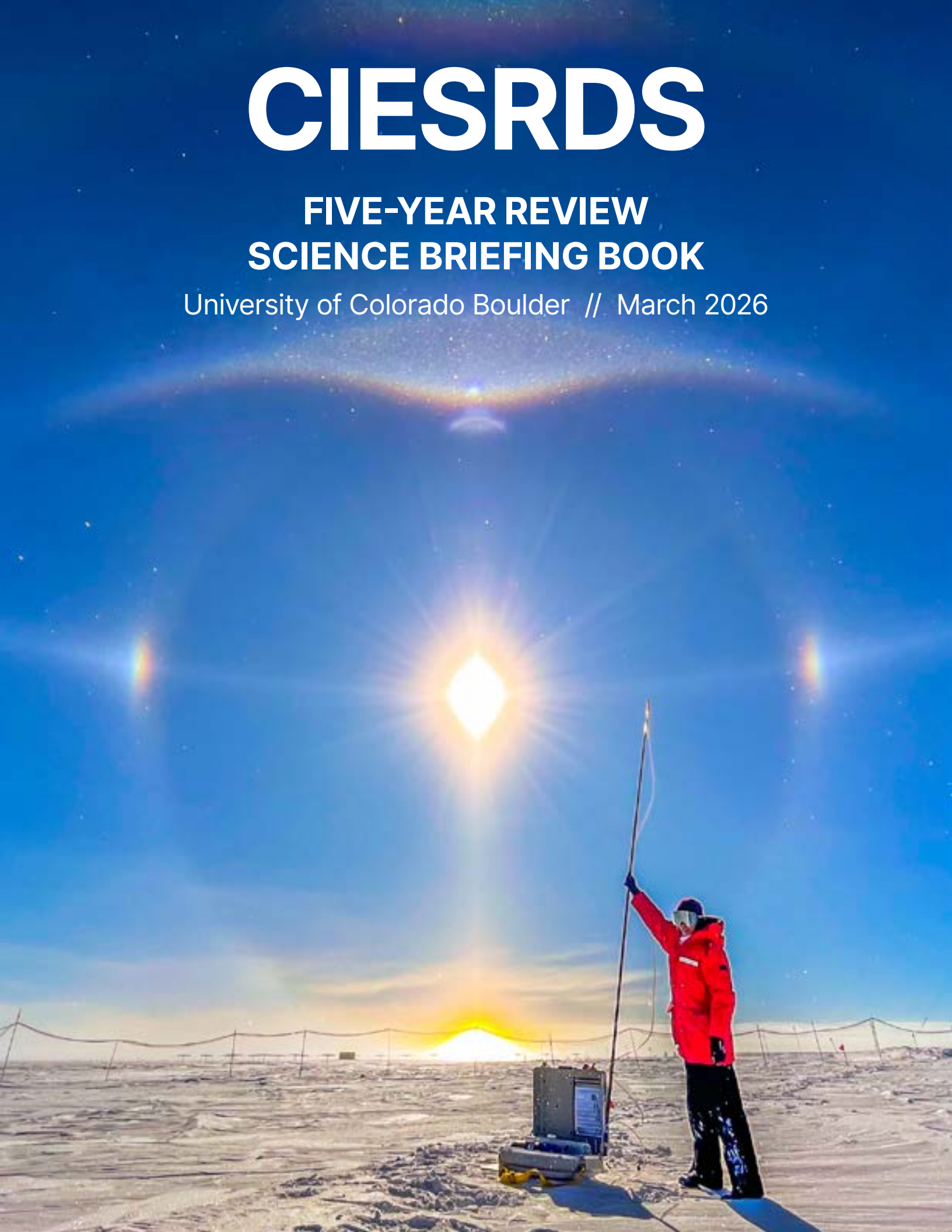
CIESRDS

FIVE-YEAR REVIEW
SCIENCE BRIEFING BOOK

University of Colorado Boulder // March 2026



CIESRDS

COOPERATIVE INSTITUTE FOR EARTH SYSTEM RESEARCH AND DATA SCIENCE

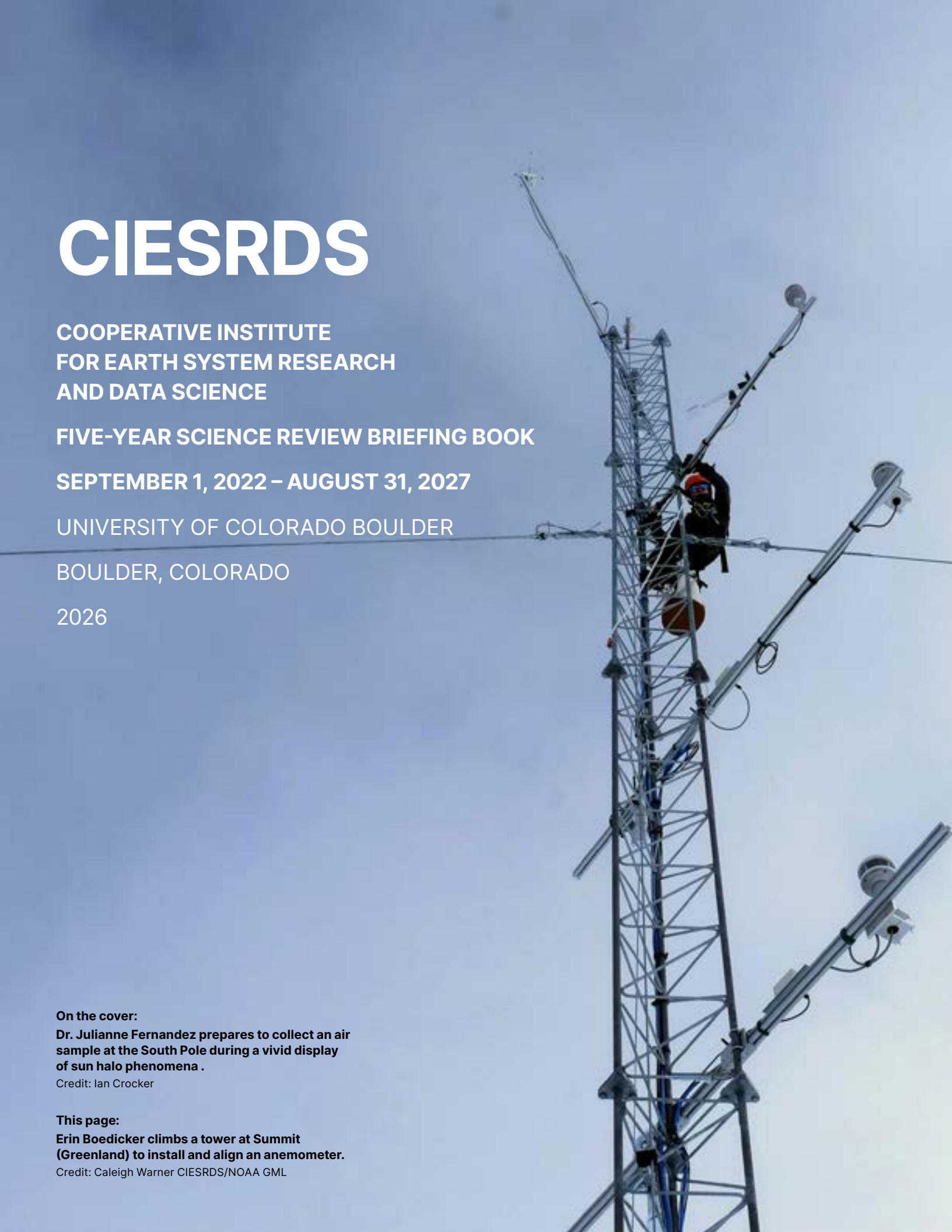
FIVE-YEAR SCIENCE REVIEW BRIEFING BOOK

SEPTEMBER 1, 2022 – AUGUST 31, 2027

UNIVERSITY OF COLORADO BOULDER

BOULDER, COLORADO

2026



On the cover:
Dr. Julianne Fernandez prepares to collect an air sample at the South Pole during a vivid display of sun halo phenomena .
Credit: Ian Crocker

This page:
Erin Boedicker climbs a tower at Summit (Greenland) to install and align an anemometer.
Credit: Caleigh Warner CIESRDS/NOAA GML

Elisabeth Andrews performs maintenance on integrating nephelometer at Bondville, Illinois site. Ccredit: Erin Boedicker

Executive Summary

The Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado Boulder has partnered with the National Oceanic and Atmospheric Administration (NOAA) since 1967, forming one of NOAA's longest-standing and most productive cooperative institute relationships. In September 2022, this partnership entered a new phase with the establishment of the Cooperative Institute for Earth System Research and Data Science (CIESRDS), a cooperative agreement that funds CIRES' research conducted in NOAA laboratories for up to ten years. CIESRDS reflects a renewed and expanded commitment to advancing Earth system research and data science in direct service to NOAA's mission and the nation's needs.

Over the past five years, CIESRDS has demonstrated exceptional performance in advancing NOAA's scientific priorities through high-impact research across eight thematic areas:

- Future Atmosphere
- Climate Science and Prediction
- Earth System Data Science, Stewardship, and Application
- Regional Science and Application
- Scientific Outreach and Education
- Space Weather Science and Prediction
- Weather Research and Forecasting
- Ecosystem Science and Prediction

CIESRDS researchers, working side-by-side with NOAA scientists, have delivered innovative science, data products, and decision-support tools that strengthen NOAA's environmental intelligence enterprise and support societal resilience to environmental change. This close integration enables interdisciplinary approaches, rapid-response capabilities, and coordinated studies at a scale that neither NOAA nor a university could achieve independently.

The overarching goal of the CIESRDS cooperative agreement is to support NOAA with Earth system research and data science on topics of significant societal importance. To meet this goal, CIESRDS is helping society respond to the urgent challenges of a changing world by conducting high-quality, mission-driven research in collaboration with NOAA; training and inspiring a diverse, skilled future workforce for NOAA and beyond; expanding Earth system and data science literacy among learners of all ages; serving the public and decision-makers with trusted information that fosters resilience; and providing the robust scientific and administrative infrastructure required to operate a cost-effective, compliant, and responsive cooperative institute while supporting growth in external funding.

CIESRDS benefits from the depth and scale of CIRES, the largest research institute at CU Boulder and one of the biggest in the country. For example, in FY 2024, CIRES managed $122 million in research awards from NOAA, NASA, NSF, and other sponsors; supported 908 scientists, engineers, developers, students, and staff; and produced 624 peer-reviewed publications. This scale is matched by a mature and highly effective management, financial, and administrative infrastructure that supports scientific excellence, accountability, and adaptability, enabling researchers to focus on delivering results that advance NOAA's mission and benefit society.

CIESRDS' vision is to be an international leader in cross-cut-

ting environmental research that bridges fundamental science and service to society. We support and develop leaders, scientists, communicators, and interdisciplinary teams dedicated to producing sound, trusted information to address pressing environmental challenges. Central to this vision is a positive and inclusive culture that recognizes that CIESRDS thrives when its people do—an approach that has proven essential to sustaining exceptional performance and impact. The CIESRDS Strategic Plan (Appendix J) guides the institute's work across four imperatives: conducting high-quality research in service to NOAA, training a diverse future workforce, growing Earth system literacy, and providing robust scientific and administrative infrastructure.

Over the course of the current award period (Sep. 1, 2022 to Dec. 31, 2025), CIESRDS has demonstrated exceptional productivity and impact across the research, research-to-operations, and operational enterprise. CIESRDS researchers have produced 1,360 peer-reviewed publications and delivered 1,780 conference presentations—averaging approximately 500 per year—reflecting both scientific excellence and sustained engagement with the broader research community. In addition, CIESRDS has supported 51 testbeds and successfully transitioned 103 research products into NOAA operations, underscoring the institute's critical role in advancing research that directly informs and strengthens NOAA's mission delivery. Beyond scientific outputs, CIESRDS has made a substantial contribution to NOAA's workforce capacity: between September 2022 and December 2025, 38 Cooperative Institute employees transitioned into NOAA federal positions. This outcome highlights the importance of the cooperative institute model in supporting NOAA not only through high-impact research, but also by cultivating and supplying a highly skilled scientific and technical workforce.

In summary, CIESRDS has delivered exceptional performance through the current award period, advancing Earth system research and data science across all eight thematic areas while directly supporting NOAA's mission and societal needs. This success reflects not only the scientific excellence and relevance of the research portfolio, but also the strength of the robust management, administrative, and support infrastructure that underpins the institute. Together, these elements enable CIESRDS to operate efficiently, remain responsive to evolving priorities, and translate research into real-world impact. By coupling high-quality, mission-aligned science with effective stewardship of people and resources, CIESRDS is well positioned to continue delivering value, innovation, and leadership throughout the remainder of the cooperative agreement.

Researchers start a day of field work in the Wrangell St. Elias National Park, Alaska.
Credit: Ethan Welty/Institute of Arctic and Alpine Research

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APPENDICES

CIRES Fellow Jen Kay and master's student Ethan Carr discuss snowpack observations in Gothic, Colorado while on a four day field trip during the Study of Precipitation, the Lower Atmosphere and Surface for Hydrometeorology (SPLASH) field campaign.
Credit: Stephanie Maltarich/CIESRDS

About CIESRDS

CIESRDS builds on a distinguished legacy that began with the establishment of the Cooperative Institute for Research in Environmental Sciences (CIRES) on September 29, 1967, under the leadership of J. C. "Chris" Harrison. Working closely with the Department of Commerce laboratories in Boulder, Harrison helped forge a new model for collaborative environmental research. Created as a joint enterprise between the University of Colorado and the Environmental Sciences Service Administration—soon renamed the National Oceanic and Atmospheric Administration (NOAA)—CIRES was envisioned as an interdisciplinary institute spanning the solid, liquid, and gaseous components of the Earth system. This foundational commitment to integrated, cross-cutting science has guided more than five decades of partnership and continues to shape the evolution of NOAA–university collaboration.

CIESRDS, the Cooperative Institute for Earth System Research and Data Science, represents the newest chapter in this long-standing relationship. Established in September 2022 through a cooperative agreement supporting CIRES research conducted within NOAA laboratories for up to ten years, CIESRDS reflects a renewed and expanded commitment to advancing Earth system research and data science in direct service to NOAA's mission and the nation's environmental and societal needs. Building on CIRES's interdisciplinary roots while embracing emerging scientific and technological frontiers, CIESRDS strengthens the partnership's capacity to address complex environmental challenges and deliver actionable knowledge for the public good.

In 1967, Dr. Chris Harrison became the first Director of CIRES. Among the accomplishments of the original steering committee were the establishment of strong support for the joint

institute and the adoption of the name Cooperative Institute for Research in Environmental Sciences (CIRES).

In 1972, Carl Kisslinger became Director of CIRES. During his tenure, CIRES worked to establish itself as a foundational institute, both in the quality of the science conducted and in employee compensation practices that had not previously been seen elsewhere.

In January 1973, a fundamental shift occurred when the Office of Management and Budget (OMB) directed that all solid-earth research be removed from NOAA and transferred to the U.S. Geological Survey (USGS) within the Department of the Interior. However, then-NOAA Administrator Robert White recognized the importance of solid-earth research to understanding the oceans and atmosphere and frequently turned to CIRES as an effective link between NOAA's research goals and the solid-earth research community.

In 1974, ties between CIRES and the NOAA research laboratories were strengthened through the expansion of research priorities and research associate appointments. In alignment with NOAA hiring practices and regulations, a procedure was established allowing a NOAA laboratory director to nominate a CIRES Ph.D.-level scientist for appointment to a specific research position with committed funding for salary and research.

In 1980, Robert E. "Bob" Sievers became Director of CIRES and served for 13 years. During his tenure, sponsored awards grew from 30 to 108 by 1992, and total CIRES funding increased from $3 million to more than $16 million. In 1988, under Sievers's leadership, CIRES moved to a newly constructed building on the CU Boulder main campus. CIRES later remodeled and expanded within the Ekeley Science Building, where it resides today.

In September 1994, Susan K. Avery was appointed Director. Under her leadership, organization and direction were strengthened, and CIRES research was grouped into a framework of scientific divisions organized under five thematic areas to provide coherence and strategic focus. A major initiative launched in 1996 was the formation of an organized outreach and K–12 education program.

Konrad Steffen became Director in 2004 and served until 2012. During his tenure, funding increased by about 50% to approximately $60M, with half coming from the cooperative agreement with NOAA. Also in that time, ties to NOAA and its other cooperative institutes were significantly strengthened.

Waleed Abdalati was appointed Director in 2013 and continues in that role today, now entering his fourth four-year term. Under Abdalati, CIRES has experienced significant growth in both scope and impact. Annual funding has risen from approximately $62 million in FY13 to more than $122 million in FY24, and the institute has grown to approximately 900 researchers and staff—about half of whom are supported through CIESRDS and work embedded in NOAA facilities. The CIRES footprint has expanded both on campus and in the broader scientific community, with Abdalati regularly called upon for advisory roles by NOAA, NASA, and international research organizations. He has also provided bipartisan congressional testimony on behalf of CIRES science, reflecting growing national recognition of the institute's contributions to understanding climate change and its impacts. Throughout his tenure, Abdalati has emphasized CIRES' guiding principle of "science in service to society"—ensuring that research not only advances fundamental understanding of the environment but also informs decisions that affect communities and the future of the planet.

In September 2022, Abdalati led the transition to a new cooperative agreement and the establishment of CIESRDS with a renewed scientific portfolio organized under eight thematic areas:

- Weather Research and Forecasting
- Climate Science and Prediction
- Earth System Data Science, Stewardship, and Application
- Future Atmosphere
- Regional Science and Applications
- Space Weather Science and Prediction
- Scientific Outreach and Education
- Ecosystem Science and Prediction

CIESRDS plays a critical role in advancing the mission and effectiveness of CIRES by providing the strategic backbone that connects, coordinates, and amplifies NOAA-focused research across the institute. Like other Cooperative Institutes, CIESRDS encompasses a broad and diverse portfolio of researchers and projects housed at a university, many of which are complementary to—but not always directly funded through—the Cooperative Agreement. CIRES provides the structure and leadership needed to align these parallel investments with NOAA priorities, enabling CIESRDS to function as a cohesive, integrated enterprise rather than a collection of independent efforts.

Through CIESRDS, CIRES leverages its institutional breadth to create synergies between Cooperative Agreement research and externally funded activities, including university, federal, and other sponsor-supported projects. This integration strengthens scientific outcomes, accelerates innovation, and enhances the relevance and impact of CIESRDS research for NOAA and the nation. By coordinating across funding sources and organizational boundaries, CIESRDS ensures that expertise, infrastructure, and scientific advances are effectively shared and applied across the institute.

Importantly, investment in CIESRDS is heavily leveraged, yielding a significantly increased return on investment for CU Boulder, CIRES, and NOAA. Targeted funding for coordination, planning, and strategic integration enables substantially larger pools of externally funded research to be aligned with NOAA mission needs. Further, CU Boulder supports 23 faculty lines that align with CIESRDS research and bring substantial benefit to NOAA. This leverage multiplies the impact of the Cooperative Agreement, enhances CIESRDS's ability to respond to emerging scientific and operational challenges, and reinforces its position as a nationally leading model for cooperative research at the science–operations interface.

1. SCIENCE PLAN

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

The Cooperative Institute for Earth System Research and Data Science (CIESRDS), based at the University of Colorado Boulder, envisions a resilient and informed society empowered by cutting-edge Earth system science, transformative data innovation, and collaborative research excellence. In close partnership with NOAA, we advance interdisciplinary investigations that illuminate the dynamics of our planet—from the surface of the sun to the bottom of the ocean—while harnessing data science to decode complexity and deliver actionable insights. Our institute elevates scientific understanding through rigorous observation, modeling, and analysis; accelerates discovery by integrating environmental intelligence with emerging technologies; and supports NOAA's mission by providing timely, trusted science that informs forecasts, hazard preparedness, and environmental resilience. By guiding societal decision-making with transparent, accessible research, we empower communities, policymakers, and industries to adapt and thrive.

CIESRDS manages its research portfolio in alignment with the CIESRDS Strategic Plan (Appendix J), which establishes four imperatives: conducting high-quality research in service to NOAA, training a diverse future workforce, growing Earth system literacy, and providing robust scientific and administrative infrastructure. CIESRDS fosters a culture of innovation, integrity, and inclusion, serving as a catalyst for environmental stewardship and scientific leadership—ensuring that our work not only advances knowledge, but also safeguards the future and competitiveness of our nation.

At the CIRES, our mission is to conduct innovative Earth system science that deepens understanding of our dynamic planet and informs solutions for societal resilience. Through CIESRDS, we advance NOAA's mission by integrating eight core research themes: Weather Research and Forecasting; Climate Science and Prediction; Earth System Data Science, Stewardship, and Application; Future Atmosphere; Regional Science and Applications; Space Weather Science and Prediction; Scientific Outreach and Education; and Ecosystem Science and Prediction.

These themes guide our interdisciplinary work—from improving forecasts and climate models to enhancing data stewardship and regional decision support. CIESRDS collaborates across disciplines and institutions to deliver actionable science, foster environmental literacy, and empower communities to navigate a changing world.

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

Yes, the CIRES/CIESRDS mission is to conduct innovative research that advances our understanding of the global, regional, and local environments and the human relationship with those environments, for the benefit of society. The CIRES/CIESRDS vision is to be an international leader in conducting cross-cutting environmental research of the highest quality while bridging fundamental science and service to society. The institute builds leaders, scientists, communicators, and teams dedicated to developing sound and trusted information to address environmental challenges. The institute embraces a positive and inclusive culture, recognizing that the institute thrives when its people do.

As an international leader in cross-cutting environmental science, CIESRDS bridges fundamental research with service to society, delivering trusted information to address pressing environmental challenges. We cultivate a vibrant culture that empowers our people to thrive, and we build leaders, scientists, communicators, and collaborative teams dedicated to excellence, integrity, and impact. Through this work, CIESRDS continues to shape a resilient future grounded in scientific insight and societal relevance.

i. How were the scientific mission/vision developed?

The vision and mission statement were developed more than a decade ago under our previous cooperative agreement. They were developed by the director at the time (who remains the director today) and presented to the CIRES Council of Fellows (the institute's advisory body, comprising faculty, researchers, and federal colleagues) for approval or modification. At the time of our last proposal submission, we determined that our vision and mission remain as relevant and appropriate as when first developed in 2013. As a result, they have not been revised.

ii. How are the science mission/vision communicated?

The scientific mission and vision are listed on the CIRES website at https://cires.colorado.edu/about. The mission and vision of CIRES and CIESRDS are also communicated to

Alex Baron demonstrates the Portable Optical Particle Spectrometer (POPS) instrument operation to B2SAP (Balloon Baseline Stratospheric Aerosol Profiles), a NOAA Earth's Radiation Budget Initiative Project) partners in Suriname. CIESRDS scientists and collaborators use high-altitude research aircraft and balloons to perform measurements and collect data from photochemical and dynamical processes that influence the composition of the atmosphere and their climate impacts. Credit: Alex Baron/CIESRDS

employees at new employee orientations and reinforced at all-hands meetings and events. In addition, they are prominently featured in CIESRDS Annual Reports and the CIRES and CIESRDS *Spheres* magazine, both of which are available on the CIRES website and distributed to all employees. Produced by the CIRES communications group, *Spheres* highlights the diverse research conducted at CIRES. Our scientists study all aspects of the Earth system, including the atmosphere, cryosphere, hydrosphere, geosphere, and biosphere. These "spheres" of expertise give our magazine its name. Further, these goals are embodied in the research we conduct, the presentations we deliver, and our education and outreach.

iii. How are the Vision and Mission related to the NOAA Strategic Plan in place at the time of adoption?

Both CIESRDS/CIRES and NOAA share a foundational commitment to advancing scientific understanding of Earth's systems and applying that knowledge for societal benefit. CIRES focuses on conducting innovative research to deepen understanding of global, regional, and local environments and the human relationship with these systems. Similarly, NOAA emphasizes understanding and predicting changes in climate, weather, oceans, and coasts. This alignment reflects a shared priority on environmental insight and predictive capability.

Both organizations underscore the importance of serving society through science. CIRES explicitly states that its research is "for the benefit of society," while NOAA commits to sharing knowledge broadly to inform communities, businesses, and decision-makers. This common goal highlights their dedication to translating scientific findings into actionable information that supports societal resilience and prosperity, as well as informed decision-making.

Environmental stewardship is another area of direct alignment. CIESRDS works to enable effective and sustainable responses to environmental challenges, which aligns with NOAA's efforts to conserve and manage coastal and marine ecosystems and resources, as well as air and water quality. While CIESRDS frames stewardship in terms of supporting solutions, NOAA operationalizes it by providing critical information for active resource management and conservation. Together, these missions demonstrate a shared responsibility for sustaining natural systems to optimally benefit people.

In summary, the key similarities between CIESRDS and NOAA can be grouped into three overarching themes:

- **Environmental Insight:** Both prioritize advancing knowledge of Earth's systems and predicting environmental changes.
- **Societal Benefit:** Each emphasizes making scientific knowledge accessible and useful for decision-making and the public good.
- **Stewardship and Sustainability:** Both CIESRDS and NOAA together enable and advocate for responsible management of the environment and ecosystems, whether through informing and enabling solutions or co-developing and applying those solutions to direct environmental practices, conservation, and resource management.

Collectively, these parallels underscore a unified vision: leveraging science to understand environmental processes, inform society, and promote sustainable stewardship of natural resources.

c. What are the CI's goals and objectives within the Scientific Plan?

