M. Pavolonis, J. Sieglaff, L. Cronce, J. Gerth, J. Brunner, 2020: ProbSevere v2.0: ProbHail, ProbWind, and ProbTor, *Wea. Forecasting*, **35**, 4, 1523-1543, https://doi.org/10.1175/WAF-D-19-0242.1.
3. Cintineo, J. L., M. J. Pavolonis, J. M. Sieglaff, A. Wimmers, J. Brunner, 2020: A deep-learning model for automated detection of intense mid-latitude convection using geostationary satellite images. *Wea. Forecasting*, **35**, 2567-2588, https://doi.org/10.1175/WAF-D-20-0028.1.
4. Di, D., Y. Xue, J. Li, W. Bai, P. Zhang, 2020: Effects of CO_2 changes on hyperspectral infrared radiances and its implications on atmospheric temperature profile retrieval and data assimilation in NWP. *Remote Sensing*, **12**, 5, 2401, https://doi.org/10.3390/rs12152401.
5. Griffin, S. M., J. A. Otkin, G. Thompson, M. Frediani, J. Berner, F. Kong, 2020: Assessing the impact of stochastic perturbations in cloud microphysics using GOES-16 infrared brightness temperatures. *Mon. Wea. Rev.*, **148**, 8, 3111-3137, https://doi.org/10.1175/MWR-D-20-0078.1.
6. Gunshor, M. M., T. J. Schmit, D. R. Pogorzala, S. S. Lindstrom, J. P. Nelson, 2020: GOES-R series ABI Imagery artifacts. *J. Appl. Rem. Sens.*, **14**, 3, 032411, https://doi.org/10.1117/1.JRS.14.032411.
7. Kossin, J. P., K. R. Knapp, T. L. Olander, C. S. Velden, 2020: Global increase in major tropical cyclone exceedance probability over the past four decades. *Proceedings of the National Academy of Sciences of the United States of America*, **117**, 22, 11975-11980, https://doi.org/10.1073/pnas.1920849117.
8. Lazzara, M. A., and Coauthors, 2020: The 13th and 14th Workshops on Antarctic Meteorology and Climate. *Advances in Atmospheric Sciences*, **37**, 423-430, https://doi.org/10.1007/s00376-019-9215-6.
9. Li, J., J. Li, C. Velden, P. Wang, T. J. Schmit, and J. Sippel, 2020: Impact of rapid-scan-based dynamical information from GOES-16 on HWRF hurricane forecasts, *Journal of Geophysical Research-Atmospheres*, **125**, 3, https://doi.org/10.1029/2019JD031647.
10. Li, Z., W. P. Menzel, J. Jung, A. Lim, J. Li, M. Matricardi, S. D. Souza-Machad, L. Strow, 2020: Improving the Understanding of CrIS Full Spectral Resolution Nonlocal Thermodynamic Equilibrium Radiances Using Spectral Correlation. *Journal of Geophysical Research: Atmospheres*, **125**, 16, https://doi.org/10.1029/2020JD032710.
11. Liu, Y., Y. Zhu, L. Ren, J. Otkin, E. D. Hunt, X. Yang, F. Yuan, S. Jiang, 2020: Two different methods for flash drought identification: comparison of their strengths and limitations. *J. Hydrometeor.*, **21**, 4, 691-704, https://doi.org/10.1175/JHM-D-19-0088.1.
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6.7 Awards

This section summarizes awards recognizing CIMSS researchers from 2020 – 2023. Note, in some cases awards recognize collaborations with NOAA employees who received medals or other awards granted only to federal employees.

2023

- Lori Borg, Dan Deslover, Robert Knuteson, Michelle Loveless, Christopher Moeller, Henry Revercomb, William Straka, Joseph Taylor, David Tobin
  - NASA Robert H. Goddard Exceptional Achievement for Science Awards - JPSS-2 Cal/Val Team, "For outstanding mission-critical support to the pre- and post-launch calibration/validation of the JPSS-2 satellite."
- Tim Schmit (NOAA)
  - NASA Goddard Group award: GeoXO Program Science Working Groups
- Mike Foster, Mathew Gunshor, Zhenglong Li, Aronne Merrelli, Nate Miller, Andi Walther
  - NOAA-CIMSS Collaboration Award
- Kyle Obremski
  - 1st place graduate poster presentation at the NOAA Corp Symposium