The overarching goal of CIESRDS within the science plan is to advance a comprehensive understanding of the Earth System—spanning solar influences, atmospheric chemistry and dynamics, terrestrial processes, oceanic depths, and biospheric interactions—and translate that knowledge into operational products and enhanced predictive capabilities. By integrating observational science, modeling, and data analytics, we aim to improve forecast accuracy across temporal and spatial scales, mitigate risk, and support informed decision-making that safeguards life and property and that enhances environmental resilience. Further, CIESRDS aims to maintain a comprehensive education and outreach program to help educate and train the next generation of NOAA scientists and the nation's scientific workforce. The overarching objectives of CIESRDS are as follows:

- Advance research and promote collaboration across our eight core research themes
- Develop and support a robust and comprehensive education and outreach program
- Ensure that data and information are shared openly with other scientific institutions and the American public
- Foster an environment where staff are valued, trained, and supported to contribute to the CIESRDS mission

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

As mandated by the Government Performance and Results Act (GPRA) Modernization Act of 2010, cooperative institute (CI) directors, in partnership with NOAA leaders, developed metrics to evaluate CIs in a quantifiable and consistent manner. While these metrics provide a common framework across all CIs, it is important to recognize that not every metric applies equally, given the diverse functions and approaches used to achieve desired outcomes. CIESRDS uses the following metrics to measure our progress:

1. Science Dissemination

Number of papers in peer-reviewed journals per year. This information is included in the CI annual reports.

Number of non-refereed reference documents (e.g., NOAA reports) and conference presentations generated per year. This information is included in the CI annual reports.

Number of testbeds conducted. Leveraging testbeds to evaluate and refine new models, techniques, and tools while expanding CIESRDS research to broader audiences and ensuring alignment with established practices and applications across NOAA offices.

2. Research Impact

Number of products transitioned into operations. This is the number of techniques, algorithms, instruments, or products transitioned into operations by NOAA, another government agency, or a private company that are currently operational or ready for operational use pending approval from NOAA or another agency.

3. Leveraged Resources

Funding leveraging. The amount of funding from NOAA and other sources that supplements CI funding.

What the parent organization, CIRES, and the University bring to CIESRDS and the cooperative agreement. How CIESRDS leverages CIRES and CU Boulder to further expand research support and resources.

4. Career Development and Training

Number of CI-supported students/postdocs/research scientists/research associates who have obtained employment in positions related to the fulfillment of NOAA's objectives. A clear description of how it is determined that an individual is employed in a position related to NOAA's objectives needs to accompany this number.

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

CIESRDS researchers conduct work on the following eight overarching themes:

- **Weather Research and Forecasting:** Research under this theme improves weather research through a focused program of investment in affordable and attainable advances in observational, computing, and modeling capabilities to support substantial improvement in weather forecasting and prediction of high-impact weather events.
  For examples of some specific projects, see pages 146-198.
- **Climate Science and Prediction:** Research under this theme advances understanding of physical processes that produce variability, change, and extreme events in the climate system, including the interactions among the atmosphere, ocean, land surface, and cryosphere.
  For examples of some specific projects, see pages 57-86.
- **Earth System Data Science, Stewardship, and Application:** Research under this theme supports properly managed data obtained from NOAA and non-NOAA observing systems, including geophysical data, coastal

bathymetry, tsunami and hazards data, precise geodetic measurements, paleoclimate data, biological data, and worldwide geomagnetic, solar, and ionospheric measurements.
For examples of some specific projects, see pages 87-115.

- **Future Atmosphere:** Research under this theme focuses on observations and modeling of the atmosphere from the surface through the stratosphere, not only to advance understanding of the processes that drive changes in atmospheric composition, but also to improve predictions of the future atmosphere.
For examples of some specific projects, see pages 42-56
- **Regional Science and Applications:** Research under this theme observes and reports on impacts by:
  - Enhancing measurement, analysis, and understanding of physical processes of the coupled atmosphere-ocean-land-ice-snow system that modulate extreme events on regional, national, and global scales
  - Advancing observations, analysis, and understanding of local changes in the tropics and polar regions, and assessing the role of these regions in the global climate system
  - Advancing observing system science, demonstration, and transition of research advances to operations through regional testbeds that could lead to improved forecasts and warnings of extreme precipitation events and flooding
  - Identifying the role of key phenomena and processes in the weather-climate system that produce extreme precipitation events, severe and prolonged droughts, and marine and terrestrial heatwaves
  - Promoting the development of decision support tools for water resource management and validation data for weather and climate models
  - Developing the ability to explain the origins of weather and climate extremes that typically occur at regional scales
  For examples of some specific projects, see pages 116-124.
- **Space Weather Science and Prediction:** Research under this theme includes harnessing cutting-edge science and technology to provide actionable space weather information that safeguards society by planning, researching, and developing improvements to the Space Weather Prediction Center (SWPC) mission.
For examples of some specific projects, see pages 133-145.
- **Scientific Outreach and Education:** Research under this theme identifies opportunities for improving environmental literacy and new technologies for learning.
For examples of some specific projects, see pages 125-132.
- **Ecosystem Science and Prediction:** Research under this theme focuses on high-resolution, multi-decadal climate and Earth system model projections for assessing climate impacts and informing adaptation planning for Large Marine Ecosystem regions, terrestrial ecosystems, and the coastal interface.
For examples of some specific projects, see pages 199-204.

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

The primary science themes of CIESRDS are identical to those that NOAA used in the competition to create the CI. Although the research being carried out in each thematic area is steadily evolving, the themes themselves are not changing because they effectively encapsulate all the work that NOAA asked to be performed.

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?

New efforts in areas such as machine learning and AI, severe and fire weather research and communication, and the development and use of autonomous research vehicles fit naturally within these existing thematic frameworks.

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

Emerging research themes are guided by societal needs and NOAA's identified priorities, aiming to improve understanding of global, regional, and local environments and the human relationship with those environments. CIESRDS continually integrates new technologies, such as machine learning and artificial intelligence, to enhance data collection, streamline communication, and improve forecasting that protects lives and property. Newly identified areas of research are incorporated within existing themes to maintain alignment and focus.

e. Scientific Partnerships

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

CIESRDS maintains extensive collaborations across three NOAA line offices, partnering with multiple labs and centers to advance Earth system research. CIESRDS partners significantly with the National Centers for Environmental Information (NCEI) under the National Environmental Satellite, Data, and Information Service (NESDIS), where 90 employees and students support critical environmental data stewardship, space weather, and arctic research, to name a few areas. In the NOAA Office of Oceanic and Atmospheric Research, CIESRDS also works closely with the Physical Sciences Laboratory (PSL), home to 70 employees focused on atmospheric and climate dynamics. At the Global Monitoring Laboratory (GML), 76 team members contribute to monitoring greenhouse gases, ozone, and radiation and aerosols. The Chemical Sciences Laboratory (CSL) employs 60 CIESRDS staff dedicated to understanding chemical processes that affect air quality and climate. Within the Global Systems Laboratory (GSL), 51 employees develop advanced modeling and forecasting systems. The Space Weather Prediction Center (SWPC) hosts 25 staff members who provide operational space weather forecasts and conduct space weather research, while 12 employees at the Weather Prediction Center (WPC) support critical surface weather analysis, prediction, and communication.

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

CIESRDS fosters cooperative planning through a structured and collaborative approach that ensures alignment between scientists and federal partners. This process begins with the coordination of a science plan, where CIESRDS researchers and federal stakeholders jointly define priorities and objectives. Oversight and strategic guidance are provided by the formal CIESRDS Executive Board, which includes the Technical Program Manager (TPM), Federal Program Officer (FPO), senior CIESRDS staff, and directors of all participating laboratories and centers under the cooperative agreement. Further, CIRES employs an Associate Director for Science to oversee CIESRDS/CIRES research activities, primarily at the NOAA David Skaggs Research Center (DSRC), and to oversee its institutional science programs. The position is recently vacant, but final candidates are under consideration and the position is expected to be filled in early 2026. The position is responsible for the effective management and execution of scientific programs, understanding and addressing issues that affect CIRES Research Scientists and Research Associates, particularly those working with the federal employees at the DSRC, and representing the interests of CIRES research scientists to the Director. To maintain strong engagement and communication, the CIESRDS/CIRES Director holds focused virtual meetings with federal directors twice per month, creating opportunities for dialogue and connection. Additionally, the establishment of the CIESRDS Administrative and Science Manager role further strengthens support for both the cooperative agreement and the scientists and federal partners operating within it. These activities collectively ensure transparent planning, frequent communication, and effective collaboration across all levels of the partnership.

CIESRDS scientists in GML use AirCore, a balloon-borne atmospheric sampling system, to collect data on trace gases in the atmosphere from the middle stratosphere to the ground.

Photo: Sonja Wolter/CIESRDS

2. SCIENCE REVIEW

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

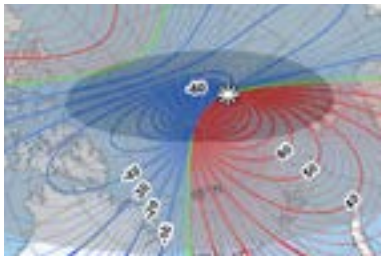
CIESRDS scientists have made significant accomplishments in science and in translation of scientific research into operations as evidenced by the 1,360 publications completed or submitted since Sept. 1, 2022, the 1,780 conference presentations, and the 103 research products successfully transitioned into NOAA operations. These accomplishments are described in the eight different theme sections that follow, with scientific highlights and accomplishments sorted according to the primary theme they represent, including:

i. Weather Research and Forecasting

See examples of some specific projects beginning on page 15.

ii. Climate Science and Prediction

See examples of some specific projects beginning on page 69.



iii. Earth System Data Science, Stewardship, and Application

See examples of some specific projects beginning on page 101.

iv. Future Atmosphere

See examples of some specific projects beginning on page 131.

v. Regional Science and Applications

See examples of some specific projects beginning on page 146.

vi. Space Weather Science and Prediction

See examples of some specific projects beginning on page 156.

vii. Scientific Outreach and Education

See examples of some specific projects beginning on page 170.

viii. Ecosystem Science and Prediction

See examples of some specific projects beginning on page 179.

Theme 1:

Weather Research and Forecasting

Lightning illuminates an evening thunderstorm. Credit: Christina Kumler/CIESRDS

WEATHER RESEARCH AND FORECASTING

The Weather Research and Forecasting Innovation Act of 2017 requires that NOAA prioritize weather research to improve weather data, modeling, computing, forecasts, and warnings to protect life and property and enhance the national economy. CIESRDS scientists' work substantially improves weather forecasting and the prediction of high-impact weather events to support this NOAA priority. Their work encompasses advancing weather observing systems, performing data assimilation, advancing high-performance computing techniques, building models, and developing weather information dissemination tools.

CIESEDS researchers are helping modernize estimates of probable maximum precipitation, working to incorporate air chemistry into forecast models, and evaluating freezing ice products used by the Weather Prediction Center.

CIESRDS scientists are also developing a next-generation hazardous weather warning dissemination software called Hazard Services. Hazard Services takes weather forecasts and generates and disseminates watches, warnings, and advisories to protect life and property. Hazard Services combines the capabilities of legacy National Weather Service applications into a single application and adds tremendous configurability to efficiently handle hazards like storm surge and tsunamis.

The two United States Tsunami Warning Centers currently issue tsunami warnings through separate systems derived from totally different code bases. CIESRDS scientists are developing a processing system that will bring their warning capabilities into a standardized NOAA system, leveraging the same architecture used by national Weather Forecasting Offices. Uniting the systems into a single infrastructure will standardize the workflow and product generation and provide seamless backup capabilities across the centers.

One key success CIESRDS scientists have had in this realm is dissecting the forecasting challenges posed by the mountain wave windstorm that contributed to Colorado's 2021 Marshall Fire. Their work could change how Red Flag Warnings are issued to warn residents of dangerous conditions and improve communication of the severity of the risk once a wildfire is burning.

CIESRDS scientists are also developing a revolutionary wildfire observing system called NightFOX, a lightweight remote sensing payload mounted on a small, uncrewed aircraft to observe wildfires. Using infrared and visible imaging instruments, NightFOX measures fire extent and intensity from safe altitudes, including at night. NightFOX fills critical observational gaps left by satellites and crewed aircraft, offering a low-cost, high-resolution alternative for improved wildfire monitoring and situational awareness.

Project: Providing operational support to the NOAA Research and Development High-Performance Computing systems

CIESRDS contributors: Eric Schnepp and Wei Yu

Relevance to NOAA: This project has directly helped move NOAA's next generation of experimental weather models from research to operations. These new weather models improve the accuracy and intensity of severe weather event forecasts to protect life and property.

This project provides high-performance computing (HPC) resources for NOAA across three geographical distribution sites, two partnership sites, and three cloud service providers. The researchers support NOAA's model and data assimilation research in weather, ocean, and hydrology. This team supports unique needs from model experiments, such as computation allocation transfer and disk storage requirements. They also install, upgrade, and track HPC-specific software to help users run their applications successfully and efficiently on research and development HPC systems, assist users via a helpdesk, and develop technical requirements for new HPC system procurements.

Over the next five years, the team will research efficient operating systems in HPC environments, architectural advances in HPC, high-performance interconnects, high-performance file systems, and their extension outside of the HPC environment. They will also create and apply new technologies to make the system more reliable and cost effective.

The state-of-the art high-performance computing center, known as JET, at NOAA Boulder.
Credit: NOAA GSL

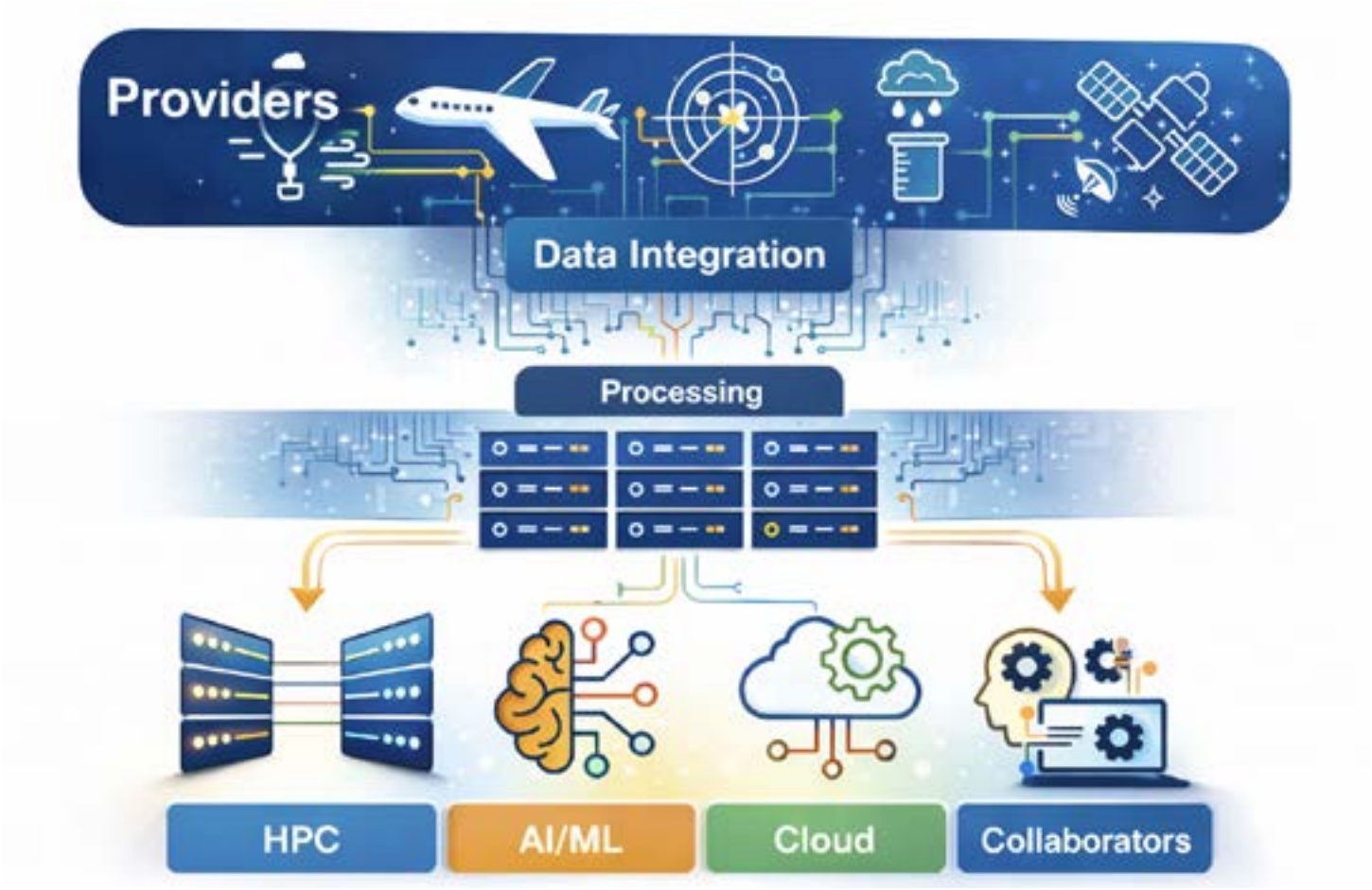
Project: Providing data services for scientific research

CIESRDS contributors: Michael Leon

Relevance to NOAA: The data services provided as part of this project have been critical in helping to facilitate NOAA scientific research projects. These datasets have benefited NOAA's high-performance computing programs and scientific research goals.

This project facilitates environmental data science research to improve and innovate atmospheric modeling techniques and revolutionize decision support. Researchers have developed and honed new tools to support a multitude of requests, from live data flows to retrospective archive retrievals, and add the ability to subset data files on the fly and speed up large transfers.

The team has so far provided new cloud-based data sources and implemented new technologies to monitor, alert, and track the performance and history of data flows and satellite signals. Customers receive frequent status updates and metrics. Over the next five years, the team will provide data services that support artificial intelligence and machine learning, a fire weather testbed, numerical weather prediction, and decision support research.



From sources to solutions: Diverse data providers feed a unified integration and processing pipeline, delivering useful outputs through HPC, AI/ML, and cloud platforms for research..

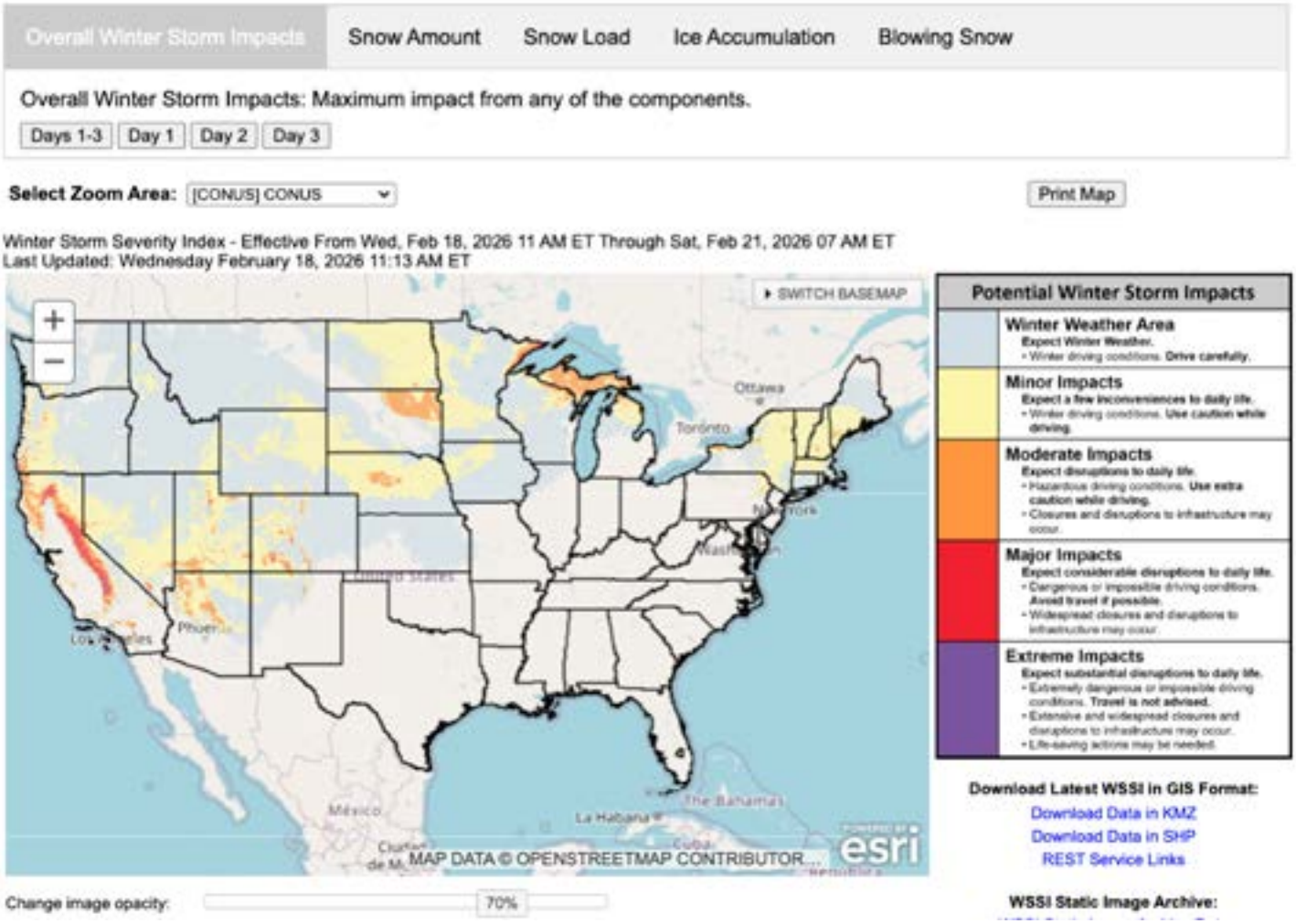
Credit: Susan Cobb/CIESRDS

Project: Developing the Winter Storm Severity Index (WSSI)

CIESRDS contributors: Dana Tobin

Relevance to NOAA: The Winter Storm Severity Index (WSSI) provides impact-based decision support services to help users anticipate and mitigate potential adverse societal impacts from winter storms, supporting the NOAA National Weather Service mission.

The Winter Storm Severity Index (WSSI) is a NOAA National Weather Service suite of forecast products used in operations that combines forecast data with climatological and non-meteorological datasets to communicate the severity and spatial distribution of anticipated societal impacts from winter weather. So far, the team has updated operational algorithms, decreased science run times for faster updates posting to the web, produced five journal articles, and held two product evaluations in NOAA testbeds. Over the next five years, they will expand the operational WSSI suite to include an Alaska version and a probabilistic hourly forecast.



Screenshot of the operational Winter Storm Severity Index (WSSI) product.
Credit: NOAA

Project: Developing an ensemble clustering application for the NOAA Weather Prediction Center

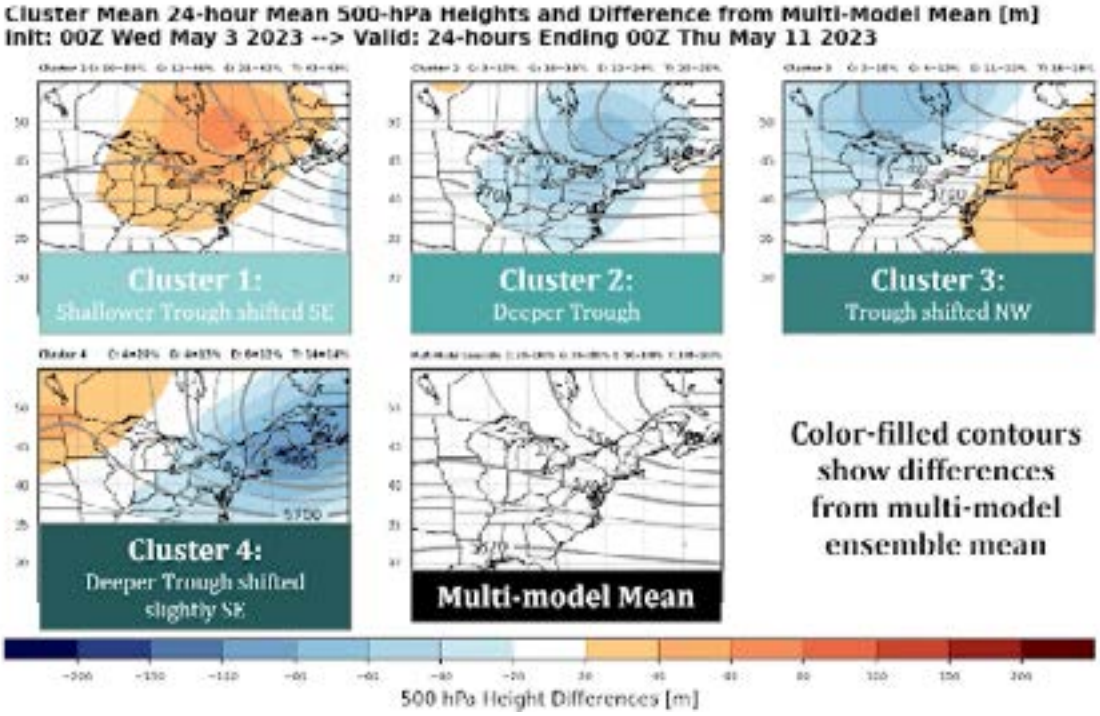
CIESRDS contributors: Austin Coleman

Relevance to NOAA: This project allows National Weather Service forecasters to quantify and provide context to forecast uncertainty to improve forecast accuracy and stakeholder collaborations, ultimately protecting lives and property.

CIESRDS scientists on this project developed an ensemble clustering application to help forecasters distill large suites of model forecast solutions into the most likely and meaningful scenarios. By reducing complex ensemble output into a small number of representative outcomes, the tool enables forecasters to better quantify uncertainty and communicate it clearly to a wide range of stakeholders. This capability is increasingly important as decision-makers rely on forecasts not only for deterministic guidance but also for context about risk, confidence, and potential alternative outcomes.

Over the past several years, the application has been significantly expanded to include additional atmospheric variables and new geographic domains, broadening its relevance across forecasting challenges. The project has produced a peer-reviewed journal article documenting the methodology and results, as well as a formal training module developed in partnership with UCAR COMET. Additional training materials were created to support operational forecasters, ensuring that the tool can be used effectively in real-time environments. The team also developed an experimental short-range version of the application based on the Rapid Refresh Forecast System (RRFS), extending ensemble clustering techniques into higher-resolution, shorter-lead-time prediction.

The products have been evaluated in two major testbeds, providing valuable feedback from operational meteorologists and helping refine both the science and the user experience. These evaluations demonstrate that the tool improves forecast accuracy and strengthens collaboration with stakeholders by allowing forecasters to quantify uncertainty and provide essential context around forecast confidence. As the next step, the project aims to transition the experimental web pages and prototype tools into fully operational status, ensuring that ensemble clustering becomes a routine part of the forecasting workflow.



A screenshot from the tutorial the team created on ensemble clustering.
Credit: COMET MetEd

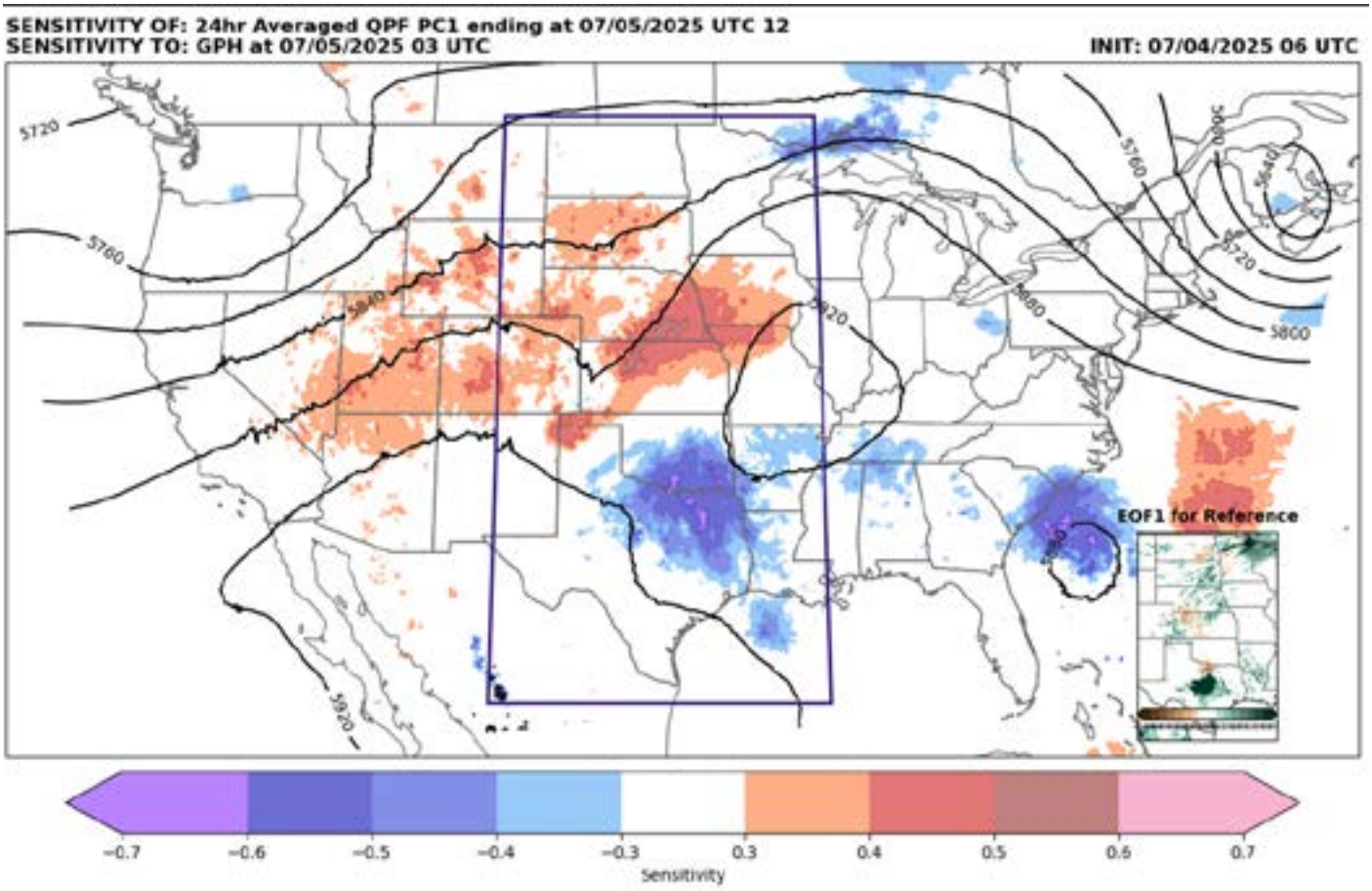
Project: Conducting ensemble sensitivity analysis for the NOAA Weather Prediction Center

CIESRDS contributors: Austin Coleman

Relevance to NOAA: This project helps weather forecasters understand sources of uncertainty in weather models, thereby improving forecasts and protecting lives and property.

For this project, CIESRDS researchers conduct ensemble sensitivity diagnoses that forecast uncertainty by linking early atmospheric features to the event of interest. These analyses show what the ensemble forecast focuses on before the event, improving forecaster awareness by explaining why uncertainty exists.

So far, researchers have developed a medium-range (3- to 7-day) application, optimized code, created a floater domain for forecasters, created an experimental short-range application based on the Rapid Refresh Forecast System, and formally evaluated the product in a testbed. Over the next five years, they will bring experimental web pages to operational status.



This figure shows which upper-level meteorological features in the new Rapid Refresh Forecast ensemble modelling system were most important in forecasting extreme precipitation for the Texas Hill Country over July 4th weekend in 2025. Interestingly, the closed upper-level pattern off the coast of South Carolina (the upper-level representation of Tropical Storm Chantal) lights up as a very important feature for successful prediction of flooding in the Texas Hill Country. This signal shows that a stronger Tropical Storm Chantal correlates to much higher precipitation amounts for Texas in the model system hours later, suggesting that taking more observations around Chantal in the hours leading up to the extreme precipitation event may have improved model predictions of the floods. It also suggests that identifying model simulations with the most accurate representations of Chantal early on in the forecast window could have identified a subset of more accurate precipitation predictions in the Texas Hill Country.

Credit: Austin Coleman/CIESRDS and NOAA WPC

Project: Understanding hydrometeorological processes in a complex mountain watershed

CIESRDS contributors: Bianca Adler, Laura Bianco, Brian Butterworth, Michael Gallagher, Matthew Shupe, Sergey Matrosov, Gijs de Boer, Jonathan Hamilton, Timothy Myers, David Costa, Ola Persson, Joe Sedlar, Laura Riihimaki, Vanessa Caicedo

Relevance to NOAA: This project supports improved predictions of weather and climate processes that influence water availability to mountain communities. The work supports NOAA's ability to make long-term predictions of water resources and short-term precipitation forecasts in areas with complex terrain.

In this project, researchers used measurements from the Study of Precipitation, the Lower Atmosphere, and Surface for Hydrometeorology (SPLASH) experiment to understand the physical processes that drive the transition of mountain precipitation to streamflow. These studies aim to constrain and quantify the land-atmosphere interactions models must represent to achieve high-fidelity water predictions. The project advances foundational understanding of the hydrometeorological cycle in complex terrain. So far, CIESRDS researchers have produced 28 datasets, more than 40 conference presentations, and nine journal articles. Over the next five years, they will synthesize atmosphere, snow, and hydrological observations to improve model representation of atmosphere-land-hydrology processes and support short-term precipitation forecasts and long-term predictions of water resources.

SPLASH instrumentation installed near Gothic, Colorado.
Credit: Janet Intrieri/CIESRDS

Project: Probing extreme weather across a southeastern U.S. observational network

CIESRDS contributors: Laura Bianco, Bianca Adler, David Costa, Irina Djalalova, Timothy Myers

Relevance to NOAA: This project examines causes of extreme weather events and how models represent them to support NOAA's mission to provide rapid and reliable forecasts that help the public prepare for emergencies.

This project, the Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX), uses a ground-based observation network to measure the environmental factors that influence tornado formation, intensity, structure, and path across the U.S. Southeast. These data are used to assess weather models such as the High-Resolution Rapid Refresh model and improve forecasts of severe weather. CIESRDS researchers have so far produced 17 datasets, three conference presentations, and one journal article. Over the next five years, the researchers will study the boundary layer conditions that cause or limit severe weather development, assess model quality, and document findings in publications. This research supports physical improvements to weather models to deliver timely and accurate forecasts of severe weather.

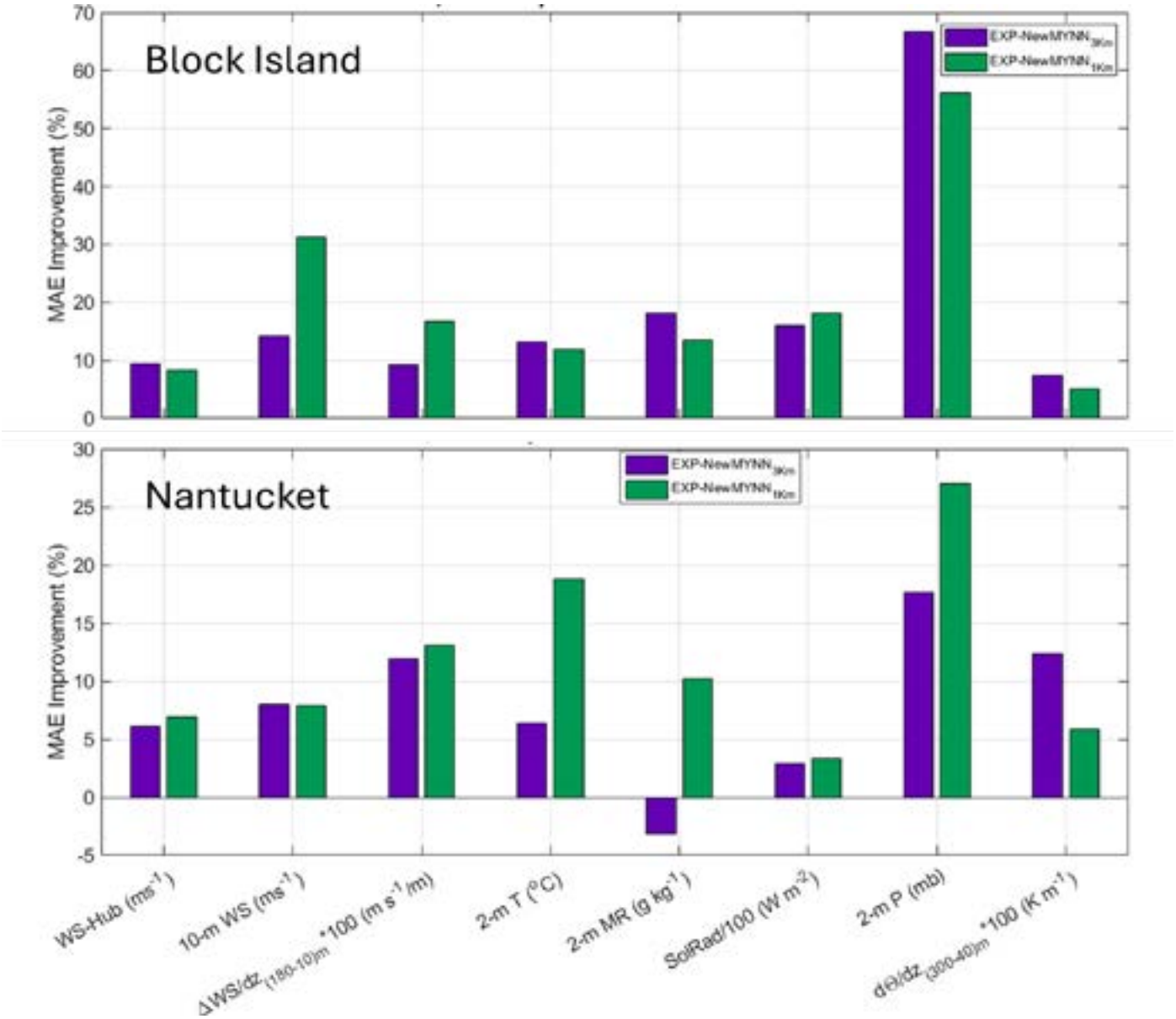
A tornado captured by the VORTEX2 field campaign in Goshen County, Wyoming in 2009.
Credit: John Oakland

Project: Improving forecasts of the offshore marine boundary layer

CIESRDS contributors: Laura Bianco, Irina Djalalova, Bianca Adler, Timothy Myers, Xia Sun, Joe Sedlar, Laura Riihimaki, Kelly Balmes

Relevance to NOAA: This project improves predictions of marine boundary layer processes and wind forecast capabilities to improve the safety of air and naval traffic near United States coastlines and keep offshore wind power production reliable.

For this project, CIESRDS researchers use ground-based observations off the northeast U.S. coast to characterize the structure and variability of the marine atmospheric boundary layer. Researchers use these observations to assess how to improve models used by fisheries, private and commercial transportation, and wind energy producers. The team has so far produced 10 datasets, 10 conference presentations, and three journal articles. Over the next five years, they will evaluate boundary layer parameterizations in the marine environment in the operational High-Resolution Rapid Refresh model and complete multiple analyses for publication.



HRRR forecast improvement when using the updated Mellor-Yamada-Nakanishi-Nino scheme for various marine boundary layer parameters (windspeed, temperature, mixing ration, solar radiation, pressure, and potential temperature), compared to observations at Block Island (top) and Nantucket (bottom) for simulations at two different resolutions (colors, inset legend).
Credit: NOAA PSL

Project: Assessing Arctic model capabilities using observation-based process relationships

CIESRDS contributors: Amy Solomon, Matthew Shupe, Anne Sledd, Michael Gallagher, Ola Persson

Relevance to NOAA: This project uses high-quality observations of the Arctic atmosphere to quantify the relationship between the surface energy budget and clouds, to improve NOAA's forecasts of weather and sea ice to support societal forecast needs.

This project's researchers use high-quality observations of the Arctic atmosphere to quantify the relationship between the surface energy budget and clouds. They evaluate models to distinguish uncertainties in model state from those in process interactions to guide model developers. The researchers also evaluate forecast models including the Unified Forecast System (UFS) and Coupled Arctic Forecast System (CAFS). Over the past five years, they have participated in the World Meteorological Organization's Polar Prediction Project activities to evaluate models and produced five datasets, four conference presentations, and 10 journal articles. Over the next five years, they will incorporate process-relationship information from multiple locations and environmental domains, assess new output from the Unified Forecast System, and provide guidance on model shortcomings. This work supports the UFS and UFS-Arctic model developers and improves regional and hemispheric forecast quality.

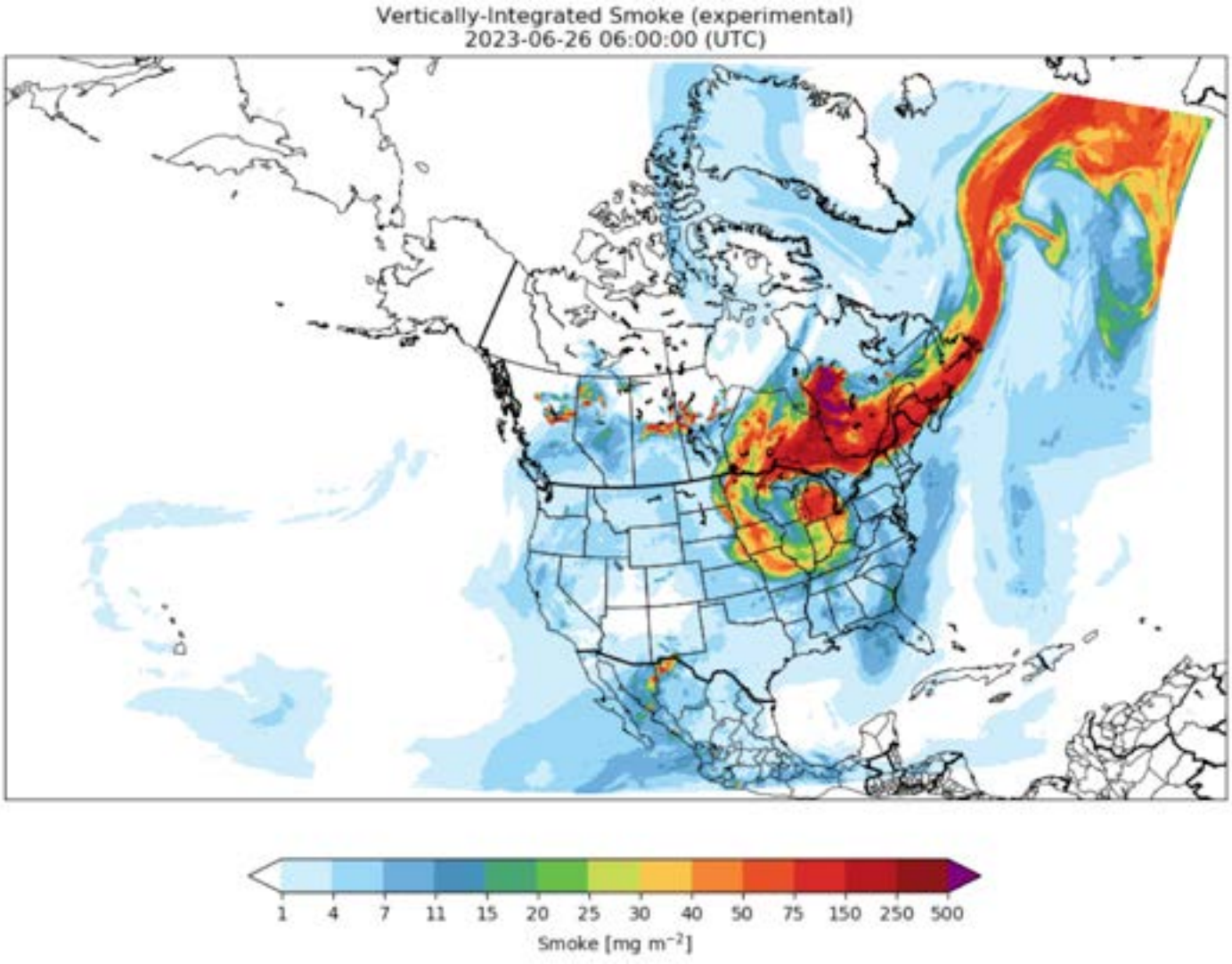
Researchers set up field equipment on Arctic sea ice during the MOSAiC expedition to study Arctic surface energy balances and other atmospheric conditions.
Credit: Lianna Nixon/CIRES

Project: Development of the Rapid Refresh Forecast System (RRFS) Version 1

CIESRDS contributors: Guoqing Ge, Chunhua Zhou, Ruifang Li, Stan Benjamin, Jeff Hamilton, Molly Smith, Eric James, Hongli Wang, Craig Hartsough

Relevance to NOAA: The Rapid Refresh Forecast System (RRFS) Version 1 consolidates multiple regional forecast systems into a single framework. This reduces maintenance and improves storm-scale forecasts of severe convection, winter weather, aviation hazards, air quality, and winds. Its rapid, high-resolution guidance directly supports National Weather Service warning operations with more consistent, unified services for the public.

CIESRDS researchers are helping develop the Rapid Refresh Forecast System (RRFS) Version 1, NOAA's next-generation, convection-allowing, hourly updating forecast system. It covers a 3-kilometer North American domain with deterministic, ensemble, and smoke/dust forecasts. So far, CIESRDS researchers have completed extensive data assimilation sensitivity studies and case evaluations for convective storms and produced real-time prototype guidance through the RRFS Amazon Web Services open-data bucket. RRFS Version 1 has been tested during multiple seasons in different testbeds to inform physics, data assimilation cycling, and ensemble design choices. The goal is to transition RRFS Version 1 to operations in early 2026. This project will conclude when it transitions to NOAA's National Weather Service for operational implementation.



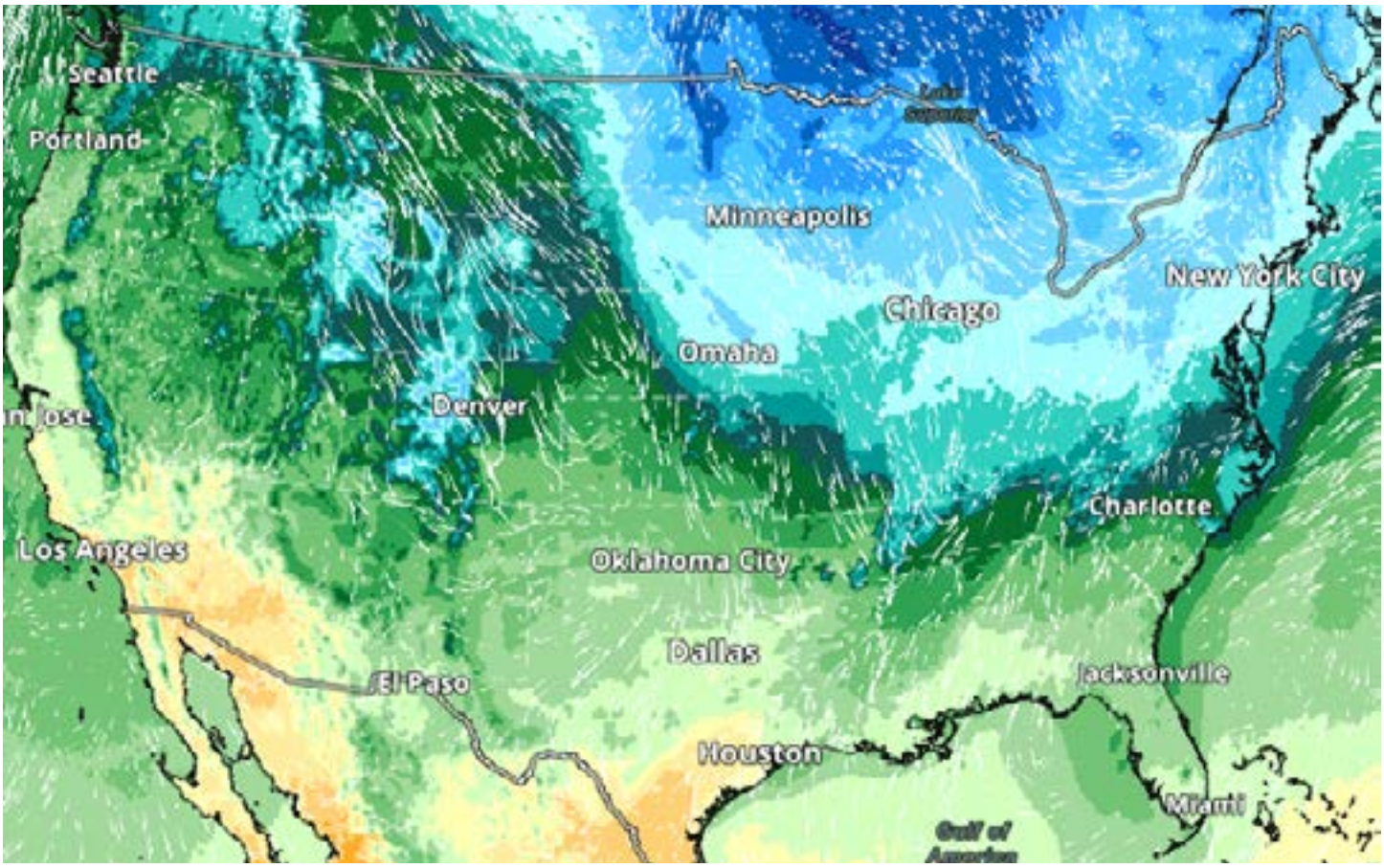
This 3-kilometer vertically integrated smoke forecast shows the RRFS system predicting how smoke from Canadian wildfires would travel over North America in late June 2023.
Credit: NOAA GSL

Project: Development of the Rapid Refresh Forecast System (RRFS) Version 2

CIESRDS contributors: Guoqing Ge, Chunhua Zhou, Junjun Hu, Sijie Pan, Hongli Wang, Shawn Murdzek, Molly Smith, Stan Benjamin, Ruifang Li, Jason English, Craig Hartsough, Jaymes Kenyon, Jeff Duda

Relevance to NOAA: The Rapid Refresh Forecast System (RRFS) V2 modernizes NOAA's regional weather forecast and data assimilation infrastructure, enabling more efficient use of new observations and computing architectures. Its storm-scale, rapidly updating guidance improves support for severe weather, aviation, hydrology, and energy applications, and and directly supports National Weather Service warning operations with more consistent, unified services for the public.

Rapid Refresh Forecast System (RRFS) Version 2 is a next-generation, convection-allowing forecast and data assimilation system that uses a non-hydrostatic dynamical core and a regional data assimilation system. It is designed to unify NOAA's regional storm-scale forecast systems and serve as the flagship regional storm forecasting system. This project started in August 2024. Since then, the researchers have established a prototype model system configuration for regional convection-allowing applications, demonstrated cycling experiments assimilating diverse conventional and satellite observations, and conducted case studies to optimize data assimilation settings for different types of observations. The new system will be evaluated in the 2026 Hazard Weather Testbed Spring Forecast Experiments. Over the next five years, researchers will continue to develop RRFS Version 2 into a robust, pre-operational regional data assimilation system. They will also demonstrate end-to-end real-time RRFS V2 prototypes in different testbeds to prepare for an operational implementation at NOAA in 2029.