2022

- Callyn Bloch
  - 2nd place poster presentation in the Joint Conference Student Competition at the AMS Annual Meeting
- Danica Fliss
  - 1st place Outstanding Poster Presentation at the 25th Conference on Satellite Meteorology, Oceanography, and Climatology / Joint 2022 NOAA Satellite Conference
- Mat Gunshor
  - UW-Madison 2022 Cool Science Image Contest winner (animation)
- Andy Heidinger (NOAA)
  - NOAA Administrator's Award
  - NOAA Bronze Medal Award
  - NASA Goddard Group Achievement Award
- Jeff Key (NOAA)
  - NOAA Silver Sherman Award
- Jim Nelson
  - UW-Madison 2022 Cool Science Image Contest winner (animation)
- Stephanie Ortland
  - 1st place oral presentation at the NOAA Corp Symposium
- Tim Schmit (NOAA)
  - NOAA Bronze Medal Award
  - NASA Goddard Group Achievement Award
  - UW-Madison 2022 Cool Science Image Contest winner (animation)
- Jongjin Seo
  - 2nd place Outstanding Poster Presentation at the 25th Conference on Satellite Meteorology, Oceanography, and Climatology / Joint 2022 NOAA Satellite Conference
- William Smith
  - Gold Medal of the International Radiation Commission
- William Straka
  - JPSS Unseen Hero Award

2021

- Wei Han
    - ITSC-23 Best Oral Presentation
- Jeff Key (NOAA)
    - NOAA Distinguished Career Award in Scientific Achievement
- Tristan L'Ecuyer
    - Outstanding Alumni Award from the Department of Atmospheric Sciences at the Colorado State University
- Scott Lindstrom
    - JPSS Unseen Hero Award
    - NESDIS Collaboration Award
- David Tobin
    - ITSC-23 Best Poster Presentation

2020

- Jay Hoffman
    - NESDIS Outstanding Science and Research Employee
- Tristan L'Ecuyer
    - American Geophysical Union Atmospheric Sciences Ascent Award
- Jerry Robaidek
    - UW-Madison Chancellor's Award for Excellence in Research: Critical Research Support
- Timothy Schmit (NOAA)
    - NOAA Administrator's Award
- William Straka
    - JPSS Innovation Award
- Tony Wimmers
    - NESDIS Outstanding Science and Research Employee

6.8 Data Services

An important step in fulfilling the role of the CI for meteorological satellite studies is the capability to routinely acquire and ingest the large volume of data collected by NOAA's environmental satellites with minimal interruption. CIMSS benefits from access to SSEC's data reception and processing facility housed on-site in the AOSS building. The facility consists of two dedicated climate-controlled computer server rooms, a rooftop antenna farm, and a system monitoring room. The facility is supported by 5 x 65 kW UPS and 65 kW of non-UPS power for a total capacity of 325 kW. The server rooms have electronic door locks for secured access. The following subsections summarize some of the satellite downlink, archive, and distribution capabilities at SSEC/CIMSS.

6.8.1 Downlink Capabilities

The Data Center routinely receives more than 8 TB of satellite data daily from 12 different geostationary satellites and 11 polar orbiting satellites via L-, C-, and X-band antennas that it operates on the AOSS rooftop and on the ground in Madison. SSEC also owns and operates four antennas at remote locations that cover most of North America and portions of the Pacific, contributing to the Direct Broadcast (DB) Network. GOES data are ingested using the locally developed CSPP-GEO software, while polar data are ingested using CSPP-LEO. In addition to satellite data, SSEC also ingests non-satellite data via its antennas, the full NOAAport feed which includes the US Nexrad radar data, global in situ observations, and model output.

Geostationary	Sub-Point	Reception Method	Source	Latency	Daily Volume
GOES-16	75.2° West	L-Band	DB	<10 seconds	130-400 GB
GOES-13/14	141°/104º West	L-Band	DB	<2 minutes	23 GB
GOES-15	128.5° West	L-Band	DB	<2 minutes	23 GB
GOES-17	137ºWest	L-Band	DB	<10 seconds	130-400 GB
Meteosat-11	0° East	Network Relay	NOAA STAR	~30 minutes	24 GB
Meteosat-8	41.5° East	Network Relay	NOAA STAR	~30 minutes	24 GB
Himawari-8	140° East	Network Relay	NOAA STAR ABOM (backup)	~ 10 minutes	300 GB
Himawari-8	140° East	Himawari Cast Network Relay	Hawaii NWS	~ 10 minutes	62 GB
FY2H	79° East	Network Relay	ABOM	15-30 minutes	4.7 GB
FY2G	99.5° East	Network Relay	ABOM	15-30 minutes	4.7 GB
COMS	128° East	Network Relay	KMA	9-24 minutes	11 GB

FY-4A (GIIRS only)	105º East	Terrestrial Eumetcast	Eumetsat	10-15 minutes	~5 – 13 GB

Low-Earth Orbit	Reception Method	Domain	ADDE Latency	Instruments	Access
NOAA-15	C-Band relay, NOAA-STAR	DB CONUS Global	DB <1 minutes after pass	AVHRR, AMSU, DCS->level-1	**ADDE**
				All other instruments Level-0	NA
NOAA-18	DB L-Band, C-Band relay, NOAA STAR	DB CONUS Global	DB <1 minutes after pass	AVHRR->level-1	**ADDE**
				All other instruments Level-0	NA
NOAA-19	DB L-Band, C-Band relay, NOAA STAR	DB CONUS Global	DB <1 minutes after pass	AVHRR->level-1	**ADDE**
				All other instruments Level-0	NA
NOAA-20	DB XL-Band, NOAA STAR, CLASS	DB CONUS Global	DB <1 minutes after pass Global network relay ~45 min	VIIRS>level-1	**ADDE**
				VIIRS,ATMS, CrIS	DB ftp (sips)
Metop-A/B/C	DB L-Band, NOAA STAR Relay	DB CONUS Global	CONUS <15 minutes after pass	AVHRR ->level-1	**ADDE**
				AVHRR, IASI	DB ftp (sips)
Suomi-NPP	DB X/L Band, NOAA STAR, CLASS	DB CONUS Global	CONUS <15 minutes after pass Global network relay ~45 min	VIIRS	**ADDE**
				VIIRS,ATMS, CrIS	DB ftp (sips)

Aqua	DB X-Band, NASA Relay	DB CONUS Global	DB <15 minutes after pass	AIRS, MODIS -> Level-1	**ADDE**
				AIRS, MODIS	DB ftp (sips)
Terra	DB X-Band, NASA Relay	DB CONUS Global	DB <15 minutes after pass	MODIS -> Level-1	**ADDE**
				MODIS	DB ftp (sips)
Landsat-8	Network Relay (USGS)	CONUS	<24 hours	Level-1	WMS
Shizuku GCOM-W1	DB X-Band	CONUS	DB <1 min after pass	Level-0	SSEC ftp
FY-3B/C	DB X/L Band	CONUS	DB <1 min after pass	Level-0	SSEC ftp

6.8.2 Geostationary Satellite Archive

SSEC/CIMSS also maintains the world's largest online archive of geostationary weather satellite data. The 40+ year continuous record of GOES satellite data that begins in 1978 and extends to the present, provides an unparalleled resource for climate research. This archive also contains GOES data that is not archived by the NOAA Comprehensive Large Array-data Stewardship System (CLASS). These unique datasets were created during satellite checkout or during periods where non-operational GOES satellites were taken out of storage for short periods. The archive now comprises more than 2 PBs of geostationary satellite data and approximately 2 TBs of new data are archived daily.

US Geostationary Satellites

- GOES-8 through GOES-17 (1994-Present) (East, West, South America and test)
- G16 and G17 L1 ABI and L2 GLM in Netcdf
- G16 and G17 CADUs (essential for SDS and CSPP-GEO debugging)
- GOES-1 through GOES-7 (1978-1996)
- SMS-1&2 (1978-1981)

International Geostationary Satellites

- GMS/MTSAT (1998-2015)
- Meteosat/Meteosat IODC (1998-Present)
- Meteosat-1 FGGE (1978-1979)
- FY2 (2004-Present)
- Kalpana (2005-2017)

- Insat-3D (June 2014-2017)
- COMS (June 2012 – Present)
- Himawari-8 (March 2015 – Present)

6.8.3 Data Distribution

SSEC/CIMSS distributes more than 3.5 petabytes of satellite observations and derived geophysical data products per year via several mechanisms. Data are provided to CIMSS scientists using direct filesystem access, McIDAS Abstract Data Distribution Environment (ADDE), file transfer protocol (ftp), ftps, http(s), Local Data Manager (LDM), and GRB fanout. Many ingested datasets utilize advanced message queue protocol (amqp) to provide events to data users to minimize latency and efficiently initiate data transfers. Data are also distributed to the university community via the Internet Data Distribution (IDD) service which is managed by Unidata. GRB data are also relayed to Unidata using GRB fanout and made available via ADDE, and LDM. SSEC also manages the North America and Pacific portions of the DBNet network of antennas relaying data from those antennas to NOAA NCEP and EUMETSAT.

6.9 Unique Data Products

CIMSS Unique Satellite Products
Geo Cloud and Moisture Imagery
Polar Composite Imagery (polar orbit)
Cloud Clear/Cloudy Detection Mask
Cloud Optical Depth
Cloud Particle Size Distribution
Cloud Top Height
Cloud Top Phase
Cloud Top Pressure
Cloud Type
Cloud Ice Water Path
Cloud Top Temperature
Polar Atmospheric motion vectors
Geostationary Derived Motion Winds
Hurricane Atmospheric motion vectors (hi-res)
Fire/Hot Spot Characterization
Hurricane Center location detection
Hurricane Intensity Detection (conventional and AI/ML satellite-based)
Hurricane Eyewall Replacement Cycle Index
Hurricane Saharan Air Layer detection
Legacy Vertical Moisture Profile
Legacy Vertical Temperature Profile
Atmospheric Stability Indices