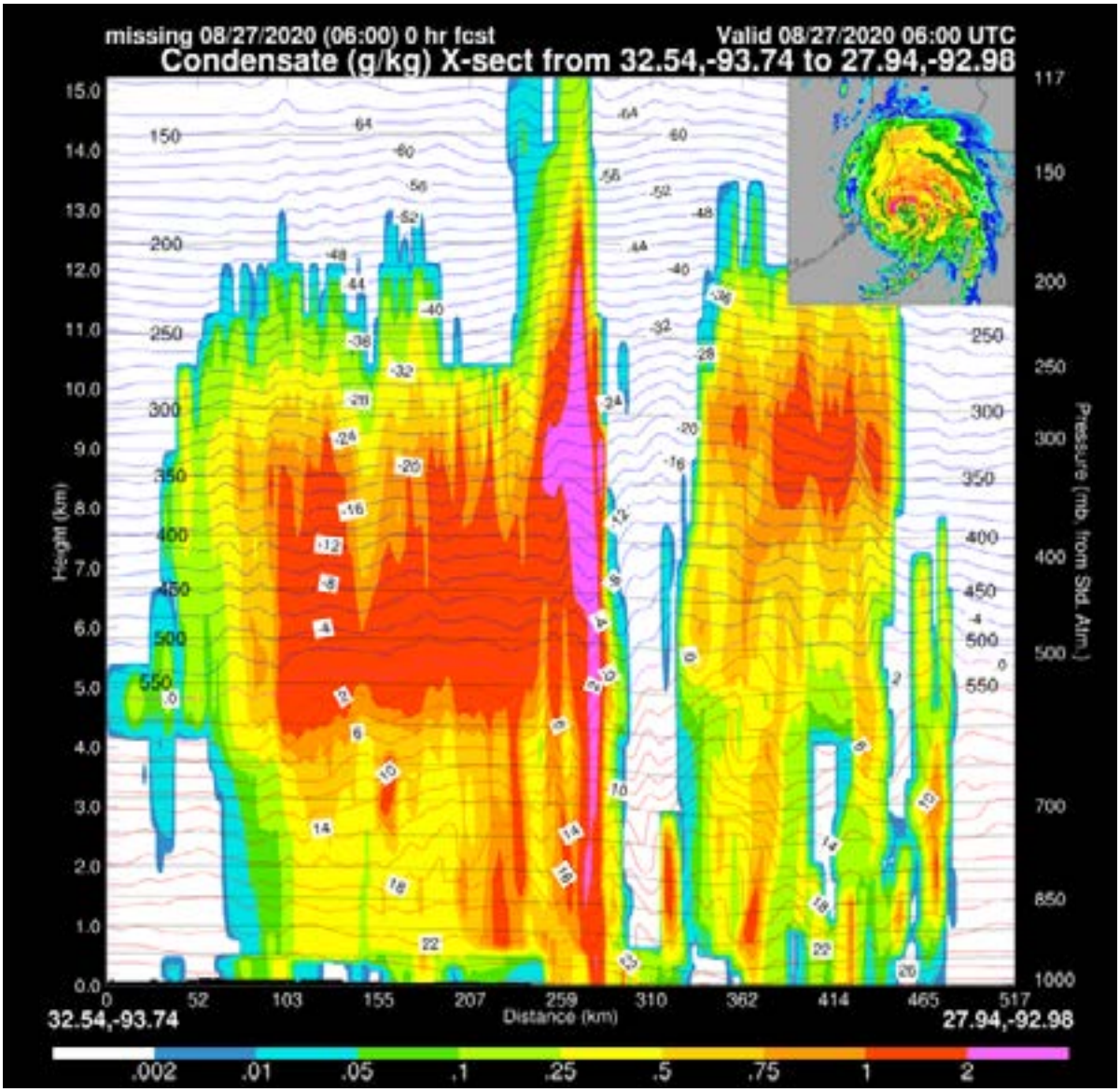
Output of the Rapid Refresh Forecast System, showing winds and temperatures over the continental United States.
Credit: NOAA GSL

Project: Developing a three-dimensional weather observation analysis of record

CIESRDS contributors: Guoqing Ge, Craig Hartsough, Ruifang Li, Molly Smith, Jaymes Kenyon

Relevance to NOAA: This project improves numerical weather prediction models and tools for situational awareness and nowcasting for National Weather Service forecast offices and centers.

This project develops a three-dimensional weather observation analysis of record to verify forecasts and correct biases. The system generates a three-dimensional representation of the atmosphere to improve situational awareness and creates a 3D analysis of record. The system runs at a 15-minute cadence at a 3-kilometer horizontal resolution and provides a full-column representation of temperature, water vapor, wind, clouds, and precipitation. Eventually, the system will include aerosols, land-surface diagnostics, and convective fields. The 3D cloud hydrometeor analysis has the potential to provide critical "nowcast" information to identify aviation and ground transportation hazards such as in-flight icing, cloud ceiling and visibility restrictions, and highway snow and ice accumulation in complex terrain. Over the past five years, CIESRDS researchers have finalized optimal data assimilation configurations, improved the cloud analysis scheme for full atmosphere awareness, and added an observation auto quality control package that was demonstrated in testbeds. They plan to transition the system to NWS operations in September 2026.



The line across the image at the upper right inset shows the 3DRTMA cross-section of condensates in Hurricane Laura at landfall on 27 August 2020 at 06 UTC.

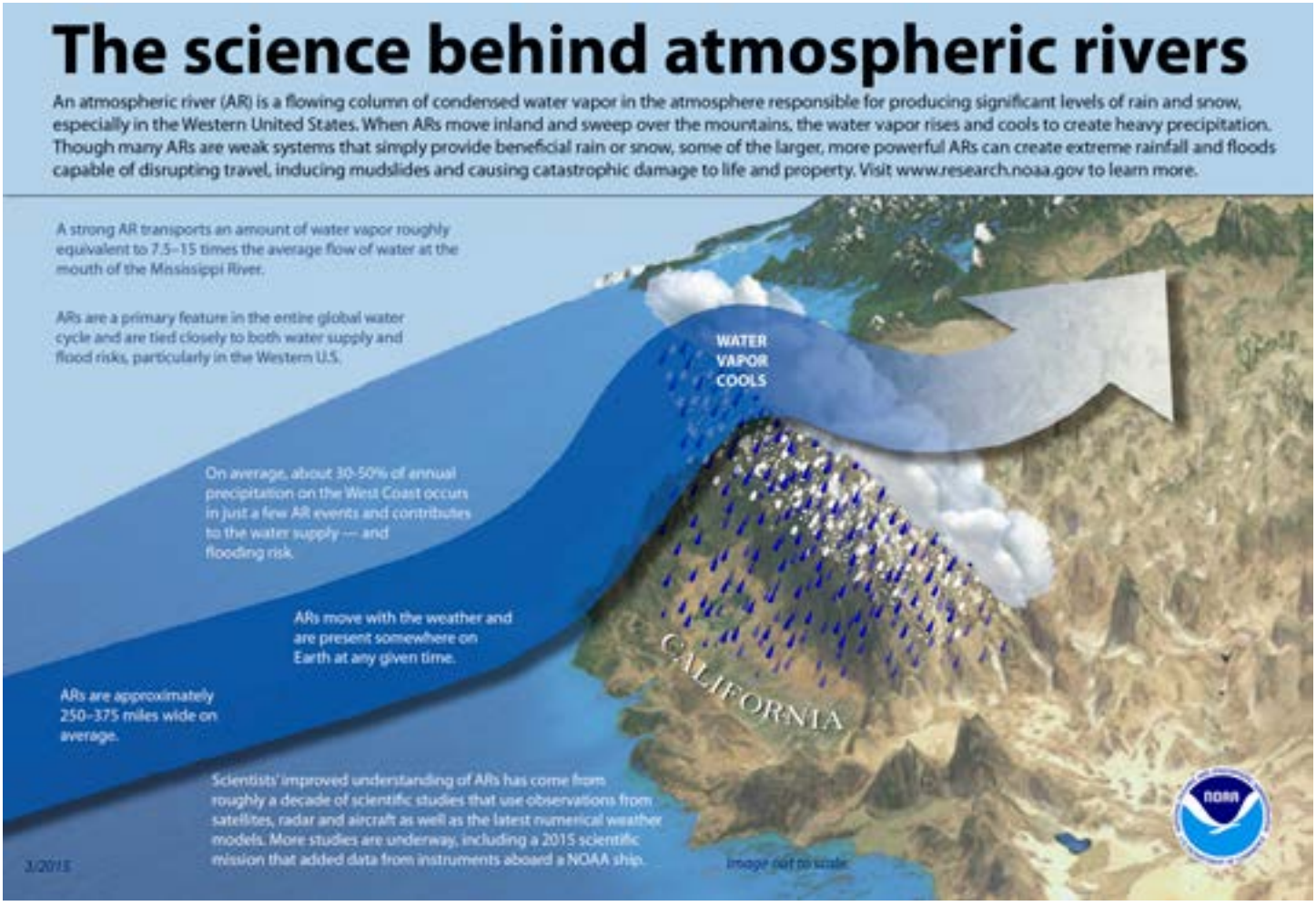
Credit: GSL/NOAA

Project: Advancing the prediction of atmospheric rivers via data assimilation

CIESRDS contributors: Guoqing Ge, Sijie Pan, Chunhua Zhou, Junjun Hu

Relevance to NOAA: This project has established a prototype forecast system that improves NOAA's ability to forecast the timing, intensity, structure and location of landfalling atmospheric rivers that can cause intense rainfall and flooding on the U.S. West Coast.

This project team has developed a series of prototype atmospheric river forecast systems to advance hourly cycled data assimilation capabilities and develop more sophisticated scale-aware physics for regional and variable-resolution global and regional applications. Since the project launch in July 2025, the researchers have prototyped a cycling data assimilation and forecast system focused on the eastern Pacific and the U.S. West Coast, examined the assimilation of aircraft data and satellite data, and improved the surface data assimilation scheme. Over the next five years, the team will run the new regional atmospheric river forecast system in real time during the active season and provide better forecasts.



An explanation of the science behind atmospheric rivers.
Credit: NOAA NWS

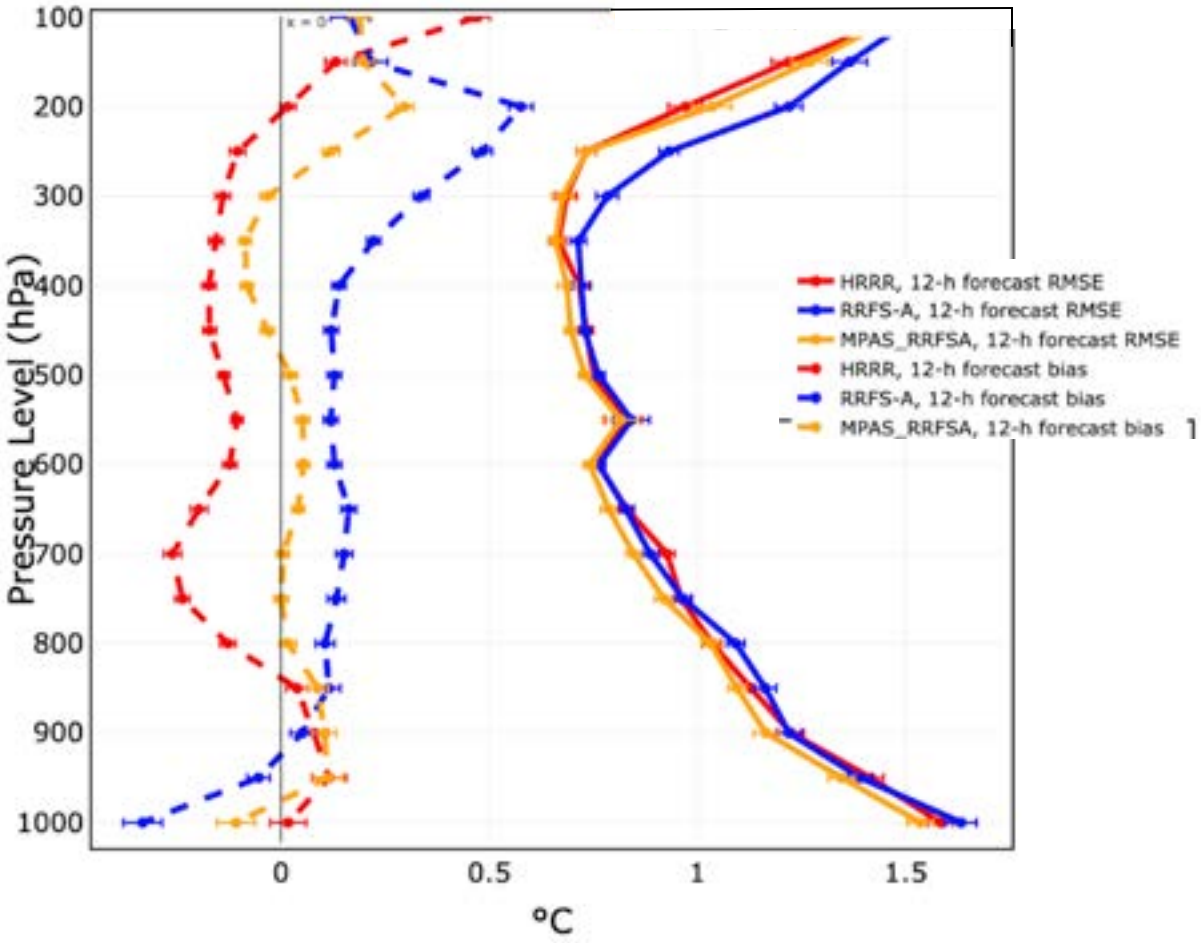
Project: Creating a versatile online verification system in support of NOAA model development

CIESRDS contributors: Molly Smith, Jeff Hamilton, Gopakumar Padmanabhan, Craig Hartsough

Relevance to NOAA: This project strengthens NOAA's modeling enterprise and provides fast, consistent verification for operational and experimental systems. It shortens the feedback loop between model development and verification and forecasters, and supports more confident, metric-driven model upgrades.

The Model Analysis Tool Suite (MATS) is a web-based system developed at CIESRDS to verify and diagnose issues with numerical weather prediction models. It provides interactive access to pre-computed verification datasets and generates customizable plots for a wide range of metrics, including surface, upper-air, precipitation, and convection-related fields. MATS streamlines comparison of operational and experimental configurations, accelerates evaluation cycles and supports science-to-operations transitions across NOAA and partner modeling systems. It now has a unified platform for quick access to many verification metrics against different types of observations and AI models, and engineering enhancements. MATS has so far advanced the Rapid Refresh Forecast System Versions 1 and 2, the three-dimensional real-time mesoscale system, the atmospheric river forecast system, and the Hurricane Forecast Improvement Program (HFIP) forecast demonstration.

Over the next five years, the researchers will collaborate with the National Weather Service to maintain and improve the MATS system to better serve the model development needs.



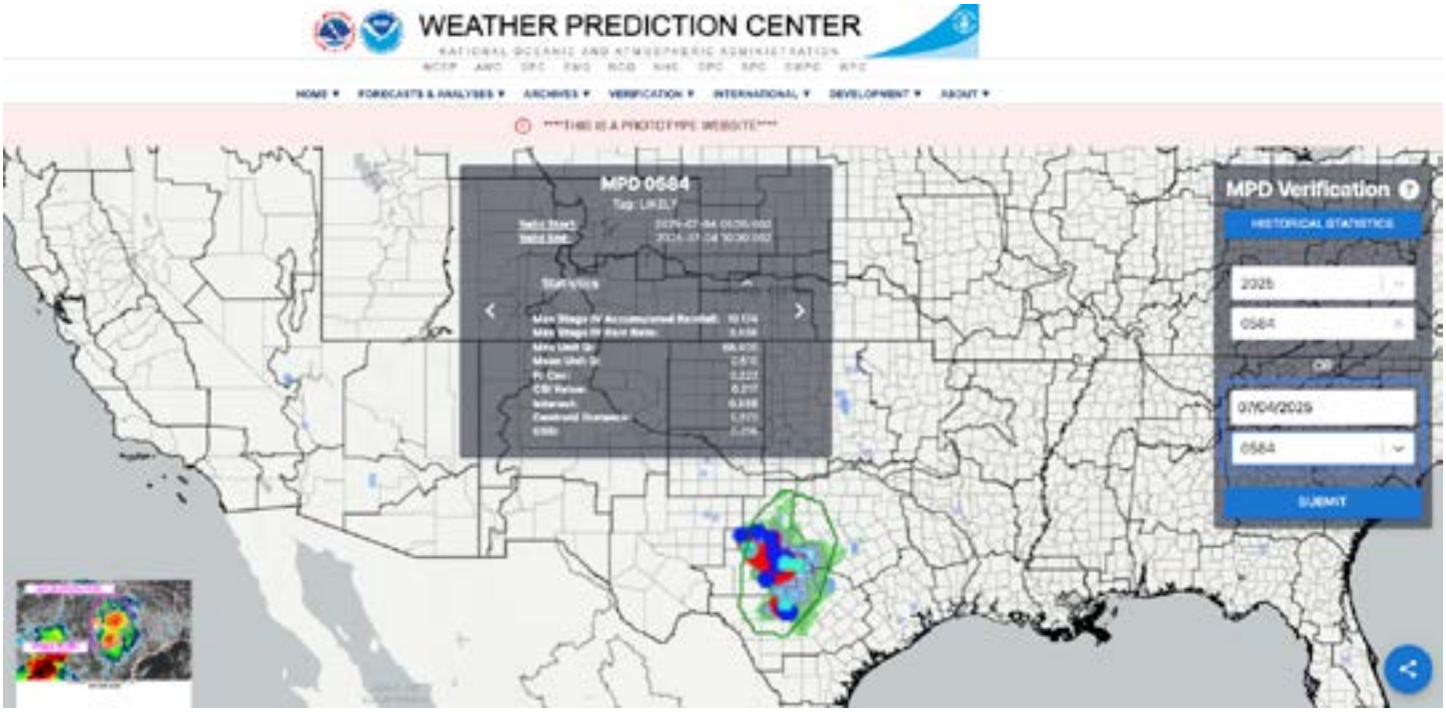
The graph produced by the Model Analysis Tools Suite (MATS) compares the performance of three weather models (HRRR, RRFS-A, and MPAS RRFSA) in predicting upper-air temperature at a 12-hour forecast lead time. The metrics used for comparison are Root Mean Square Error (RMSE) (solid lines) and bias (dashed lines) across various atmospheric pressure levels.
Credit: NOAA GSL

Project: Verification of Mesoscale Precipitation Discussions (MPD)

CIESRDS contributors: Erica Bower, Austin King

Relevance to NOAA: This project analyzes trends within NOAA's operational forecast systems to communicate the performance of forecast products available to the public, ultimately improving NOAA's weather forecasting capabilities.

The NOAA Weather Prediction Center (WPC) issues Mesoscale Precipitation Discussions (MPDs) to highlight regions where heavy rainfall is expected to pose a threat for flash flooding. CIESRDS researchers use a system of flood observations and proxies to verify MPDs produced by WPC. So far, they have created an archive of MPD verifications to analyze forecast trends and migrated the system to servers provided and supported by NOAA. Over the next five years, the researchers will optimize flood observation data to apply across multiple verification products and deploy a new, improved display and user interface.



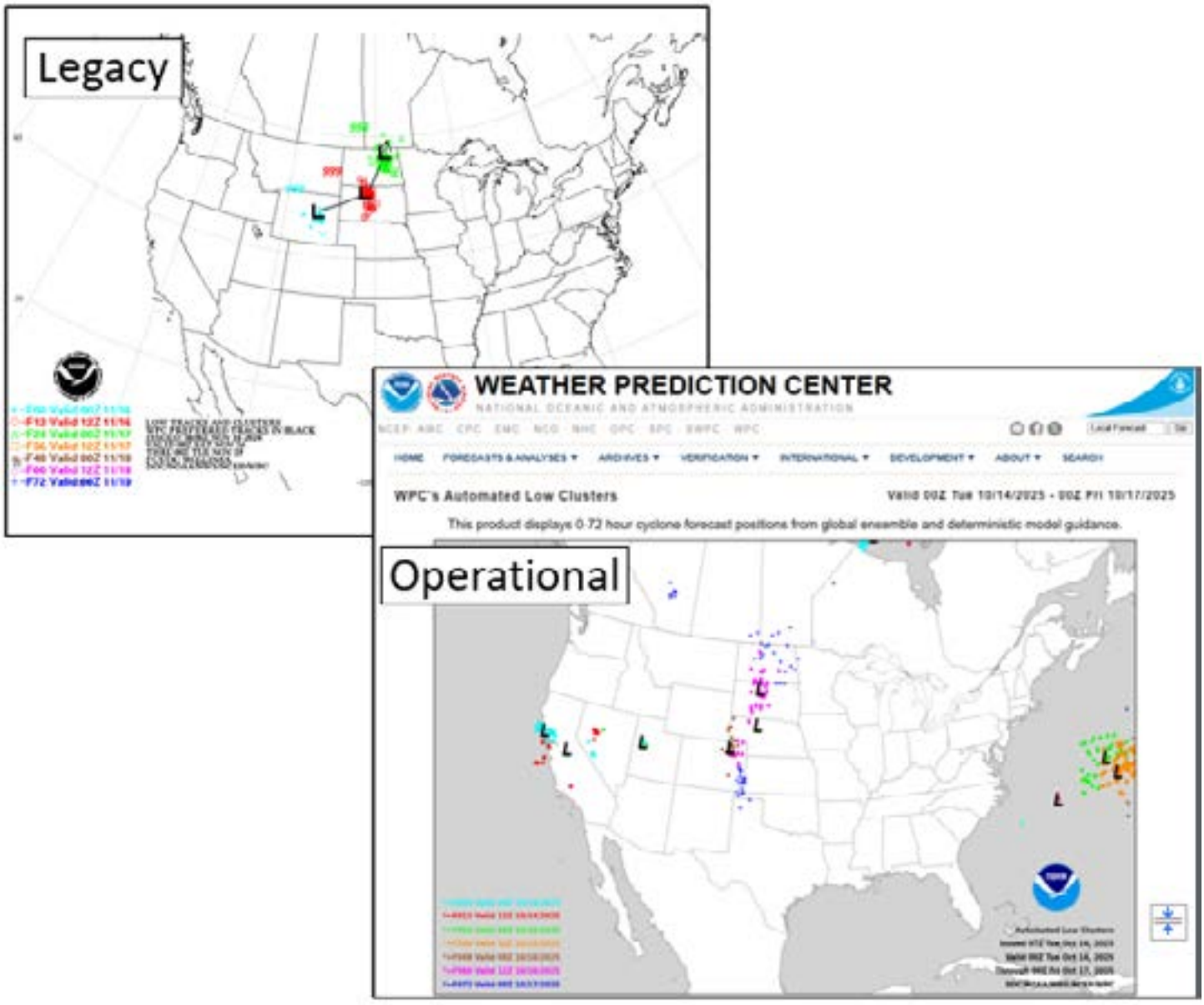
Mesoscale Precipitation Discussion verification website display for the deadly July 4, 2025 flooding in Texas. The colored dots identify measurements and reports of flooding. The green outline is the same as the magenta scalloped outline in the inset, which is the published graphic identifying the areas likely to be affected by significant flash flooding. Dots within the green outline confirm that flooding occurred in the area as predicted.

Project: Tracking forecasted low pressure centers using low cluster analysis

CIESRDS contributors: Erica Bower

Relevance to NOAA: Low cluster analysis communicates uncertainty and spread in the forecasted location of ensemble and deterministic model low-pressure centers.

This project tracks forecasted low-pressure centers using machine learning clustering techniques and was transitioned to operations on January 20, 2024. CIESRDS researchers used machine learning techniques to update the system to an automated interface and integrated it into the National Weather Service operational forecast processing system. Over the next five years, researchers will use operational servers to develop and process the tool.



Top: The legacy Low Tracker compared with the new WPC's automated Low Clusters product (lower).
Lower: WPC's automated low clusters product is generated using cyclone tracks from the Environmental Modeling Center's (EMC) extratropical cyclone tracker. The cyclone tracker comprises 103 global forecasts from ensemble and deterministic guidance. Surface low positions from 0-72 hours are plotted as different colored symbols; colors represent the valid forecast times of the lows which are listed in the legend at the lower left corner of the plot. This forecast is issued twice daily at 0700 UTC and 2000 UTC.
Credit: Erica Bower/CIESRDS and NOAA WPC

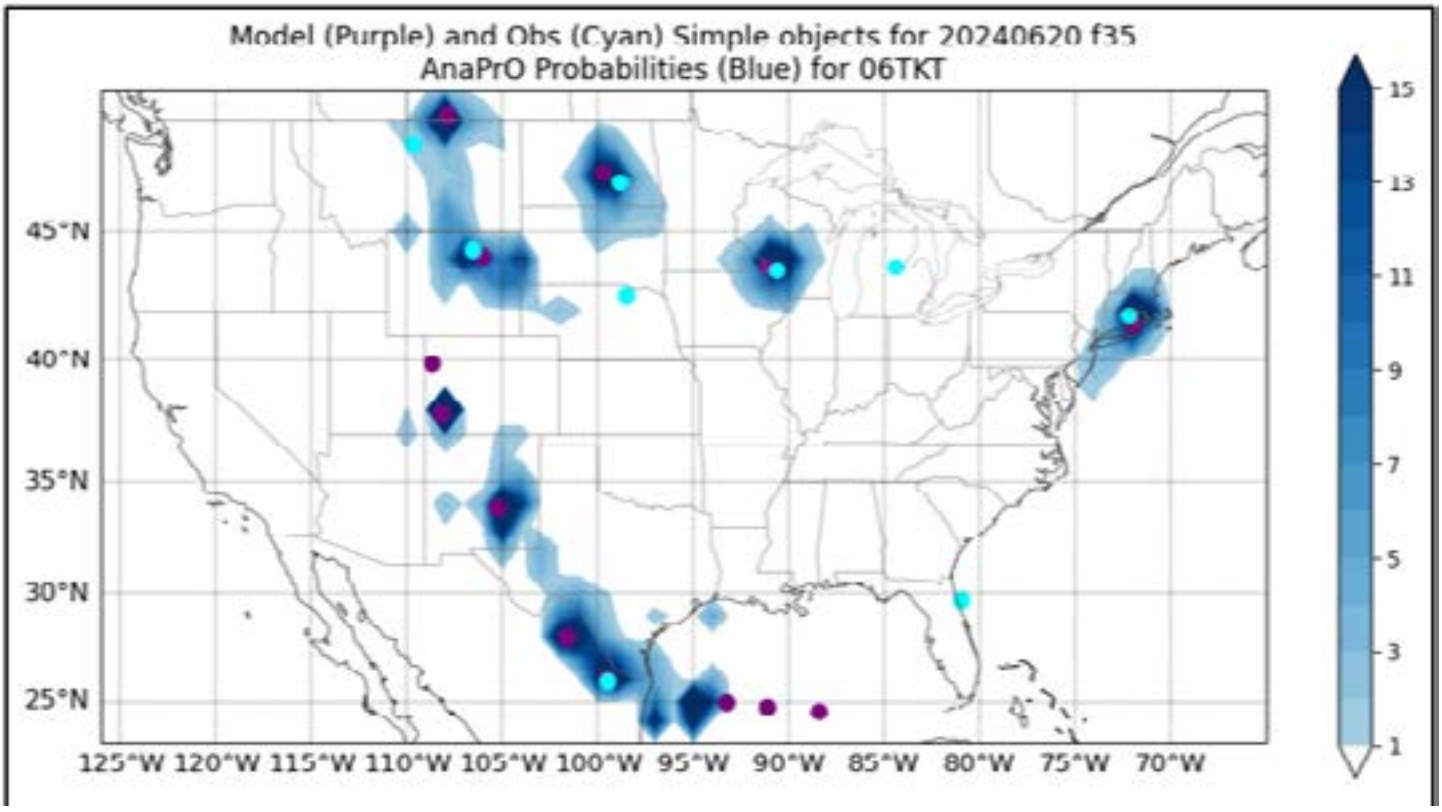
Project: Developing an Analog Forecasting of Precipitation Objects (AnaPrO) Tool

CIESRDS contributors: Timothy Thielke, Noah Brauer, Austin King, Matthew Green

Relevance to NOAA: The Analog Forecasting of Precipitation Objects (AnaPrO) tool provides situational awareness of the uncertainty for heavy rain events in the context of a historical archive for National Weather Service forecasters. This tool is crucial for NOAA's ability to predict excessive rainfall and manage flash flood risks.