Nearcasting Instability
Total Precipitable Water
Volcanic Ash: Detection
Volcanic Ash: Height
Volcanic Ash: Motion
Volcanic activity SO2 Detection
Aviation Low/Cloud Fog (MVFR, IFR, and LIFR conditions)
Turbulence (Aviation Atmospheric) nowcast
Icing
Overshooting Top Detection
LightningCast
ProbSevere
Cloud Cover Layers
Visibility
Total Ozone
Fire radiative power (intensity)
Fire Hot Spot Detection
Flood Detection
Flash Drought Detection
Surface Ice temperature
Sea/Lake Ice Age
Sea/Lake Ice Detection
Sea/Lake Ice Concentration
Sea/Lake Ice Motion
Lake effect snowfall detection
Snow Cover
Snow Depth
Vegetation Index
Surface Emissivity
Surface Albedo
Sea Surface temperature
Land Surface temperature
Aerosol particle size
Aerosol optical depth
Aerosol dust/plume detection
Infrared Radiometric Satellite Calibration
Rainfall accumulation
Solar insolation
Derived Imagery: Dust, weather systems, cloud type, cloud phase, fog, volcanic ash etc)

Appendices

Appendix A: Acronyms

AACP Above-Anvil Cirrus Plumes
ABBA Automated Biomass Burning Algorithm
ABI Advanced Baseline Imager
ADDE Abstract Data Distribution Environment
ADT Advance Dvorak Technique
AERI Atmospheric Emitted Radiance Interferometer
AEROMMA Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas
AI – Artificial Intelligence
AIC Aviation-induced Cirrus
AiDT AI-enhanced Advanced Dvorak Technique
AIRS Atmospheric InfraRed Sounder
AMS American Meteorological Society
AMSU Advanced Microwave Sounder Unit
AMV Atmospheric Motion Vectors
AO Announcement of Opportunity
AOS Department of Atmospheric and Oceanic Sciences
AOSS Atmospheric, Oceanic and Space Sciences
AQ Air Quality
AHI Advanced Himawari Imager (Japan)
APP-x AVHRR Polar Pathfinder-Extended
ARI Absolute Radiance Interferometer
ARM Atmospheric Radiation Measurement
ARPA-E Advanced Research Projects Agency-Energy
ASIP Alaska Sea Ice Program
ATMS Advanced Technology Microwave Sounder
ATOVS Advanced TIROS Operational Vertical Sounder
AVHRR Advanced Very High-Resolution Radiometer
AWG Algorithm Working Group
AWC Aviation Weather Center
AWIPS Advanced Weather Interactive Processing System
BAMS Bulletin of the American Meteorological Society
CA Cooperative Agreement
CCR Cloud Cleared Radiance or Center for Climatic Research
CDR Climate Data Record
CESSRST Center for Earth System Sciences and Remote Sensing Technologies
CGMS Coordination Group for Meteorological Satellites
CI Cooperative Institute
CIGLR Cooperative Institute for Great Lakes Research
CIMSS Cooperative Institute for Meteorological Satellite Studies
CIRA Cooperative Institute for Research in the Atmosphere (Colorado State University)
CISESS Cooperative Institute for Satellite Earth System Studies
CIWRO Cooperative Institute for Severe and High-Impact Weather Research and Operations
CLASS Comprehensive Large Array-data Stewardship System
CLAVR-x Clouds from AVHRR-Extended
CMAQ Community Multiscale Air Quality
CMIP Cloud and Moisture Imagery Product
CNN Convolutional Neural Network
CO_2 Carbon Dioxide
COMS Communication, Ocean, Meteorological Satellite (South Korea)
CONUS CONtinental (or CONterminus) United States
CoRP Cooperative Research Program (STAR)
CPI Consumer Price Index

CPO Climate Program Office
CREST Cooperative Remote Sensing Science and Technology Center (consortium of 8 universities)
CrIS Cross-track Infrared Sounder
CRTM Community Radiative Transfer Model
CSC Cooperative Science Center
CSPP Community Satellite Processing Package
CSR Clear Sky Radiance
CSV Comma Separated Values
CUNY City University of New York
CWG Calibration Working Group or Cloud Working Group
DA Data Assimilation
DB Direct Broadcast
DBNet Direct Broadcast Network
DL Deep Learning
D-MINT Deep Multispectral Intensity of TCs estimator
DOD Department of Defense
DOE Department of Energy
D-PRINT Deep IR Intensity of TCs estimator
DWL Doppler Wind Lidar
ECM Enterprise Cloud Mask
ECMWF European Centre for Medium-Range Weather Forecasts
ED-A Executive Director – Administration (SSEC)
ED-S Executive Director – Science (SSEC)
EDR Environmental Data Record
EMC Environmental Modeling Center
EOS Earth Observing System
EPA Environmental Protection Agency
ESI Evaporative Stress Index
ESIP Earth Science Information Partners
ESPC Environmental Satellite Processing Center
ET Evapotranspiration
FAA Federal Aviation Administration
FDCA Fire Detection and Characterization Algorithm
FDII Flash Drought Intensity Index
FEMA Federal Emergency Management Agency
FGGE First GARP Global Experiment
FIRE First ISCCP Regional Field Experiment
FOV Field Of View
FTP File Transfer Protocol
FTS Fourier Transform Spectrometers
FV3 Finite Volume Cubed-Sphere Dynamical Core
FY Fiscal Year
GB Gigabyte
GDP Gross Domestic Product
GEO Geostationary
GeoXO Geostationary Extended Observations
GFS Global Forecast Systerm
GFSFV3 GFS Finite Volume Cubed-Sphere dynamical core
GIIRS Geostationary Interferometric Infrared Sounder
GIS Geographic Information Systems
GLM GOES Lightning Mapper
GMAO Global Modeling and Assimilation Office
GMS Geostationary Meteorological Satellite
GOES Geostationary Operational Environmental Satellite
GOES-R Geostationary Operational Environmental Satellite – R(S,T,U) Series once operational GOES 16-19
GOSAT Greenhouse gases Observing SATellite

GPS Global Positioning System
GPU Graphics Processing Unit
GRB GOES Rebroadcast
GSI Gridpoint Statistical Interpolation
GXI GeoXO Imager
GXS GeoXO Sounder
HDF Hierarchical Data Format
HIRS High-resolution Infrared Radiation Sounder
HIS High-spectral resolution Interferometer Sounder
HPCC High-Performance Computing Cluster
HRRR High Resolution Rapid Refresh
HSRL High Spectral Resolution Lidar
HU Hampton University
HWRF Hurricane Weather Research and Forecast model
HWT Hazardous Weather Testbed (NOAA)
HYDRA Hyper-spectral Data Research Application
IAPP International ATOVS Processing Package
IASI Infrared Atmospheric Sounding Interferometer
ICAO International Civil Aviation Organization
IDD Internet Data Distribution
IEEE Institute of Electrical and Electronics Engineers
IFR Instrument Flight Rules
IMAPP International MODIS/AIRS Processing Package
IMETs Incident Meteorologists
IODC Indian Ocean Data Coverage
IPCC Intergovernmental Panel on Climate Change
IPO Integrated Program Office
IR InfraRed
IRS InfraRed Sounder
ISCCP International Satellite Cloud Climatology Project
ITPP International TOVS Processing Package
ITWG International TOVS Working Group
IUCRC Industry-University Cooperative Research Center
IWP Ice Water Path
JPSS Joint Polar Satellite System
JMA Japan Meteorological Agency
JPL Jet Propulsion Laboratory
JPSS Joint Polar Satellite System
KML Keyhole Markup Language
KPP Key Performance Parameter
KSC Kennedy Space Center
LDM Local Data Manager
LEO Low Earth Orbit
LHP Loop Heat Pipe
LSC Life Science Communications
LWP Liquid Water Path
M.S. Master of Science
McIDAS Man computer Interactive Data Access System
MERSI Medium Resolution Spectral Imager
Meteosat METEOrological SATellite
METOP Series of polar orbiting meteorological satellites (EUMETSAT)
MiRS Microwave integrated retrieval system
ML Machine Learning
MODAPS MODIS Adaptive Processing System
MODIS Moderate Resolution Imaging Spectroradiometer
MOU Memorandum of Understanding
MRMS Multi-Radar/Multi-Sensor

MSI Minority Serving Institution
MTG-IRS European Meteosat Third Generation – Infrared Sounder
MTSAT-1R Japan's geostationary imager
MVCM MODIS-VIIRS Cloud Mask
MW Microwave
NASA National Aeronautics and Space Administration
NCA National Climate Assessment
NCEI National Centers for Environmental Information
NCEP National Centers for Environmental Prediction
NERTO NOAA Experiential Research and Training Opportunity
NESDIS National Environmental Satellite, Data and Information Services
NEON National Environmental Observatory Network
NGFS Next Generation Fire System
NGGPS Next Generation Global Prediction System
NHC National Hurricane Center
NOAA National Oceanic and Atmospheric Administration
NPOESS National Polar Orbiter Environmental Satellite System
NPP NPOESS Preparatory Project
NR Nature Run
NREL National Renewable Energy Laboratory
NSF National Science Foundation
NSRDB National Solar Radiation Database
NSSL National Severe Storms Laboratory
NUCAPS NOAA Unique Combined Atmospheric Processing System
NWP Numerical Weather Prediction
NWS National Weather Service
NWSFO NWS Forecast Office
OAR Office of Oceanic and Atmospheric Research
OCLO/FDTD Office of the Chief Learning Officer/Forecast Decision Training Division
OGC Open Geospatial Consortium
OMPS Ozone Mapping Profiler Suite
ONR Office of Naval Research
OPC Ocean Prediction Center
OSE Observing System Experiments
OSPO NOAA Office of Satellite Product Operations
OSSE Observing System Simulation Experiments
OVCR Office of the Vice Chancellor for Research
PATMOS-x Pathfinder Atmosphere
PB Petabytes
Ph.D. Doctor of Philosophy
PHS Polar Hyperspectral Soundings
PI Principal Investigator
PM Program Manager
POES Polar Orbiting Environmental Satellite
PoR Program of Record
PREFIRE Polar Radiant Energy in the Far-Infrared Experiment
ProbSevere Probability of Severe Thunderstorm at earth surface
QC Quality Control
QOSAP Quantitative Observing System Assessment Program
RAQMS Regional Air Quality Modeling System
RPPR Research Performance Progress Report
RT Radiative Transfer
S4 Supercomputer for Satellite Simulations and Data Assimilation Studies
SAF Satellite Applications Facility
SATMOC Satellite Meteorology Oceanography and Climatology
SBIR Small Business Innovation Research
SCO State Climatology Office