CIESRDS scientists developed the Analog Forecasting of Precipitation Objects (AnaPrO) tool to predict heavy rainfall by matching current atmospheric, radar, and satellite weather patterns with similar, high-impact events from historical archives. This technique provides 2–3 day probabilistic forecasts for flood-producing rain, specifically tracking the movement and intensity of precipitation objects (organized, heavy precipitation systems).

The AnaPrO tool references a historical archive of model errors to analyze uncertainty and display the probabilities of precipitation object locations for heavy rainfall events in high resolution precipitation forecasts. So far, researchers have reconstructed the tool's code to quickly process the product and make it easier to maintain and further develop. They also transferred the tool from a development framework for testing to a real-time prototype. Over the next five years, researchers will transition the prototype product to a web-based display supported by the NOAA Weather Prediction Center. They will also incorporate machine learning algorithms to improve skill and situational bias.



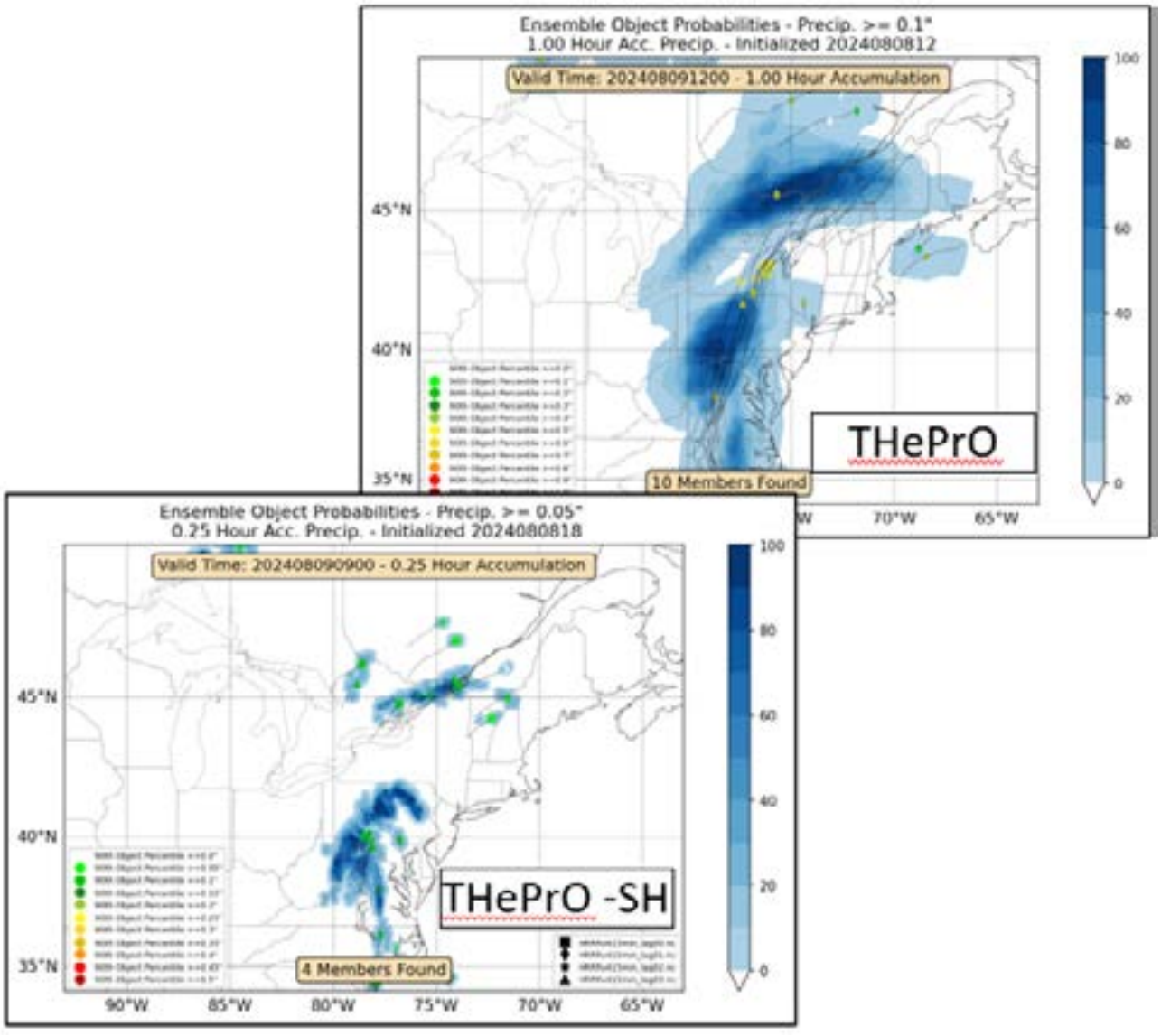
AnaPrO example displaying displacement probabilities for heavy precipitation objects. During events, this helps forecasters by identifying uncertainty for areas of enhanced concern by providing historical context from both the model and observations.
Credit: Matthew Green/Timothy Thielke/CIESRDS and NOAA WPC

Project: Developing object-tracking forecast tools

CIESRDS contributors: Matthew Green, Timothy Thielke, Noah Brauer, Austin King

Relevance to NOAA: Tools developed in this project assess the location, timing, and magnitude uncertainty within model-forecasted precipitation for NOAA Weather Prediction Center operational forecasters.

CIESRDS scientists have developed multiple products that track heavy precipitation events in weather forecast models using object-based evaluation tools. The tools use an ensemble-based approach to communicate the uncertainty and spread of forecasted events. So far, the researchers have transferred the tool technology to servers supported and provided by the NOAA Weather Prediction Center. They have also developed a webpage to display each of the forecast tools and provide an improved interface for users to interact with the forecast data. Over the next five years, the researchers will develop a tool to analyze 1-hour and 15-minute high-resolution model precipitation and include an accumulated precipitation forecast for both liquid and frozen precipitation types over the continental United States. They will also expand these capabilities to Alaska and Hawaii.



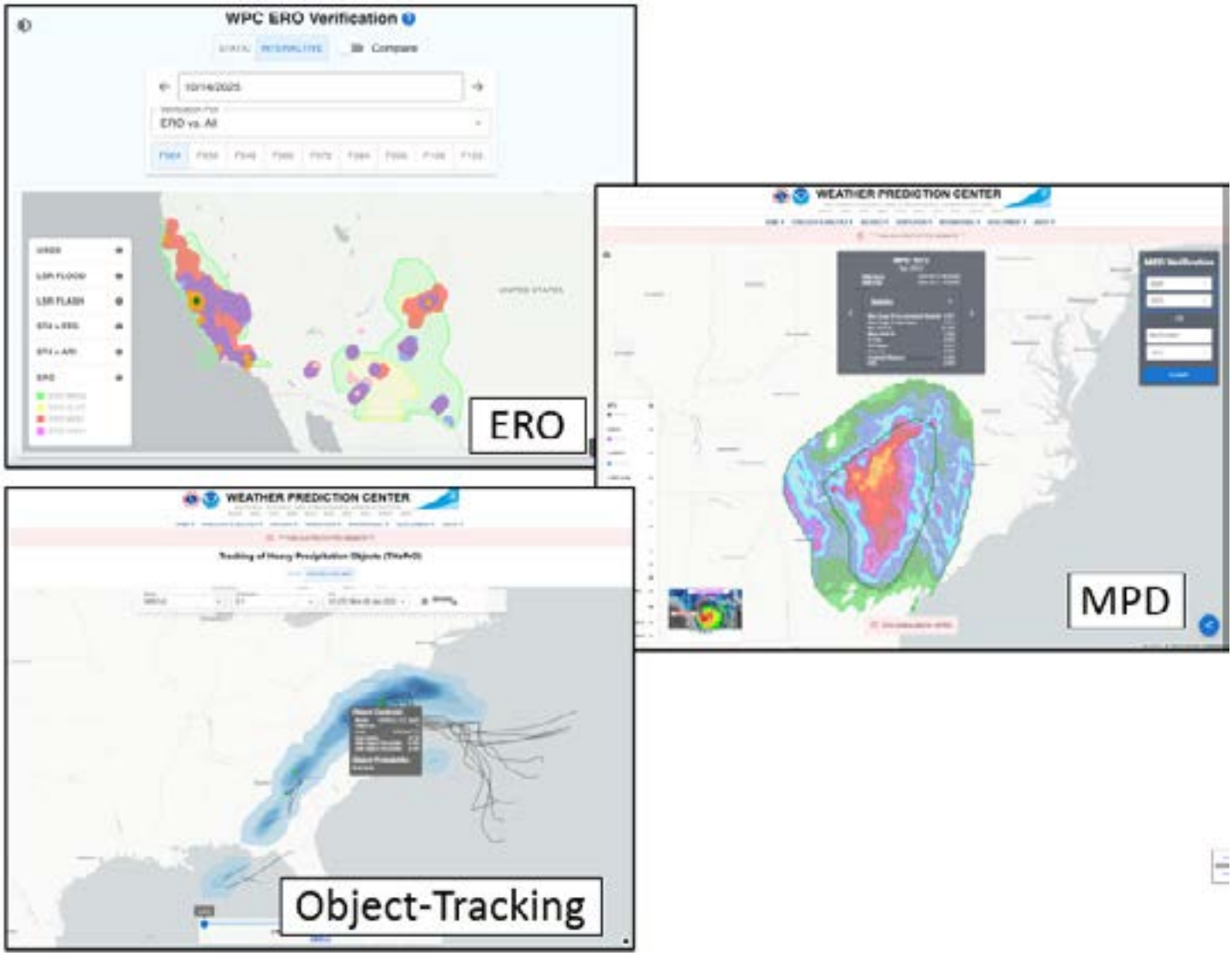
Top: Tracking of Heavy Precipitation Objects (THePrO) displays the probability of heavy rain accumulated over 1-hour. Bottom: HRRR Sub-Hourly Tracking of Heavy Precipitation Objects (THePrO-SH) displays the probability of heavy rain accumulated over 15 minutes. Credit: NOAA WPC

Project: Developing new and improved web tools for National Weather Service forecast and verification products

CIESRDS contributors: Austin King, Erica Bower, Matthew Green

Relevance to NOAA: This project created new web pages to communicate verification results and post-processed forecast tools for National Weather Service meteorologists.

CIESRDS researchers have created new web pages to display multiple forecast and verification products for National Weather Service meteorologists. So far, they have developed the Excessive Rainfall Outlook (ERO) and Mesoscale Precipitation Discussion (MPD) verification interactive webpages. The object-tracking suite of products are displayed from a central webpage and static images progress to an enhanced interaction. Over the next five years, the researchers will transition all webpages to operate on servers provided by the NOAA Weather Prediction Center. Researchers will continue to explore best practices for communicating forecast products to forecasters, the public, and other stakeholders.



These are three main webpages that have undergone improvement work. All of these prototype products are available to WPC forecasters.
Credit: Austin King/CIESRDS and NOAA WPC

Project: Studying fire dynamics and predictability at the wildfire-drought nexus

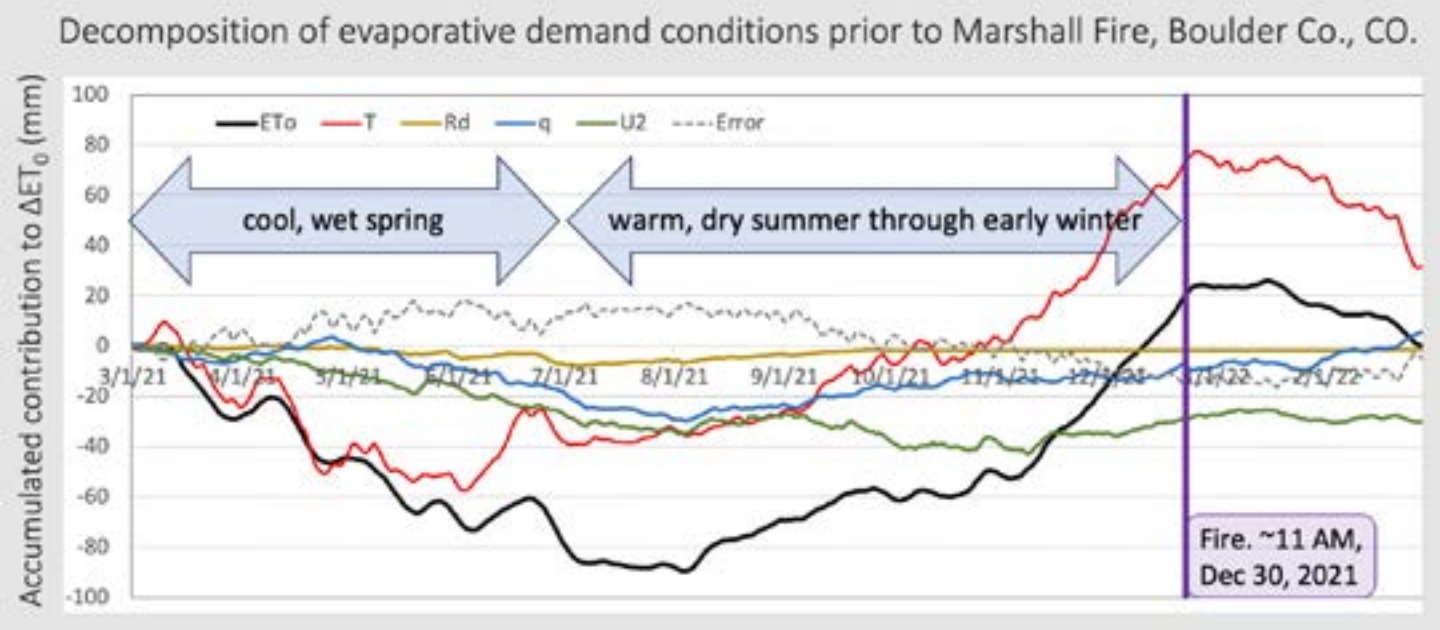
CIESRDS contributors: Mike Hobbins, Rachael Robinson, John Albers

Relevance to NOAA: Improved wildfire predictability will support earlier warnings and proactive management, supporting NOAA's goals of protecting lives, property, and ecosystems. This project links ENSO phases to fire risk, diagnoses evaporative demand drivers, and improves forecasts of prescribed fire opportunities to help communities reduce catastrophic losses, safeguard resources, and strengthen resilience against climate-driven wildfire threats.

In this project, CIESRDS researchers apply linear inverse modeling techniques to improve predictions of vapor pressure deficit, a key wildfire driver, to enhance forecast skill. So far, they have used the NOAA Physical Sciences Laboratory's long-term reanalysis of evaporative demand and the Evaporative Demand Drought Index (EDDI) to quantify meteorological drivers and their role in drought-wildfire dynamics. With these tools, forecasters can monitor and predict fuel conditions and fire weather in real time and support proactive wildfire management to reduce the risk to the public.

Since September 2022, the team has analyzed the relationship between ENSO phases and area burned from 1984 to 2022 to advance wildfire predictability. They found La Niña significantly increases wildfire risk for up to nine months, while El Niño reduces it. This predictability stems from seasonal shifts in evaporative demand and precipitation and influences fuel growth and drying cycles. These insights will improve long-range fire forecasts and support proactive management strategies to reduce wildfire impacts on communities and ecosystems.

Over the next five years, the team will improve wildfire predictability by linking ENSO phases to area burned. Future work will diagnose meteorological drivers of evaporative demand during drought and fire events and develop regional, seasonal forecasts for prescribed fire opportunities, supporting proactive wildfire and land management.



The lines show changes in meteorological variables from March 1, 2021 to fire ignition on December 30, 2021. The black line shows changes in potential evapotranspiration, the red line is changes in air temperature, the gold line shows solar radiation, the blue line shows humidity, the green line is wind speed, and the dashed black line shows error.

Credit: CIESRDS and NOAA PSL

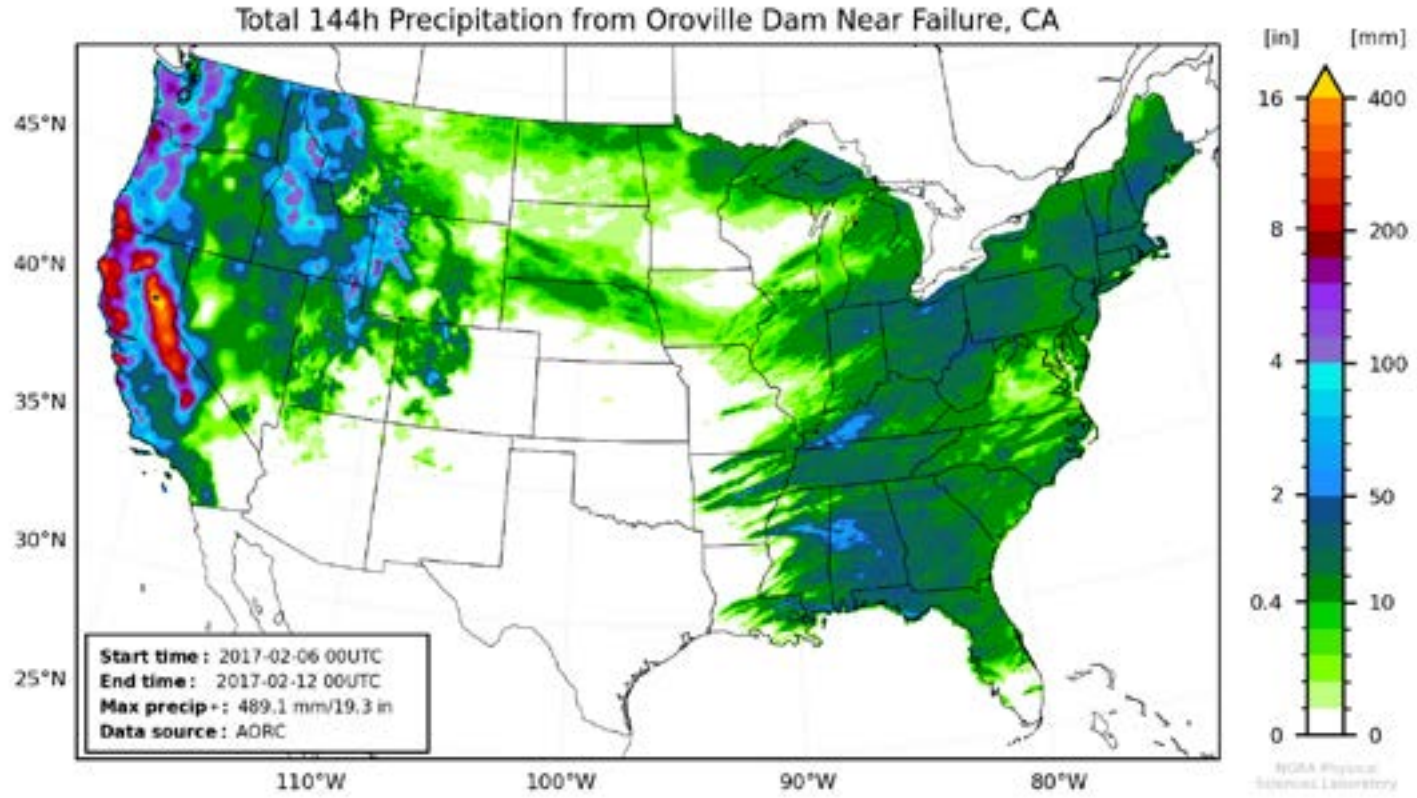
Project: Developing high-resolution weather and climate simulations for extreme precipitation guidance

CIESRDS contributors: Mike Hobbins, Kinya Toride

Relevance to NOAA: This project modernizes NextGen Hydrologic Modeling and precipitation risk assessment through nested replay that creates a 3-kilometer Unified Forecast System-based reanalysis. These advances improve extreme precipitation forecasts and safeguard infrastructure and communities.

In this project, CIESEDS researchers modernize estimates of probable maximum precipitation. The Nested Replay project used a novel approach to create a Unified Forecast System-based precipitation reanalysis with a 3-kilometer nest over the contermi-nous United States (CONUS) to improve how they understand extreme events. The CONUS Additional Futures initiative down-scales global climate models onto a 4-kilometer grid and produces high-resolution future climate simulations to create more accurate assessments of future extremes. These two major efforts will transform precipitation risk assessment and support infrastructure resilience.

Together, these initiatives will modernize probable maximum precipitation estimates, strengthen NOAA's forecasting capabil-ities, and provide actionable data for planners and emergency managers. Over the next five years, the team will run a down-scaled climate simulation over the continental United States for a 40-year period that starts around 2025 and requires approxi-mately 15 million core-hours on a supercomputer and 8 to 12 months to complete. If successful, this effort will pave the way for multiple high-resolution simulations and advance climate risk assessment and infrastructure planning.



A map showing total storm precipitation that led to the Oroville Dam crisis in 2017.
Credit: NOAA PSL

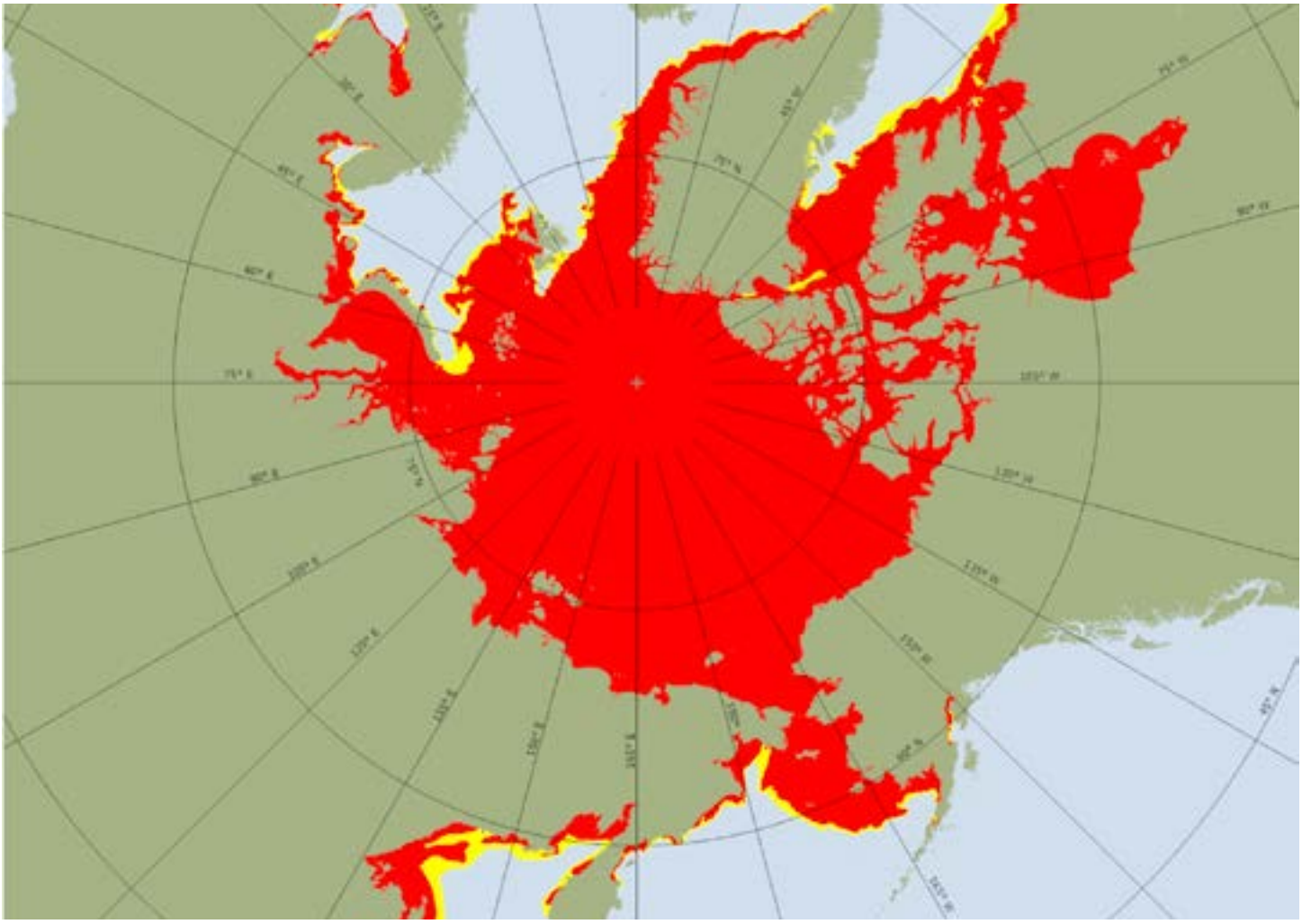
Project: Supporting users of the U.S. National Ice Center's interactive multisensor snow and ice mapping system

CIESRDS contributors: Ann Windnagel, Florence Fetterer, Danica Cantarero

Relevance to NOAA: This project serves operational users of the U.S. National Ice Center's (USNIC) products with accurate, timely, and high resolution products, as well as offering the knowledge to document them for use by academic researchers. By supporting these users, the researchers also support USNIC, broadening knowledge of its services and increasing taxpayer return on investment.