SDR Sensor Data Record
SDS Satellite Data Services
SFY State Fiscal Year
S-HIS Scanning High resolution Interferometer Sounder
SHyMet Satellite Hydrology and Meteorology
SMS Synchronous Meteorological Satellite
SNO Simultaneous Nadir Overpass
SOO Science and Operations Officer
SOS Science on a Sphere
SPARC SSEC Portable Atmospheric Research Center
SPC Storm Prediction Center
SSEC Space Science and Engineering Center
STAQS Synergistic TEMPO Air Quality Science
STAR Satellite Applications and Research
STEM Science, Technology, Engineering, Mathematics
STORM REU Student Training in Oceanography Remote Sensing and Meteorology
STTR Small Business Technology Transfer
SWIR Shortwave Infrared
TAF Terminal Aerodrome Forecast
TB Terabytes
TC Tropical Cyclones
TEMPO Tropospheric Emissions: Monitoring of Pollution
TIM Technical Interchange Meeting
TIROS Television InfraRed Observation Satellite
TOVS TIROS Operational Vertical Sounder
TPC Tropical Prediction Center
TPW Total Precipitable Water
TROPICS Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats
TROPOMI Tropospheric Monitoring Instrument
TROWALs Troughs of Warm Air Aloft
UPS Uninterruptible Power Supply
USNIC U.S. National Ice Center
UTC Universal Coordinated Time or Universal Time Coordinated
UW University of Wisconsin
VAAC Volcanic Ash Advisory Center
VAS VISSR Atmospheric Sounder
VIIRS Visible/Infrared Imager and Radiometer Suite
VISIT Virtual Institute for Satellite Integration Training
VISSR Visible and Infrared Spin-Scan Radiometer
VOLCAT Volcanic Cloud Analysis Toolkit
VSF Virtual Science Fair
WARF Wisconsin Alumni Research Foundation
WF_ABBA Wildfire Automated Biomass Burning Algorithm
WFO Weather Forecast Office (NWS)
WICCI Wisconsin Initiative on Climate Change Impacts
WMO World Meteorological Organization
WMS Web Map Service
WMTS Web Map Tile Service
WRF Weather Research and Forecasting model

Appendix B: CIMSS Executive Board and Council of Fellows

CIMSS EXECUTIVE BOARD

CIMSS Executive Board (Board) – The Executive Board will consist of senior employees from NOAA and UW–Madison. The Board shall review the policies, research themes, and priorities of CIMSS, including budget and scientific activities and will also provide for the periodic external review of the scientific activities of CIMSS. The Director of CIMSS or his/her designee shall serve as a non-voting member of the Board.

Cynthia Czajkowski
Interim Associate Vice Chancellor for Research and Graduate Education

Tristan L'Ecuyer
Director, CIMSS

R. Bradley Pierce
Director, Space Science and Engineering Center, UW–Madison

Ankur Desai
Chair, Department of Atmospheric and Oceanic Sciences, UW–Madison

Steven Volz
Assistant Administrator for Satellite and Information Services, NOAA/NESDIS

Doug Howard
Director, Center for Satellite Applications and Research, NOAA/NESDIS

Jeff Key
NOAA/NESDIS

Jack A. Kaye
Assoc. Director for Research, NASA

Dalia Kirschbaum
Director, Earth-Sun Exploration Division of the Sciences and Exploration Directorate, NASA Goddard Space Flight Center

CIMSS COUNCIL OF FELLOWS

CIMSS Council of Fellows (Council) - The Council of Fellows advises the CIMSS Director in establishing the broad scientific content of CIMSS programs, promoting cooperation among CIMSS, NOAA, NASA, and other agencies, maintaining high scientific and professional standards, and preparing reports of CIMSS activities. All Council members shall be recommended and selected by the Director of CIMSS, in consultation with the Executive Board. In addition, the Executive Director of SSEC or designee shall be a Council member. Council members shall serve three-year terms. Reappointment is possible for additional three-year terms pending approval by the Board. The number of Council members shall be set by the Board, provided the number of University members equal the total number of agency members. The Director of CIMSS will serve as the Chairperson of the Council.

Tristan L'Ecuyer	Director, CIMSS, Professor, UW–Madison Atmospheric and Oceanic Sciences
Dave Tobin	Distinguished Scientist, CIMSS
Chris Velden	Senior Scientist, CIMSS
Mayra Oyola-Merced	Professor, UW–Madison Atmospheric and Oceanic Sciences
Tracey Holloway	Professor, UW–Madison, SAGE
Steven Miller	Professor, Department of Atmospheric Science, Colorado State Univ.
Dan Lindsey	GOES-R Program Scientist, NOAA/NESDIS
Mitch Goldberg	Distinguished Research Scientist, CCNY, NOAA/CESSRST
Lazaros Oreopoulos	Chief Climate Radiation Lab, NASA Goddard Space Flight Center

Title

A Proposal to

The National Oceanic and Atmospheric Administration
National Environmental Satellite Data and Information Service
Center for SaTellite Applications and Research (STAR)

Program:

For the Period
1 July 2024 – 30 June 2025

Support Requested: $
Total Task I: $
Total Task II: $

Submitted by the
University of Wisconsin-Madison

On behalf of

The Cooperative Institute for Meteorological Satellite Studies (CIMSS)
Space Science and Engineering Center (SSEC)
at the University of Wisconsin-Madison
1225 West Dayton Street
Madison, Wisconsin 53706

Dr. Tristan L'Ecuyer
Principal Investigator / CIMSS Director

Brenda Egan, Managing Officer Pre-award
Research and Sponsored Programs

Date

NOAA's Mission: Science, Service, and Stewardship
To understand and predict changes in climate, weather, oceans, and coasts,
To share that knowledge and information with others, and
To conserve and manage coastal and marine ecosystems

NOAA's Long-Term Goals:
Weather-Ready Nation: Society is prepared for and responds to weather-related events

NOAA Strategic Plan-Mission Goals
- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

Cross-Cutting Priorities
1. Accurate and reliable data from sustained and integrated earth observing systems
2. An engaged and educated public with an improved capacity to make scientifically informed environmental systems
3. Diverse and constantly evolving capabilities in NOAA's workforce

CIMSS Research Themes
Theme 1. Satellite Meteorology Research and Applications
Theme 2. Satellite Sensors and Techniques
Theme 3. Environmental Models and Data Assimilation
Theme 4. Education and Outreach

CIMSS Tasks
Task I: Administrative Activities – CIMSS Management, Education, Outreach
Task II: Research involving direct collaboration with NOAA scientists, including research collaborations with locally stationed NOAA scientists

NOAA Funding Source:
Contact Information:

Brief Summary:

Short description of project, goals, and benefits to stakeholders and the public

Introduction

CIMSS CA Task I: CIMSS management support, including General Education and Outreach Activities

Project Lead:

Total Task I Budget: $

CIMSS Support:

Project Description

Task I activities are related to the overall management of CIMSS, as well as general education and outreach activities. These are activities that support the operation of CIMSS; provide outreach platforms to transmit CIMSS science to varied audiences; train and develop future scientists in the workforce, and provide capabilities requested under the Federal Funding Opportunity NOAA-NESDIS-NESDISPO-2024-2008175, but which are not tied to a specific project or projects. Task I funding includes partial funding/salary support for the CIMSS PI/Director, Tristan L'Ecuyer, and other CIMSS management support staff, travel, and visiting researcher support. Also, inclusive of Task I are educational and outreach activities including support of post-docs and graduate students within CIMSS not assigned to specific projects or research; support of undergraduate research interns; development of community outreach, education, and training programs; and support for CIMSS education and outreach staff. The inclusion of Task I for all CIMSS submissions are based on NOAA requirement as part of the FY24 Funding Guidance Memo directive, with a provided target value of ~3.6% of Task II and III activities.

CIMSS CA Task II: Research involving direct collaboration with NOAA scientists, including locally stationed NOAA scientists

Task 2.1: Title

Project Lead:

CIMSS Support Scientists:

Budget $

NOAA Collaborators:

2.1.1) Project description

2.1.2) Background and Previous Work

2.1.3) Proposed Activities for 2024-2025

2.1.4) Milestones

Management, Facilities and Reporting

Management and Personnel (Example)

The Cooperative Institute for Meteorological Satellite Studies (CIMSS) is a scientific research unit within the Space Science and Engineering Center (SSEC). Dr. L'Ecuyer, Principal Investigator and CIMSS Director, has a successful research career working in the atmospheric sciences in studies pertaining to radiation, radiative transfer, cloud microphysics and their impact on climate. Dr. L'Ecuyer's research has involved the extensive use of NOAA weather satellite data. Dr. L'Ecuyer will be responsible for overseeing and managing the activities described above. The CIMSS Executive Director - Science, Wayne Feltz, will also provide oversight to the project. Mr. Feltz oversees the day-to-day operations of SSEC scientific research, and provides management and coordination for the more than 50 current CIMSS research grants and contracts. The Project Leaders provide the important expertise to the research components of this proposal. Project Leaders are responsible to the Director for their individual research tasks, presenting their results at meetings and conferences, and submitting reports on their findings.