The U.S. National Ice Center (USNIC) is a collaboration between NOAA, the Navy, and the Coast Guard that empowers mariners and Naval forces operating in polar, subpolar, and Great Lakes regions with authoritative and timely snow, sea ice, and lake ice products and forecasts.

Analysts within the NOAA component of the USNIC map snow cover and sea ice daily for assimilation by forecast models. The Interactive Multisensor Snow and Ice Mapping System is an operational software package used to demarcate the presence of snow and ice across the entire northern hemisphere. The product has broad research uses beyond modeling. CIESRDS scientists archive, document, maintain, and answer user questions about this product. The product has about 1,700 registered users; over 86,000 users downloaded data in 2025. Over the next five years, CIESRDS scientists plan to partner with USNIC to accelerate research that can benefit from operational products. For example, ice services are exploring machine learning as a tool for analysis.



The U.S. National Ice Center daily marginal ice zone product displayed for the Arctic region on January 29, 2026. The marginal ice zone product shows ice concentrations between 1/10 and 8/10, or about 10% to 80% concentration. Red indicates 8 to 10 tenths sea ice concentration, yellow is 1 to 8 tenths, blue is ice free, and land is green.

Credit: U.S. National Ice Center

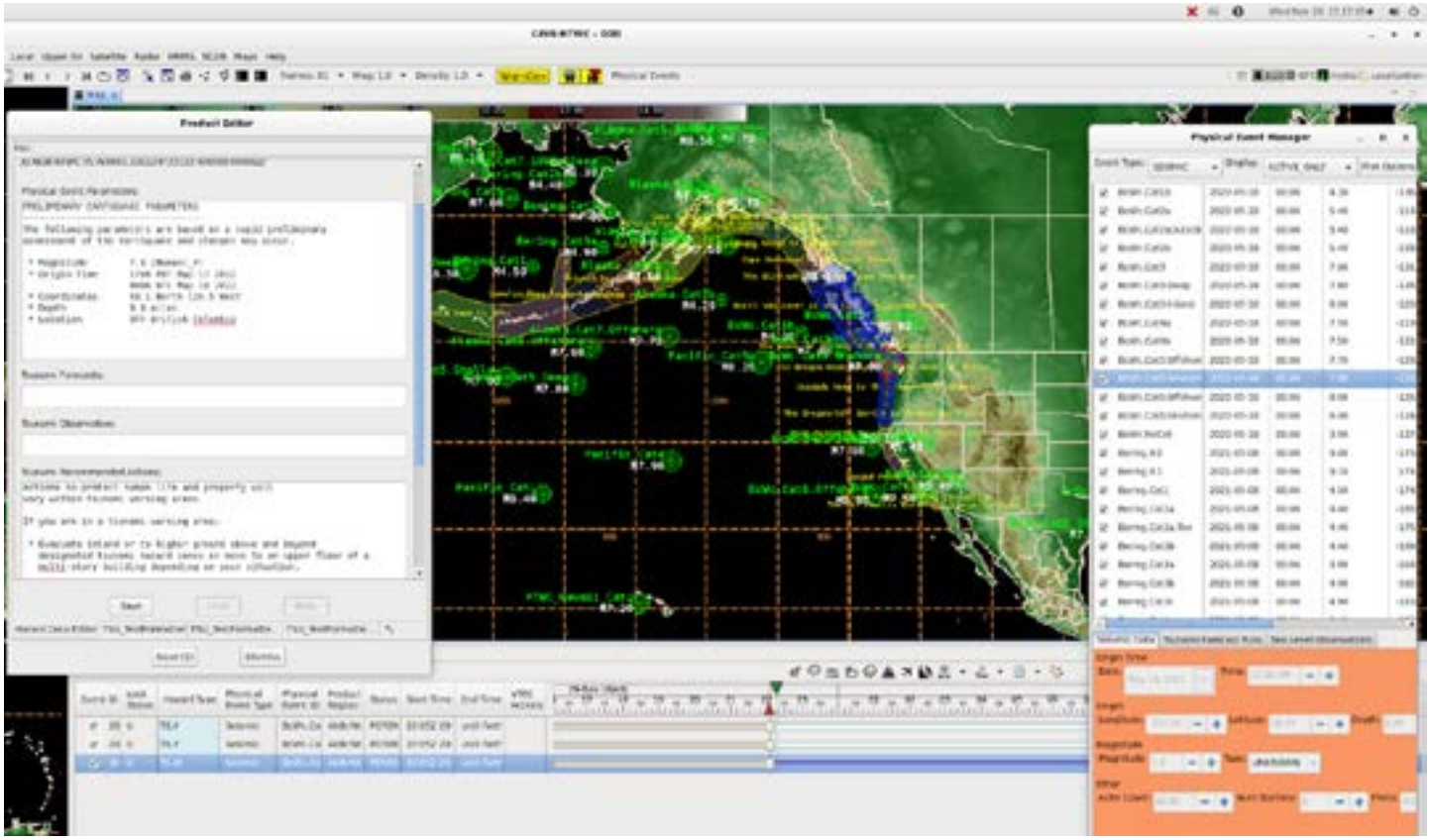
Project: Developing a product to revolutionize U.S. tsunami warning capabilities

CIESRDS contributors: Rob Weingruber, Suneng Zhuo, Chris Golden

Relevance to NOAA: This project supports the modernization of the tsunami warning systems that reinforce NOAA's goal to save lives and property.

The two United States Tsunami Warning Centers currently issue tsunami warnings through separate systems derived from totally different code bases. CIESRDS scientists are developing a processing system called the AWIPS Tsunami Operations Messaging Service (ATOMS) that will bring their warning capabilities into a standardized NOAA system, leveraging the same architecture used by NOAA Weather Forecasting Offices. Uniting the systems into a single infrastructure will standardize the workflow and product generation and provide seamless backup capabilities across the centers.

To date, ATOMS has gone through architecture and design to implementation of much of the system, which has been integrated with Hazard Services. Each Tsunami Warning Center has acquired a complete system for training and testing and ultimately for operations. Over the next five years, the researchers will make ATOMS operational at each Tsunami Warning Center and integrate it with the Common Analytical System, which generates and provides the tsunamigenic parameters and forecast data. ATOMS will operationally allow the Tsunami Warning Centers to create, manage, and issue standardized tsunami warnings in a timely manner.



The ATOMS used by the NWS Tsunami Warning Centers to issue call-to-action products about a potential tsunami following an oceanic earthquake. Magnitude and locations are identified by the green circles. The outlined areas along the coast indicate a warning, alert, or advisory.

Credit: NOAA GSL

Project: Developing a next-generation hazardous weather warning generation and dissemination software for the National Weather Service

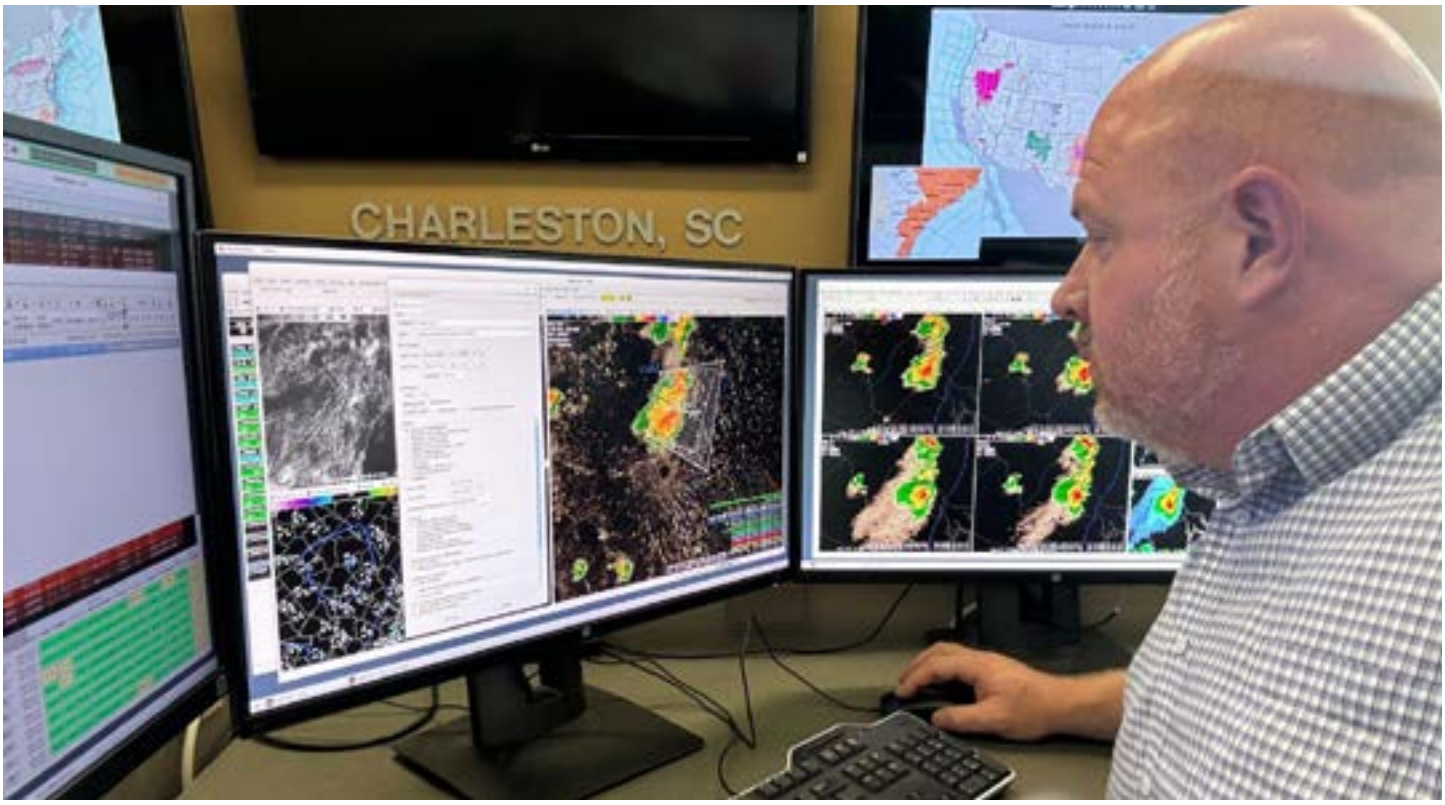
CIESRDS contributors: Chris Golden, Suneng Zhuo, Rob Weingruber, Vada Dreisbach, Tracy Hansen

Relevance to NOAA: Weather forecasting in and of itself is not enough to create a weather-ready nation, one of NOAA's long-term goals. Forecasting must also support the generation of notifications of various phenomena that could result in hazardous conditions like flooding, tornadoes, blizzards, and dust storms. The goal of this project is to develop Hazard Services, a next-generation hazardous weather warning generation and dissemination software.

CIESRDS scientists are developing a next-generation hazardous weather warning generation and dissemination software called Hazard Services. Hazard Services takes weather forecasting of conditions and generates and disseminates hazard notifications (watches, warnings, and advisories) to allow stakeholders, including the general public, to avoid loss of life and property. Hazard Services combines the capabilities of legacy National Weather Service applications into a single application and adds tremendous configurability to efficiently handle other hazard types like storm surges and tsunamis.

So far, Version 4, developed entirely in-house, has been deployed in a number of National Weather Service Weather Forecasting Offices (WFOs) for extensive on-the-ground testing. Some WFOs have moved beyond testing and are using Hazard Services for operational issuance of convective warnings, watches, and advisories, thus using it today to protect lives and property.

Over the next five years, Hazard Services will be deployed at all NWS Weather Forecast Offices and elsewhere, a standard part of the software suite used by forecasters to issue warnings to the public and to other stakeholders. It will also be employed overseas; for example, in Taiwan. The next version will be moved to the cloud.



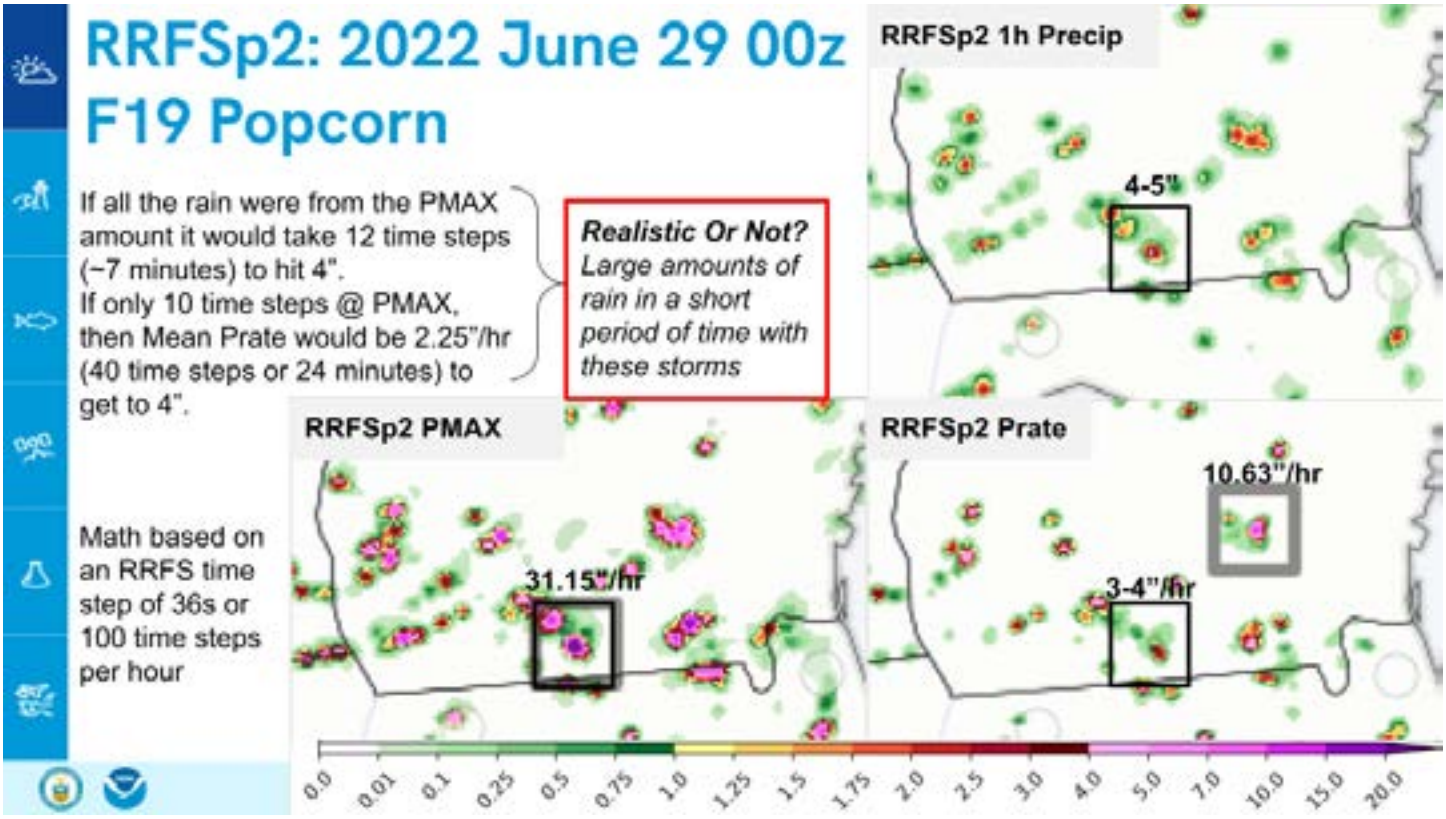
Steven Taylor, NWS forecaster at the WFO in Charleston, South Carolina, issuing the first Special Marine Warning with version 4 of Hazard Services on July 10, 2024.
Credit: NOAA WFO Charleston

Project: Evaluating the Rapid Refresh Forecast System (RRFS)

CIESRDS contributors: James Correia Jr., Massey Bartolini, Sarah Trojniak, Tomer Berg, Kirstin Harnos

Relevance to NOAA: This project helps improve NOAA weather forecast models by calling attention to previously unknown shortcomings.

CIESRDS scientists are helping NOAA improve its Rapid Refresh Forecast System (RRFS) through model evaluation. For this project, researchers evaluated the model's performance over multiple years for heavy rainfall, snow, freezing rain, temperature, and precipitation forecasts. The team offered feedback to model developers through final reports, conference presentations, and National Weather Service presentations. They contributed their findings to a NOAA white paper on the challenges of the RRFS, noting the deficiency of the model to produce excessive grid point storms resulting in too much unorganized heavy rain. They helped identify problems in the partitioning of snow and sleet, while noting physics deficiencies over snow-covered ground. During the next five years, the researchers will perform model surveillance in order to monitor the strengths and weaknesses of the modeling system and train forecasters to be aware of them.



A map of surface temperatures across the continental United States on February 3, 2026, derived from the Rapid Refresh Forecast System.
Credit: NOAA GSL

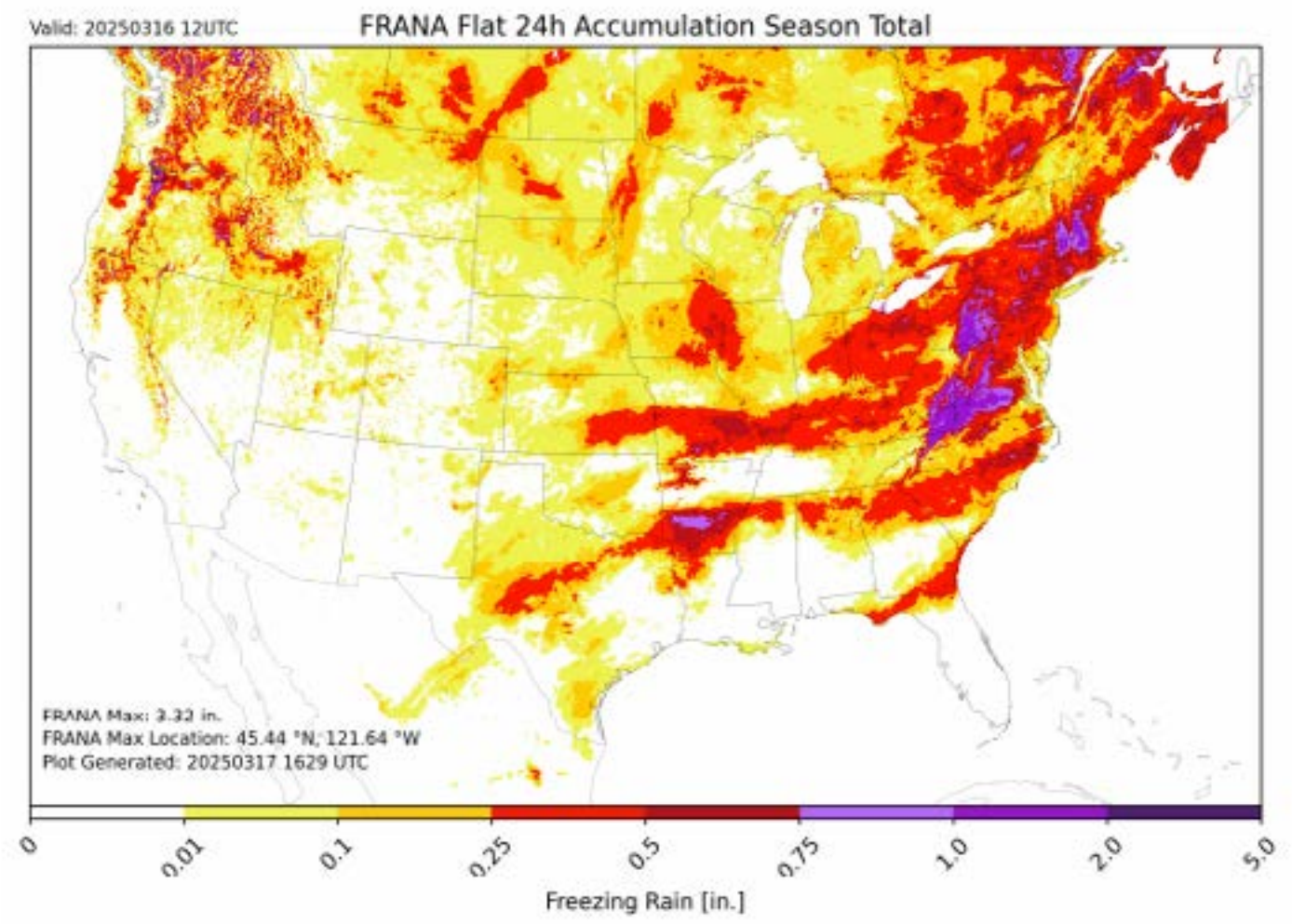
Project: Using observational data to evaluate freezing rain forecast systems

CIESRDS contributors: Massey Bartolini, James Correia Jr.

Relevance to NOAA: This project developed a first-of-its-kind observational algorithm to derive freezing rain forecasts, which will be experimentally transitioned to operations this season. This will allow NOAA's Weather Prediction Center to evaluate its freezing rain forecast system for the first time with reliable observational data.

This CIESRDS research team evaluated the National Severe Storms Laboratory's Freezing Rain Analysis system for incorporation into the observations suite for winter weather. This will allow researchers to evaluate model predictions of freezing rain. So far, the researchers have examined numerous case studies and worked with partners to offer suggestions for improvement. Feedback came via focus groups, experiments, summaries, and final reports. The team used this feedback to develop bias corrections using observations and to develop strengths and weaknesses that can be used to train forecasters using this product.

Over the next five years, the CIESRDS team will continue to collect case studies to measure performance of the observational system and continue formal evaluation and verification of freezing rain forecasts.



Summary of estimated winter 2024-2025 freezing rain (flat ice) using the Freezing Rain Accumulation National Analysis (FRANA) dataset. Yellow to purple areas indicate the amount of accumulation, purple being the highest.
Credit: NOAA WPC

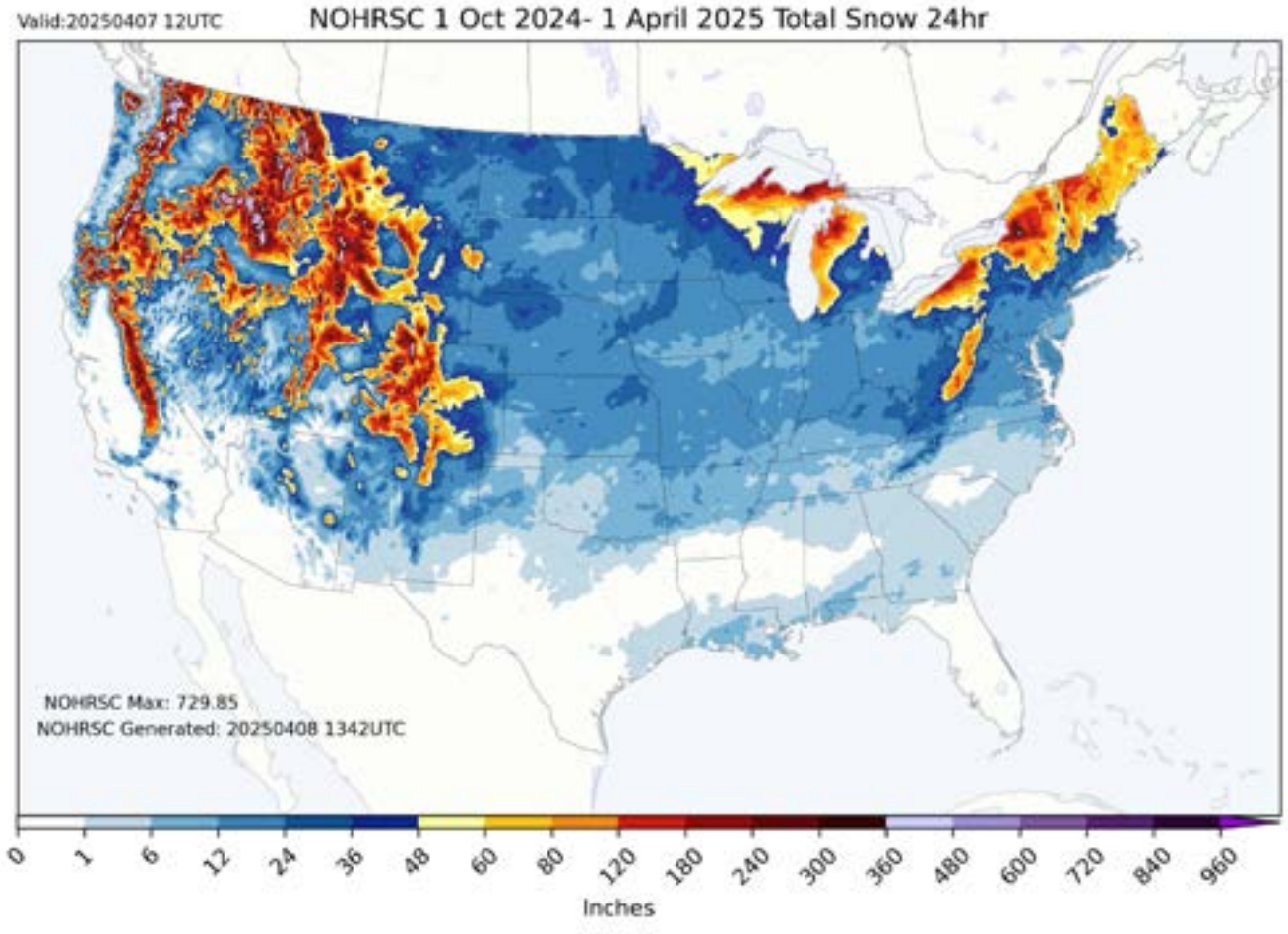
Project: Developing hydrometeorology testbed software

CIESRDS contributors: James Correia Jr, Massey Bartolini, Sarah Trojniak, Tomer Berg, Kirstin Harnos, Bill Lamberson

Relevance to NOAA: The hydrometeorology testbed software developed as part of this project detects problems in models and algorithms used to forecast high-impact weather, As a result of this project, NOAA can develop mitigation plans for known issues prior to implementing models and algorithms into the Weather Prediction Center's operational forecast products and services.