Facilities

The Space Science and Engineering Center (SSEC) is a research facility within the Office of the Vice Chancellor for Research (OVCR) of the University of Wisconsin-Madison. The Center is in a 15-story building on the UW-Madison campus. Within SSEC, the Cooperative Institute for Meteorological Satellite Studies (CIMSS) was established in 1980 to formalize and support cooperative research between the National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) and the UW-Madison's Space Science and Engineering Center. CIMSS serves as an international center for research on the interpretation and uses of operational and experimental satellite observations for a wide variety of atmospheric and oceanographic studies and for their potential operational applications. CIMSS works in close collaboration with the UW-Madison Department of Atmospheric and Oceanic Sciences to provide graduate student research support to more than fifteen students per year. The education/research center link provides an excellent path for young scientists entering geophysical fields.

SSEC Data Center

The SSEC Data Center's Satellite Data Services receives real-time, full resolution data from the GOES-16/17/18, Himawari, COMS, METEOSAT, MTSAT, and FY2 geostationary satellites, and NOAA, METOP, JPSS, Suomi NPP, EOS and FY1/3 polar orbiting (POES) meteorological satellites. It also receives the GEOnetcst, NWS NOAAport data streams and other alphanumeric, grid, model and radar data feeds. The Data Center has been archiving GOES data since 1978, and has access to all GOES imager and sounding data since that time. Over 8 TBs of data are ingested daily, of which, approximately 1 TB of the geostationary data are archived. The current archive of geostationary data exceeds 1.4 PBs, all of which are online and accessible by UW CIMSS researchers.

Reporting

An Annual Progress Report will be provided via grants online to the NOAA Grants Management Division and to the NOAA/NESDIS/STAR Cooperative Institute Program Officer as part of the CIMSS Cooperative Agreement reporting requirements.

Data Management Plan (maximum 2 pages)

1. Principal Investigator contact and descriptions of types of environmental data and information to be created or collected during the course of the project

a. PI contact information (name, institutional affiliation, email, phone).
b. Type(s) (aircraft, ship, satellite, etc.) to be collected

c. Will all data have value to other researchers?
d. What resources will you require to deliver this plan – either reflected in the budget or external to the project?

2. Type of collection method

a. ***Type(s) (aircraft, ship, satellite, etc.) to be collected*** and anticipated volume/scope of data to be generated.
b. Describe the method for documentation (including version control, directory structures, etc.) and for periodically checking the integrity of the data
c. If there is pre-existing data, describe its provenance (lineage, how was it derived)

3. Standards to be used for data/metadata format and content

a. Are there governing standards? If so, what are they? For example: NetCDF (https://www.nodc.noaa.gov/data/formats/netcdf/v2.0/), FGDC, HDF
b. Include descriptions of file formats and names and their organization, parameter names and units, spatial and temporal resolution, metadata content, etc.

4. Policies addressing data stewardship and preservation

a. Describe methods for preserving the data.
b. What hardware and/or software resources are required to store the data?
c. How will the data be stored and backed up (include frequency and who is responsible for this process)?

5. Procedures for providing access, sharing, and security and prior experience in publishing such data

a. What access or security requirements does your sponsor have, if any (are there any embargo periods, for example)?
b. Are there any privacy / confidentiality /export controls / intellectual property (copyright) requirements ?
c. Who can access the data:
    i. During active data collection
    ii. When data are being analyzed and incorporated into publications
    iii. When data have been published
    iv. After the project ends
    v. Tentative date by which data will be publicly shared
d. Are there any policies for re-use, redistribution or the production of derivatives?
e. How should the data be cited and the data collectors acknowledged?
f. What is the URL for public access to this Data Sharing Plan and the data? How long will they be available at that location?
g. Briefly describe previous experience, if any
h. Any peer-reviewed manuscripts produced with NOAA funding are to be submitted to the NOAA Institutional Repository to be made publicly available after an embargo of not more than one year: https://library.noaa.gov/Research-Tools/IR

6. Optional: Plans for eventual transition of the data to an archive after the project ends

a. If appropriate, identify a suitable data center within your discipline (SSEC Data Center, NODC, NCEI, NGDC, NSIDC, CDIAC, NSSDC, UCAR, etc.)
b. Consider establishing an agreement for archival storage.
c. Understand the data center's requirements, including costs, for submission and incorporate into data sharing plan.