NOAA's hydrometeorology testbed consists of activities to accelerate the assessment and implementation of new technology, research results, and other scientific advancements into Weather Prediction Center (WPC) operational forecast products and services. These activities include the Flash Flood and Intense Rainfall Experiment (FFaIR) and the Winter Weather Experiment (WWE), which are designed to enhance forecast skill for high-impact weather, especially precipitation, by facilitating interactions among researchers, operational forecasters, and users.

CIESRDS researchers in WPC crafted a hydrometeorology testbed software ecosystem during the COVID-19 pandemic to engage experiment participants with forecasting activities. Since then, the software has evolved to showcase and visualize model and observational data for forecasting, evaluation, verification, and surveillance of everyday events. This core infrastructure serves the team, participants, and researchers, ensuring a layer of connectivity and transparency across models and algorithms. The researchers have been able to use these software implementations to expose new model strengths and weaknesses, provide visibility for funded project partners' research, and assist the team in its core functions to identify and expose algorithm, model, or data challenges. Over the next five years, they will continue developing software to analyze multiple models, algorithms for the detection of faulty algorithms, or modeled processes for the purposes of improvement.



Total seasonal snowfall estimates for November 2024 through April 2025 used in the 2024-2025 Winter Weather Experiment (WWE). Credit: NOAA WPC

Project: Developing a drone-based wildfire observing system

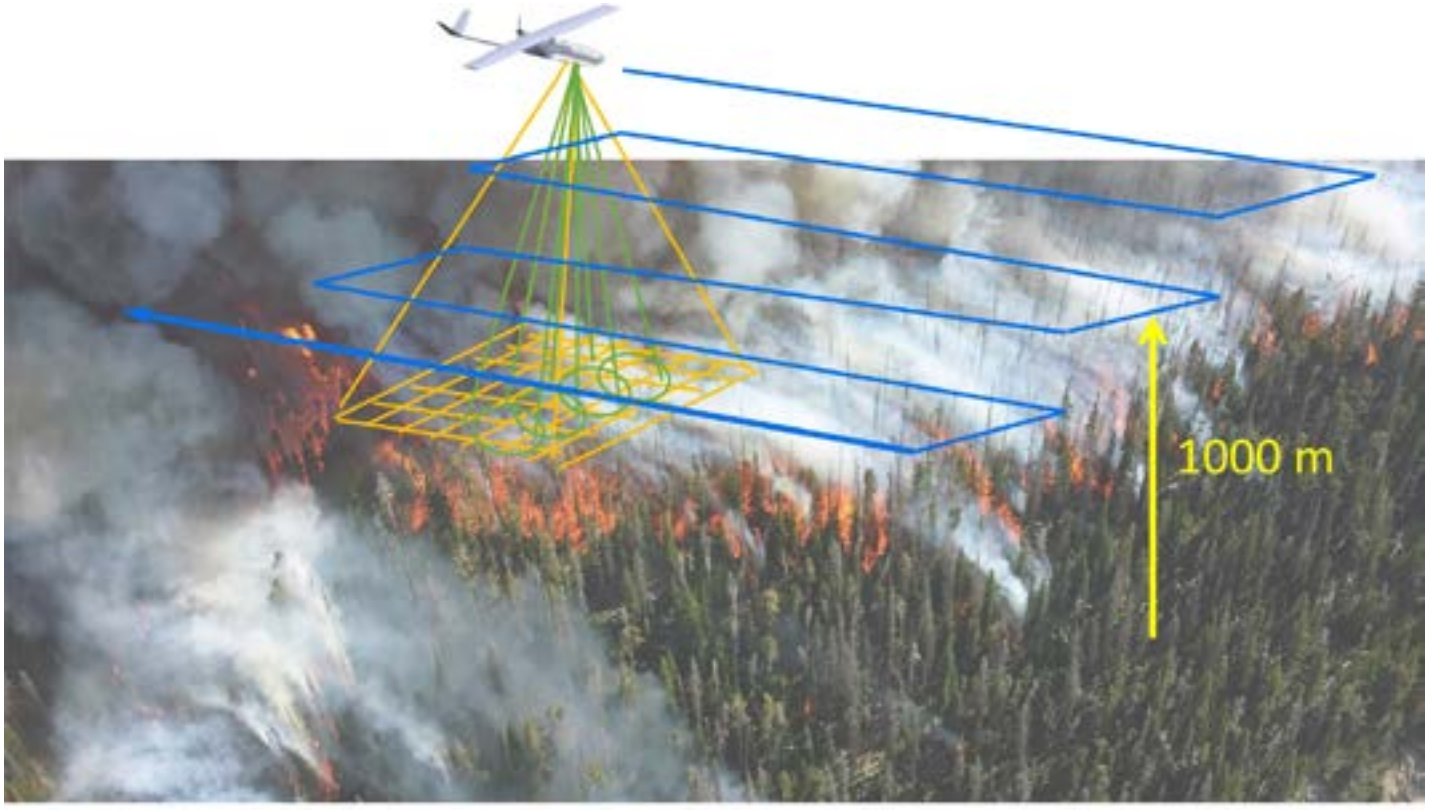
CIESRDS contributors: Joey Taylor, Matthew Forbes, Samantha Delone, Rushan Gao

Relevance to NOAA: This project advances NOAA's mission by providing low-cost, high-resolution wildfire monitoring using uncrewed aerial system (UAS) platforms. Improved nighttime and close-range observations strengthen fire detection, behavior analysis, and response planning. The resulting data support public safety, reduce risk to personnel and communities, and enhance understanding of wildfire impacts on air quality and climate.

NightFOX is a lightweight payload developed by CIESRDS that is mounted on a small, uncrewed aircraft to observe wildfires. Using infrared and visible imaging instruments, NightFOX measures fire extent and intensity at less than 20-meter resolution from safe altitudes, including at night. NightFOX fills critical observational gaps left by satellites and crewed aircraft, offering a low-cost, high-resolution alternative for improved wildfire monitoring, situational awareness, and support for fire behavior research and response efforts.

Since September 2022, NOAA has leveraged CIESRDS expertise in instrument development and field deployment to advance NightFOX's observational capabilities. The team has published one paper and completed multiple field deployments, using both fixed-wing and quadcopter UAS platforms. These efforts enable detailed, high-resolution analysis of fire behavior across a range of scales, from small burns to larger wildfire events, strengthening NOAA's applied monitoring, research, and response capabilities.

Over the next five years, CIESRDS researchers will refine the measurement platform and deploy it on multiple uncrewed systems to demonstrate its performance and reliability. These efforts will enable broader application and commercialization of the technology for wildfire monitoring and related environmental needs.



A UAS outfitted with infrared sensors and an onboard data system measures the extent and intensity of a fire from a safe altitude.
Credit: Joey Taylor/CIESRDS; photo by National Park Service

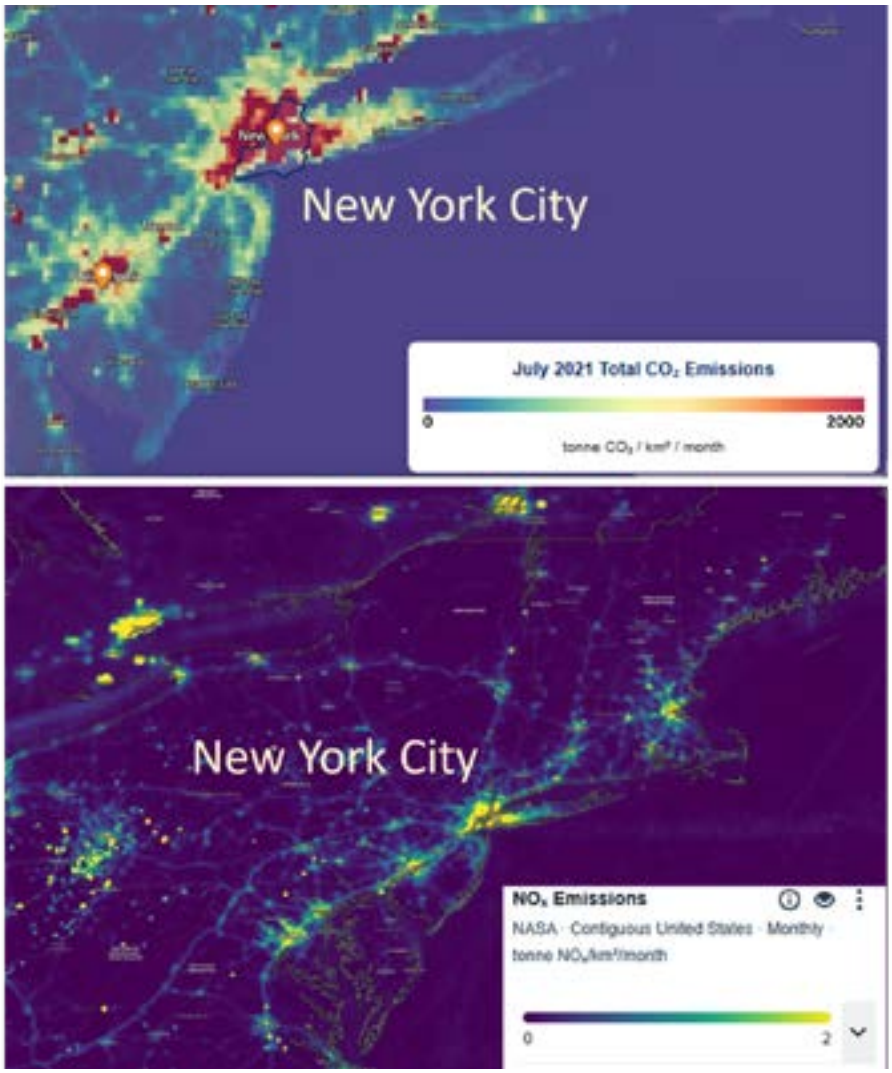
Project: Developing the U.S. Greenhouse Gas and Air Pollutant Emissions System (GRAAPES)

CIESRDS contributors: Congmeng Lyu, Meng Li, Quazi Rasool, Colin Harkins

Relevance to NOAA: This project creates a unified, high-resolution dataset of U.S. greenhouse gas and air pollutant emissions with data from various sectors like energy, transport, and agriculture. The project considerably improves decision-makers' ability to quantify emission reductions for climate and air quality purposes.

The U.S. Greenhouse Gas and Air Pollutant Emissions System (GRAAPES) is a tool developed by NOAA, CIESRDS, and NIST that creates a unified, high-resolution dataset of U.S. greenhouse gas and air pollutant emissions, integrating data from various sectors like energy, transport, and agriculture.

GRAAPES uses national surface and energy data to bridge the gap between greenhouse gas and air quality emissions inventory development in the United States. So far, the GRAAPES team has published three articles, presented six times at conferences, and developed one provisional patent. Over the next five years, the researchers will update the GRAAPES inventory to include methane, nitrous oxide, and other greenhouse gases. They also plan robust evaluations with additional observational datasets and updates to inventory through inverse modeling methods, as well as extending GRAAPES data back to 2010 and expanding the inventory to estimate emissions outside of the continental United States.



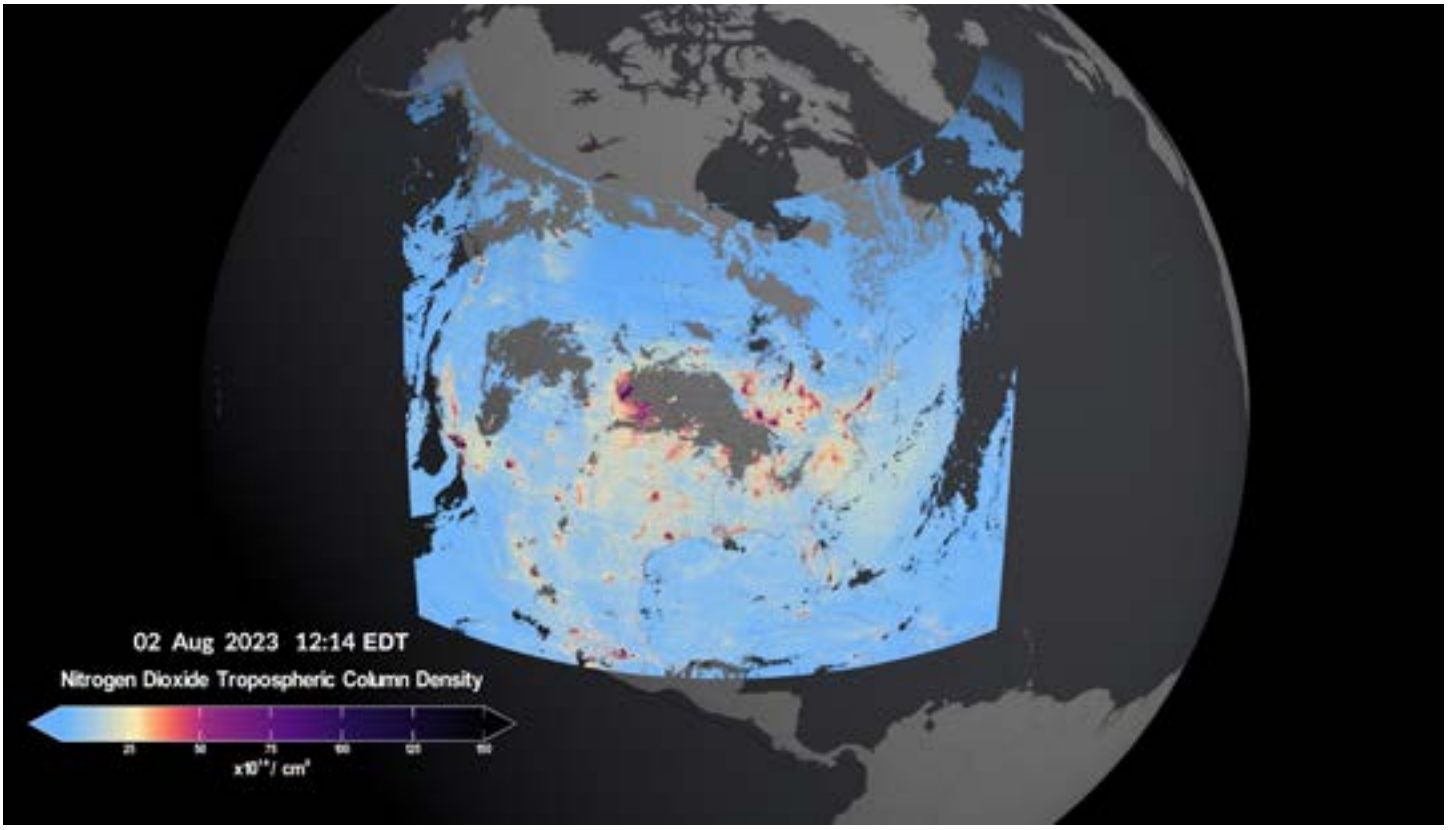
Maps visualizing GRAAPES emission inventories for carbon dioxide and nitrogen dioxide above New York City.
Credit Audrey Gaudel NOAA CSL and CIESRDS

Project: Using satellite data to improve air quality and wildfire forecasting

CIESRDS contributors: Siyuan Wang, Chia-Hua Hsu, Congmeng Lyu

Relevance to NOAA: This project improves NOAA's air quality and wildfire smoke forecasting capabilities.

CIESRDS scientists use the Tropospheric Emissions: Monitoring of Pollution (TEMPO) and the TROPOspheric Monitoring Instrument (TROPOMI) satellites to improve emissions inventories of nitrogen oxides, improving air quality and wildfire forecasting. Since undertaking the project, the researchers have published three articles and presented their work at three conferences. Over the next five years, the team will continue evaluating atmospheric composition products from the NOAA JPSS/GeoXO satellites for air composition monitoring, air quality forecasting, and near-real-time emissions monitoring applications. Further, they will explore emerging artificial intelligence and data assimilation tools for satellite applications.



Nitrogen dioxide concentrations over North America captured by the TEMPO satellite on August 2, 2023.
Credit: NASA Scientific Visualization Studio

Project: Developing a forecasting system that includes atmospheric chemistry

CIESRDS contributors: Jian He, Quazi Rasool, Meng Li, Congmeng Lyu, Colin Harkins

Relevance to NOAA: This project develops tools to significantly improve NOAA's ability to model air composition and generate air quality forecasts. Adding atmospheric chemistry to current forecast models will make NOAA's forecasting system more robust and reliable.

CIESRDS researchers have developed a Configurable Atmospheric Chemistry (CATChem) library and modeling component, which has been connected into NOAA's next generation Unified Forecast System (UFS) to create UFS-Chem. Initial success by a NOAA/CIESRDS team led to the further collaboration with NOAA's Environmental Modeling Center (EMC) to develop the Global Chemistry and Aerosol Forecast System (GCAFS v2), which will use UFS-Chem and its model evaluation tool, MELODIES MONET, to support operational weather, air quality, and smoke forecasts. So far, CIESRDS researchers have published one article and given 10 conference presentations on this work. Over the next five years, they will continue to develop UFS-Chem and MELODIES MONET, especially for applications involving air quality forecasting and satellite data assimilation.

The World Health Organization estimates that air pollution accounts for over eight million deaths each year. This image shows smog blanketing the Los Angeles metro area.
Credit: Wikimedia Commons

Project: Conducting modeling and analysis to support stakeholder science

CIESRDS contributors: Jian He, Siyuan Wang, Quazi Rasool, Congmeng Lyu, Meng Li, Audrey Gaudel, Colin Harkins

Relevance to NOAA: This project tackles air quality and climate projects relevant to policy.

This project answers air quality questions with improved modeling and observational data. So far, CIESRDS scientists on this team have used data from NOAA's 2023 AEROMMA field campaign to improve air quality modeling and analysis. Over the next five years, the researchers will continue modeling and analysis activities using data from the AEROMMA campaign and continue to contribute to research-to-operations efforts.

An aerial view of Chicago taken from the NASA DC-8 during the 2023 AEROMMA field campaign.
Credit: Brian Baxler/NOAA

Project: Identifying physical processes responsible for cloud response using field observations and models

CIESRDS contributors: Xuanyu Chen, Brandon Wolding

Relevance to NOAA: This project improves how NOAA's high-resolution weather and climate models represent shallow convection over warm ocean surfaces, enhancing the ability of models to simulate air-sea interactions in the tropics and improving predictions of downstream extreme weather events.

CIESRDS scientists participated in the 2020 Atlantic Tradewind Ocean-Atmosphere Mesoscale Interaction Campaign (ATOMIC) field campaign, where they used coordinated measurements from ships, airplanes, and uncrewed aircraft to investigate cloud and air-sea interaction processes in the tropical North Atlantic Ocean. ATOMIC's goal was to advance understanding and prediction of U.S. weather and climate by gaining a better understanding of the micrcophysics of clouds and air-sea interactions.

The campaign's results show that weak sea surface temperature variations drive a low-level cloud response in the atmosphere that current climate models underestimate. To address this, CIESRDS researchers developed an idealized ensemble framework model to pinpoint the specific physical processes responsible for the observed cloud behavior.

CIESRDS researchers found surface-driven convective turbulence to be the main driver of the observed cloud behavior and made this result available to the modeling community by providing benchmark satellite composites and high-resolution simulations. Over the next five years, the researchers will continue to employ idealized modeling approaches. They will test a coupled atmosphere-ocean large eddy simulation model in idealized, ATOMIC campaign-like conditions to assess the environmental controls of shallow convection responses to tropical mesoscale sea surface temperature variability. This work will advance understanding and modeling of tropical processes, including their impacts on global climate predictions.

An overview of the platforms used to collect data for the ATOMIC campaign.
Credit: NOAA PSL

Project: Advancing NOAA forecast systems through the development and implementation of process-based diagnostics for tropical convection

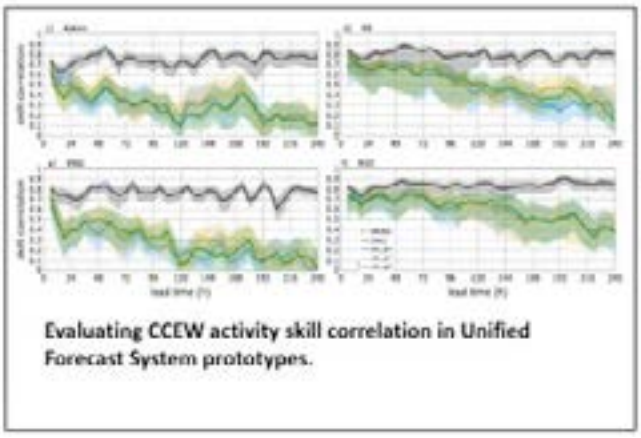
CIESRDS contributors: Maria Gehne, Brandon Wolding

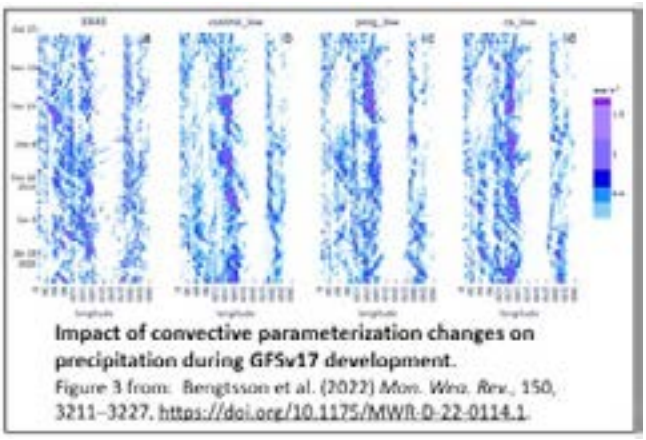
Relevance to NOAA: This project diagnoses the evolution of weather prediction model performance in the tropics and translates model advancements into improved predictive skill, thereby supporting NOAA's goals of better understanding changes in Earth's climate, weather, oceans, and coasts.

Forecast models struggle with predicting large-scale convective activity in the tropics. Leveraging the theoretical predictability inherent in tropical large-scale convective features could significantly reduce forecast errors. This error reduction would both improve tropical forecasts and limit the propagation of these errors into the midlatitudes. The goals of this project are to diagnose the evolution of weather prediction model performance in the tropics by lead time, assessing their sources, and aiding in translating model advancements into improved skill.

CIESRDS scientists developed a Python package which is available on GitHub and provides a valuable resource for researchers and model developers working on tropical meteorology and climate. The package offers standardized tools and instructions for using them to evaluate and understand tropical processes within models and observational data. In October 2025, the repository had 35 unique visitors and 22 unique cloners.

Over the next five years, the researchers will continue to support NOAA model development through diagnostics and analysis to assess the representation of tropical convection in machine learning-based models. Immediate goals are to evaluate machine learning forecasts against traditional weather forecasts, focusing on their representation of tropical convection and its coupling to large-scale circulation.





Left: Skill correlation between UFS prototype wave activity and IMERG activity for (c) Kelvin activity, (d) ER activity, (e) MRG activity, and (f) MJO activity. In (c)–(f) the skill correlation between IMERG and ERA5 is shown at all lead times (black solid) for comparison. The 95% confidence intervals are shown in shading.

Credit: Lisa Bengtsson/NOAA PSL

Right: Hovmöller diagram of 6-hourly precipitation (mm h–1) initialized at 29 Oct 2019 for (a) ERA5, (b) control_low, (c) prog_low, and (d) ca_low. The precipitation is averaged over the latitude bands 5°S–5°N.

Credit: Bengtsson et al. 2022, *Monthly Weather Review*

Project: Advancing NOAA's airborne wind profiling capabilities

CIESRDS contributors: Michael Zucker, Maxwell Holloway, Richard Marchbanks, Sunil Baidar, Brian Carroll, Brandi McCarty, Nathan Malarich, Yelena Pichugina, Amanda Makowiecki

Relevance to NOAA: Wind measurements are important for a range of weather and air quality studies, and this project fills a niche otherwise vacant in NOAA.

This CIESRDS research team developed and deployed state-of-the-art wind lidar instruments on NOAA aircraft, providing profiles of winds, aerosol, and boundary layer heights for a wide range of applications. The lidar has world-class, unique capability to profile winds above and below the aircraft. Over the next five years, CIESRDS researchers will update and field-harden these unique instruments for continuing field projects with a roughly once-annual cadence.

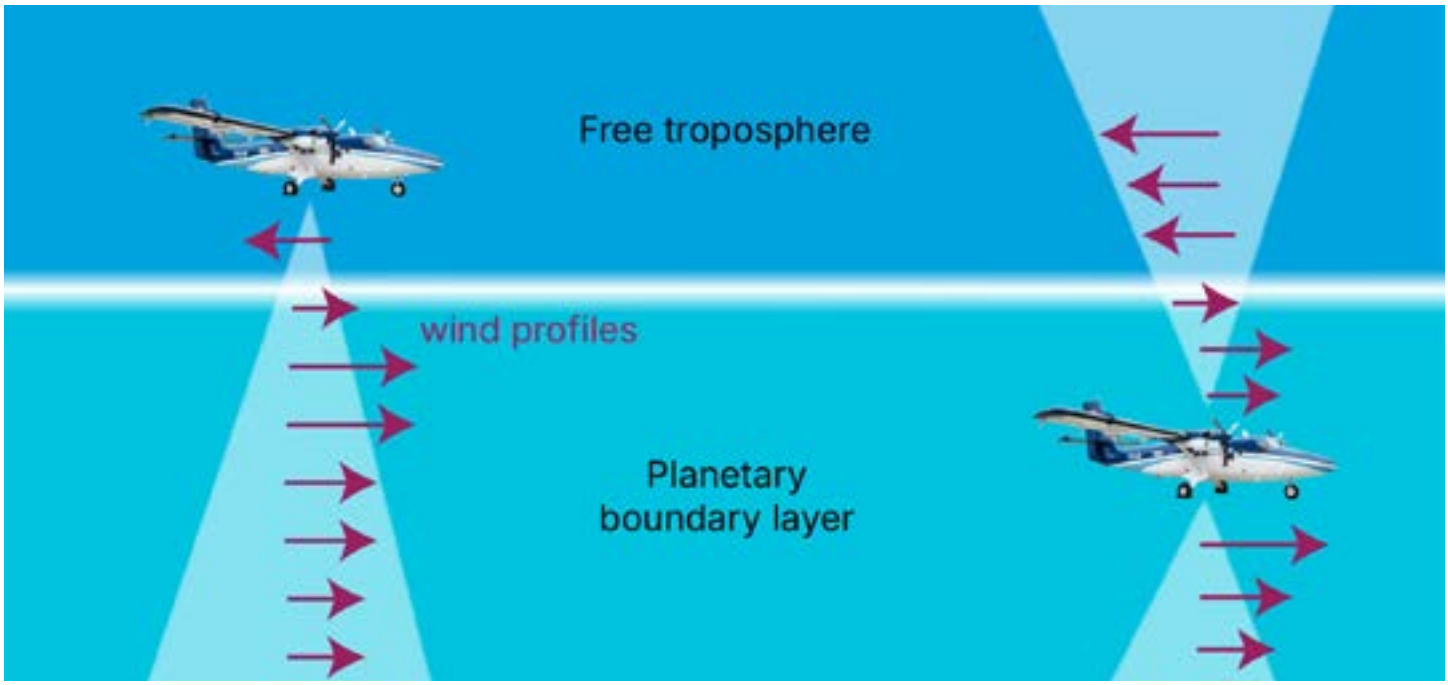


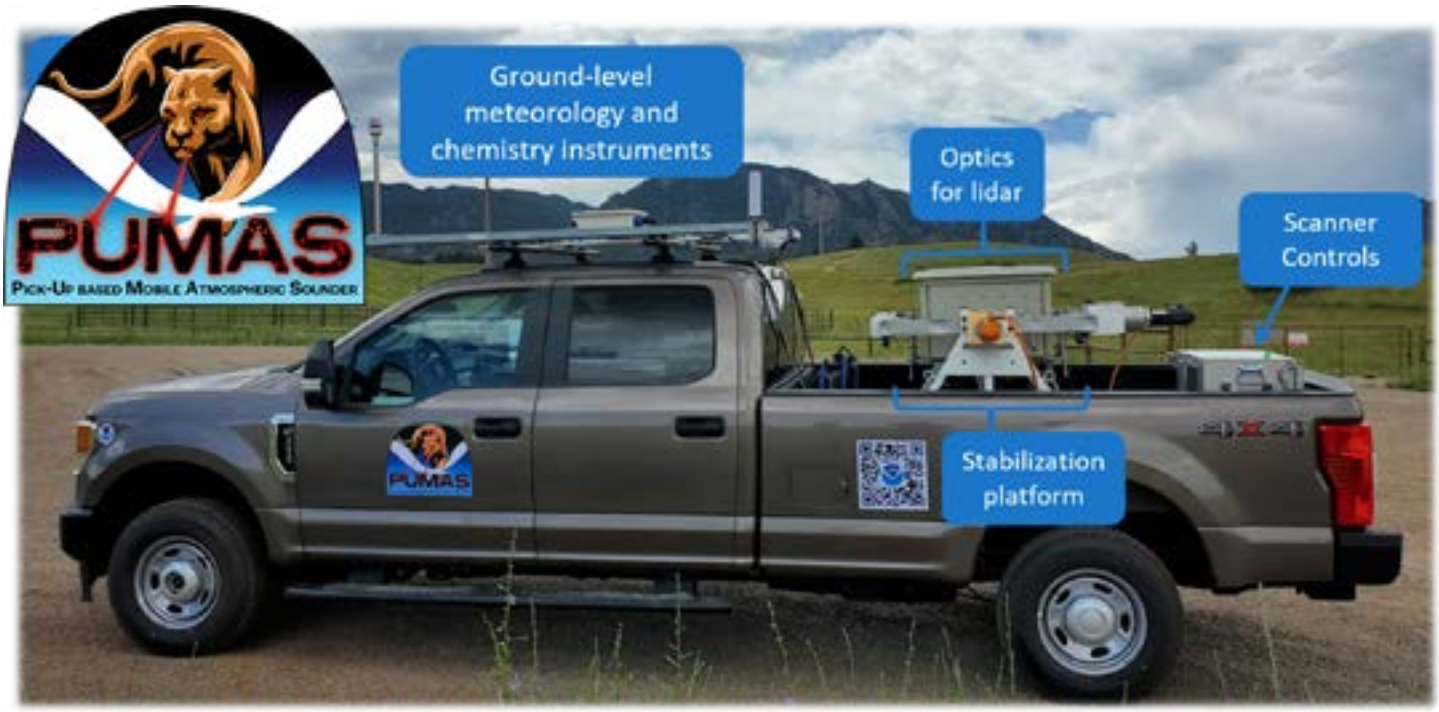
Diagram showing how lidar instruments installed on a NOAA aircraft can take wind profiles above and below the aircraft and in the free troposphere and planetary boundary layer. Wind profiling above and below an aircraft is a unique capability that provides maximum flexibility and synergy with both remote sensing and in situ instruments.
Credit: Lauren Lipuma/CIESRDS

Project: Developing a unique truck-based wind profiling instrument

CIESRDS contributors: Maxwell Holloway, Michael Zucker, Richard Marchbanks, Sunil Baidar, Brian Carroll, Brandi McCarty, Nathan Malarich, Yelena Pichugina, Amanda Makowiecki

Relevance to NOAA: This project developed and deployed a state-of-the-art wind-profiling mobile lidar instrument, providing profiles of winds, aerosol, and boundary layer heights for a wide range of NOAA applications. This work gives NOAA the ability to profile winds in real time from a moving truck, providing NOAA the only existing mobile platform with this capability.

CIESRDS researchers have developed a state-of-the-art wind-profiling lidar instrument on a truck, capable of taking measurements while the truck is moving. This mobile lidar has many research applications: studying air quality, wildfires, wind energy, and more. It has been deployed on four NOAA field campaigns already, including on the 2022 CalFiDE campaign, where it measured wind profiles in real time around active wildfires. It has also been deployed on a NOAA ship for marine boundary layer studies. Over the next five years, the researchers plan to update and field-harden this instrument for additional field projects and develop its readiness for immediate deployment.



The unique Pick-Up based Mobile Atmospheric Sounder (PUMAS) platform for fully mobile wind profiling and in situ measurements.
Credit: NOAA CSL

Project: Regional air quality modeling

CIESRDS contributors: Jordan Schnell, Johana Romero-Alvarez, Haiqin Li, Sudheer Bhimreddy, Jeff Duda

Relevance to NOAA: This project incorporates smoke, dust, and pollen into NOAA's flagship convection-allowing model, the Rapid Refresh Forecast System (RRFS), improving prediction of weather and climate, fire weather, and urban air quality.

This project involves incorporating the physical processes involving smoke, dust, and pollen (emissions, transport, and removal of fine smoke and fine and coarse dust) into NOAA's flagship convection-allowing model, the Rapid Refresh Forecast System (RRFS) and other regional scale models.

The team's accomplishments over the project's first five years include development of a verification tool to demonstrate model improvements; implementation of the Hourly Wildfire Potential (HWP) diagnostic tool in real-time to help predict how fires will evolve; launch of an experimental pollen forecast predicting hourly concentrations of tree, grass, and weed pollen; installation of multiple real-time systems, including an interactive site-level verification tool to quickly assess model performance; implementation of smoke, dust, pollen, and aerosol forecast capabilities in NCAR's newest dynamical core, the Model for Prediction Across Scales (MPAS); 10 journal manuscripts; and 10 conference presentations. Over the next five years, the researchers will continue to improve predictions of atmospheric composition, chemistry-physics interactions, fire weather, and pollen on both regional and global scales and transfer these prediction capabilities to the MPAS.

The Rapid Refresh Forecast System (RRFS) Hourly Wildfire Potential diagnostic incorporates predicted winds to estimate fire spread and intensity, humidity to estimate influence of atmospheric dryness on fuel moisture, and soil moisture to predict the response of flammable vegetation to precipitation and drought on a scale from 0% in white to 100% in red and orange shades.
Credit: NOAA GSL

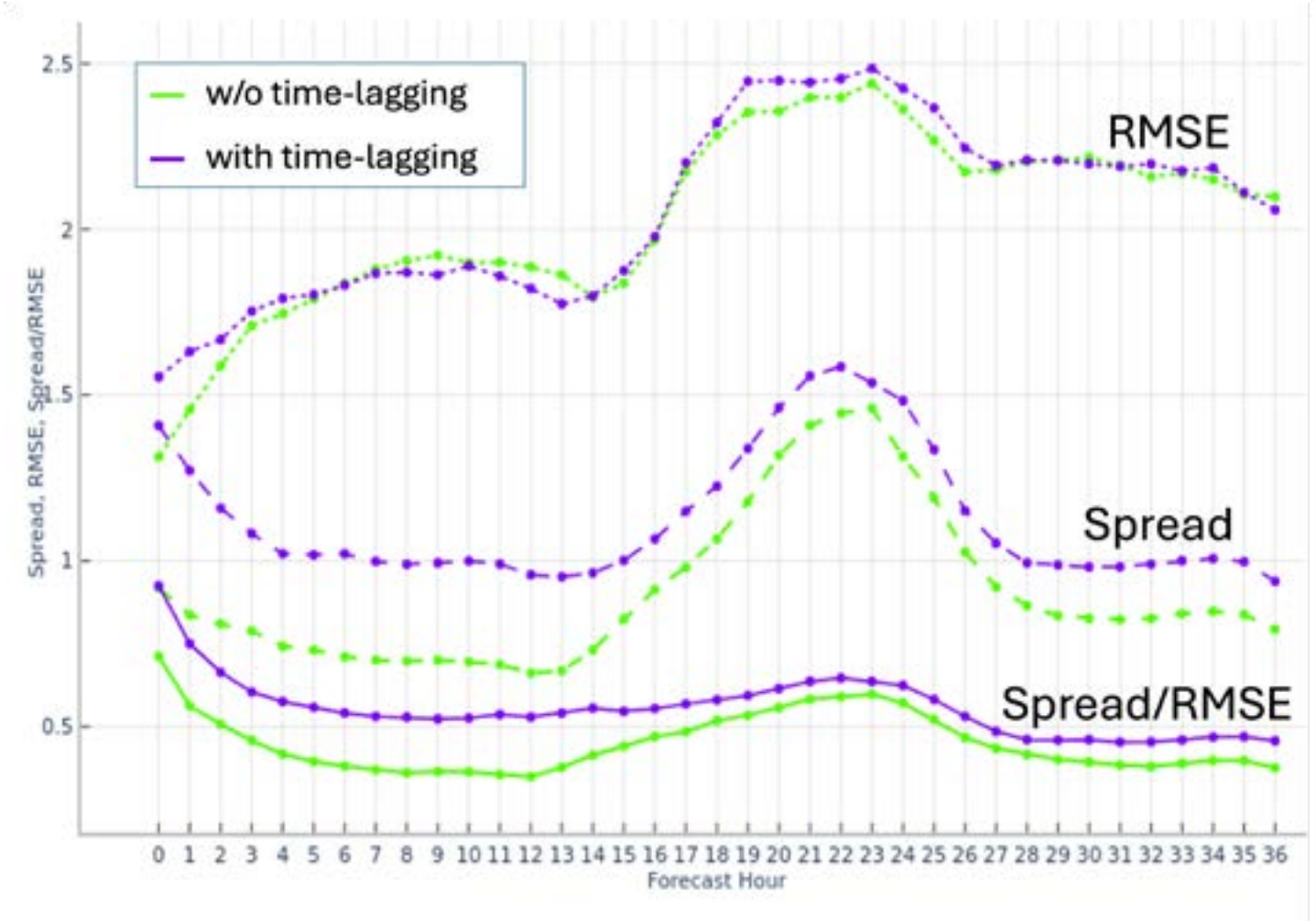
Project: Optimization of ensemble design in the RRFS Version 1

CIESRDS contributors: Gerard Ketefian

Relevance to NOAA: This project helps NOAA's Environmental Modeling Center (EMC) and the National Weather Service determine the best design for its operational Rapid Refresh Forecast System (RRFS) ensemble.

This project explores the viability of member time-lagging and stochastic physics perturbations as techniques to increase the spread of an ensemble of forecasts while maintaining an ensemble spread-to-skill ratio of about 1. A ratio of 1 indicates that the ensemble is well-calibrated, i.e. that the forecast is neither overconfident (under-dispersive) nor underconfident (over-dispersive).

NOAA adopted member time-lagging and stochastic physics perturbations in the design of its Rapid Refresh Forecast System (RRFS) ensemble to help ensure the ensembles are well-calibrated. In the next five years, the project will collaborate with the National Center for Atmospheric Research (NCAR) and continue testing and evaluation activities as part of the Developmental Testbed Center (DTC). This includes developing a stand-alone Github code repository containing a verification framework based on NCAR's METplus verification software that can be used both by other DTC projects and by various unified forecast system applications and using this framework to continue to verify new forecast model innovations.



Spread-Skill Ratio for 2-meter Temperature without (green) and with (purple) Ensemble-Member Time-Lagging.
Credit: Gerard Ketefian/CIESRDS and NOAA GSL

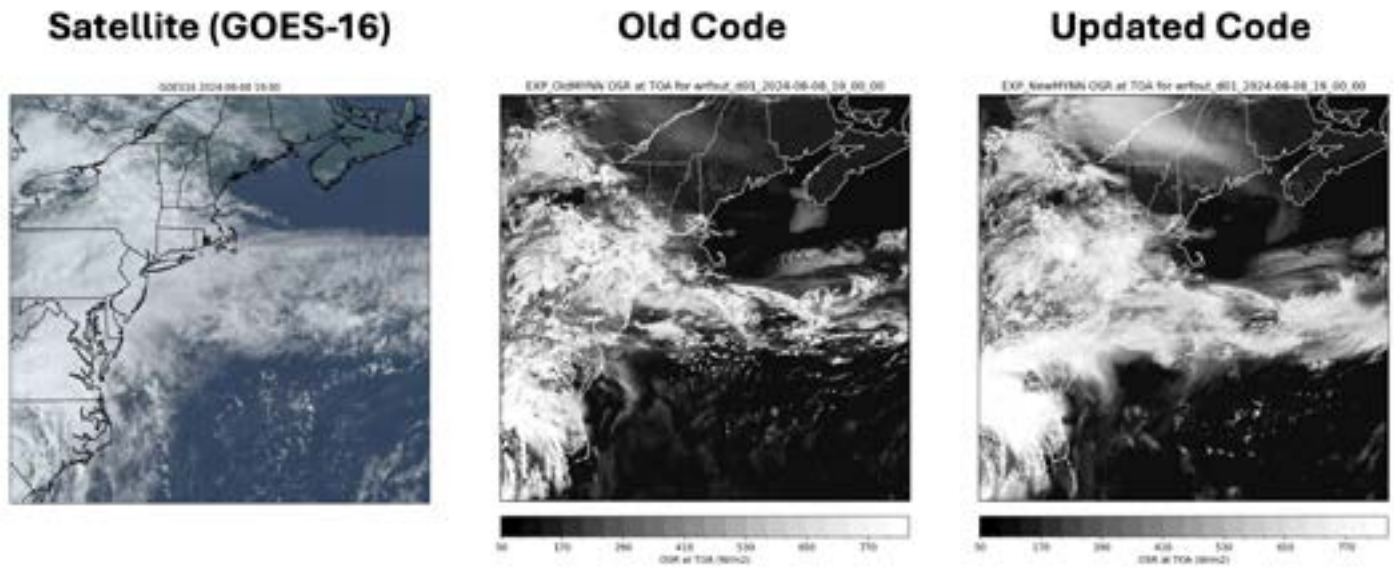
Project: Model physics development for improved weather prediction

CIESRDS contributors: Xia Sun

Relevance to NOAA: This project improves NOAA's numerical weather prediction capabilities through model physics development with a focus on boundary layer physics.

This project advances understanding of physical processes in the marine boundary layer, quantifies model biases, develops model physics for improved wind and cloud forecasts, and transfers model improvements to NOAA's Unified Forecast System (UFS) community code for use in future versions of NOAA's operational forecast models.

The team's accomplishments so far include updating code committed to the official submodule repository for the boundary layer scheme; one updated technical memorandum (under review); five journal manuscripts (in preparation); and seven conference presentations. Over the next five years, the researchers will improve cloud representation and boundary layer structures in models by developing and refining the coupling between a planetary boundary layer scheme and the prognostic cloud extension of the microphysics parameterization scheme.



Comparison of GOES-16 satellite image (left) to forecasts demonstrating that the updated code (right) generates more robust overall clouds than the old code (center).
Credit: Xia Sun/CIESRDS and NOAA GSL

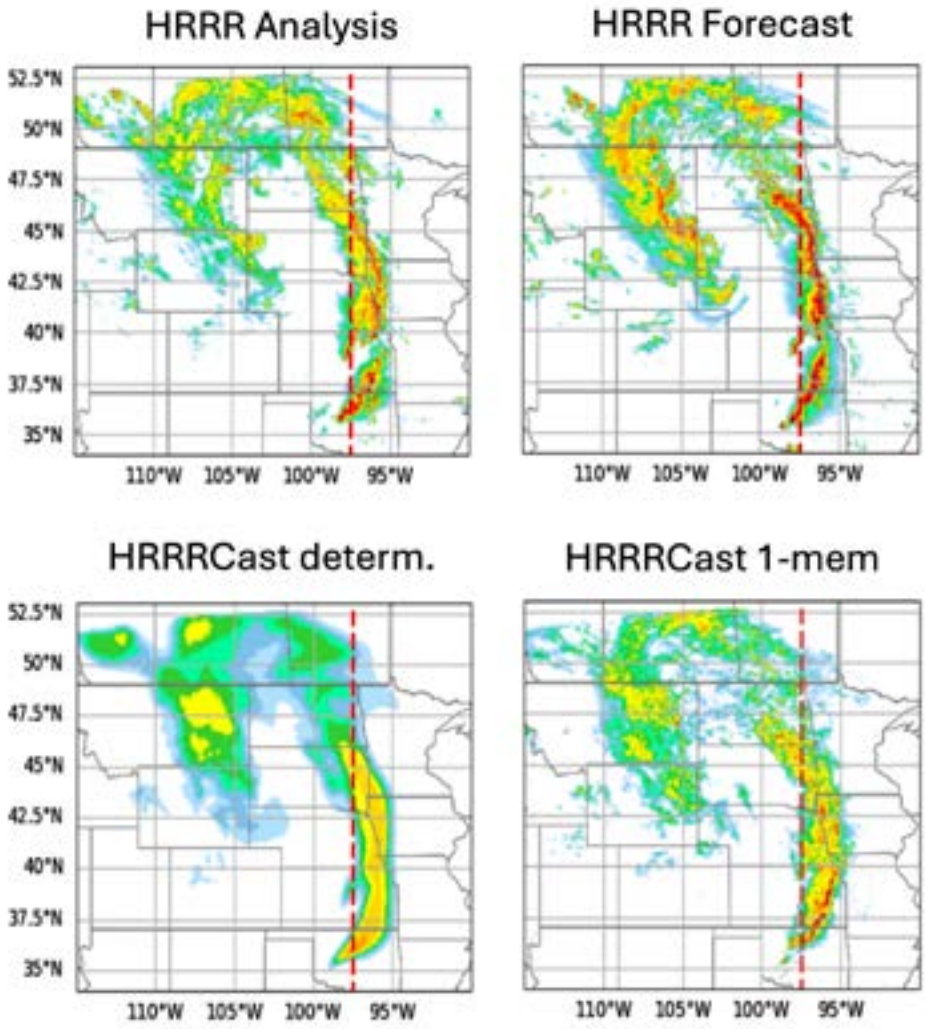
Project: Developing NOAA's first convection-resolving data-driven model

CIESRDS contributors: Daniel Abdi, Paul Madden, Emily Carpenter

Relevance to NOAA: This project improves NOAA's numerical weather prediction capabilities.

CIESRDS researchers on this project developed HRRRCast, a key component of NOAA's broader Project EAGLE (Experimental AI Global and Limited-area Ensemble forecast system), a long-term project to provide NOAA with the ability to rapidly test, develop, and identify the most promising AI models for global to regional ensemble forecasting.

HRRRCast is an AI forecast model trained on 8.5 years of data from NOAA's short-term regional weather forecast model High Resolution Rapid Refresh (HRRR) and its Global Forecast System (GFS) model. So far, the team has developed HRRRCast Version 1, and the team is currently developing a model evaluation tool-based software kit for verifying AI forecast models. The team has published one journal paper and presented 16 invited talks on HRRRCast. Over the next five years, the researchers will deploy Version 2 of HRRRCast and develop versions 3 and 4. The verification software developed by this team will continue to be used to verify several NOAA AI models.



Comparison of composite reflectivity from the HRRRCast (lower right, labeled "HRRRCast 1-mem") with the HRRR analysis (upper left), HRRR forecast (upper right), and a previous version of the HRRRCast (lower left, labeled "HRRRCast determ.") for a severe tornado outbreak on May 6, 2024 (T23:00:00).

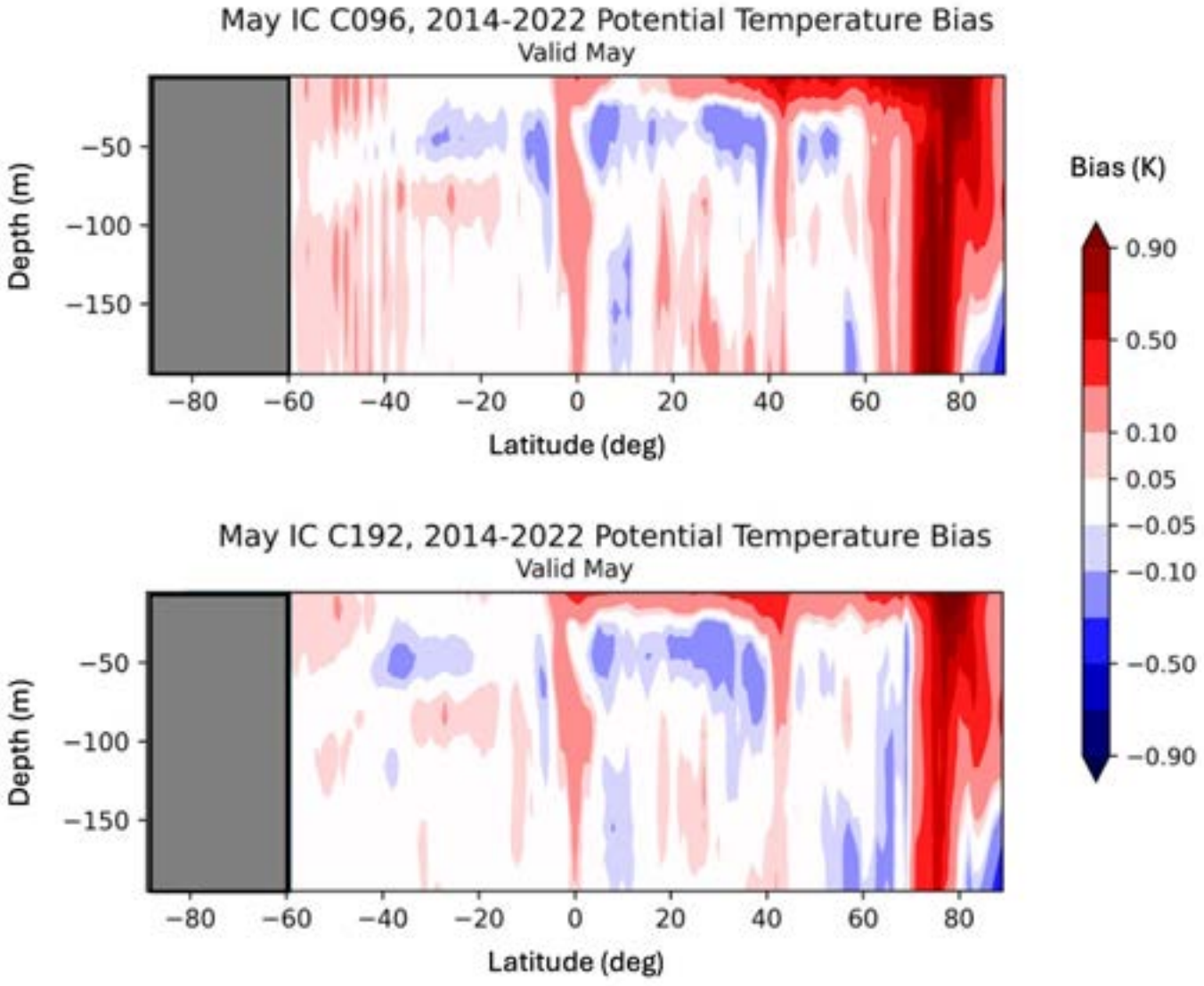
Credit: Daniel Abdi/CIERDS and NOAA GSL

Project: Building NOAA's Seasonal Forecast System (SFS)

CIESRDS contributors: Ben Green, Sina Khani

Relevance to NOAA: This project improves seasonal forecast guidance (out to 12 months) for NOAA's Climate Prediction Center forecasters and other downstream users.

This project focuses on the impacts of microphysics parameterizations, atmosphere and ocean model resolutions, and model initialization strategies to produce the best forecasts for NOAA's Seasonal Forecast System. So far, the project team has collaborated with the NOAA Environmental Modeling Center, Climate Prediction Center, and Physical Sciences Laboratory to develop evaluation techniques for microphysics, model resolution, upper ocean, and model initialization. Over the next five years, the researchers will continue to improve seasonal-to-subseasonal forecast quality and transition the Seasonal Forecast System to operations in 2028.



Mean upper-ocean (top 200 m) temperature bias averaged across nine May forecast cycles (2014–2022) for two Seasonal Forecast System configurations. The lower-resolution system (C096; ~1° atmosphere and ~1° ocean) shows larger warm and cool biases, while the higher-resolution system (C192; ~0.5° atmosphere and ~0.25° ocean) reduces these errors, particularly across the Southern Hemisphere and mid-latitude Northern Hemisphere. The Antarctic land mass south of 60S is masked out.

Credit: Ben Green/CIESRDS and NOAA GSL

Project: Expanding the NOAA-CIRES-DOE 20th Century Reanalysis Version 3 tool (20CRv3) for fire weather and hydrological variability

CIESRDS contributors: Chesley McColl, Lawrence Spencer, Laura Slivinski, Gilbert P. Compo, Prashant D. Sardeshmukh

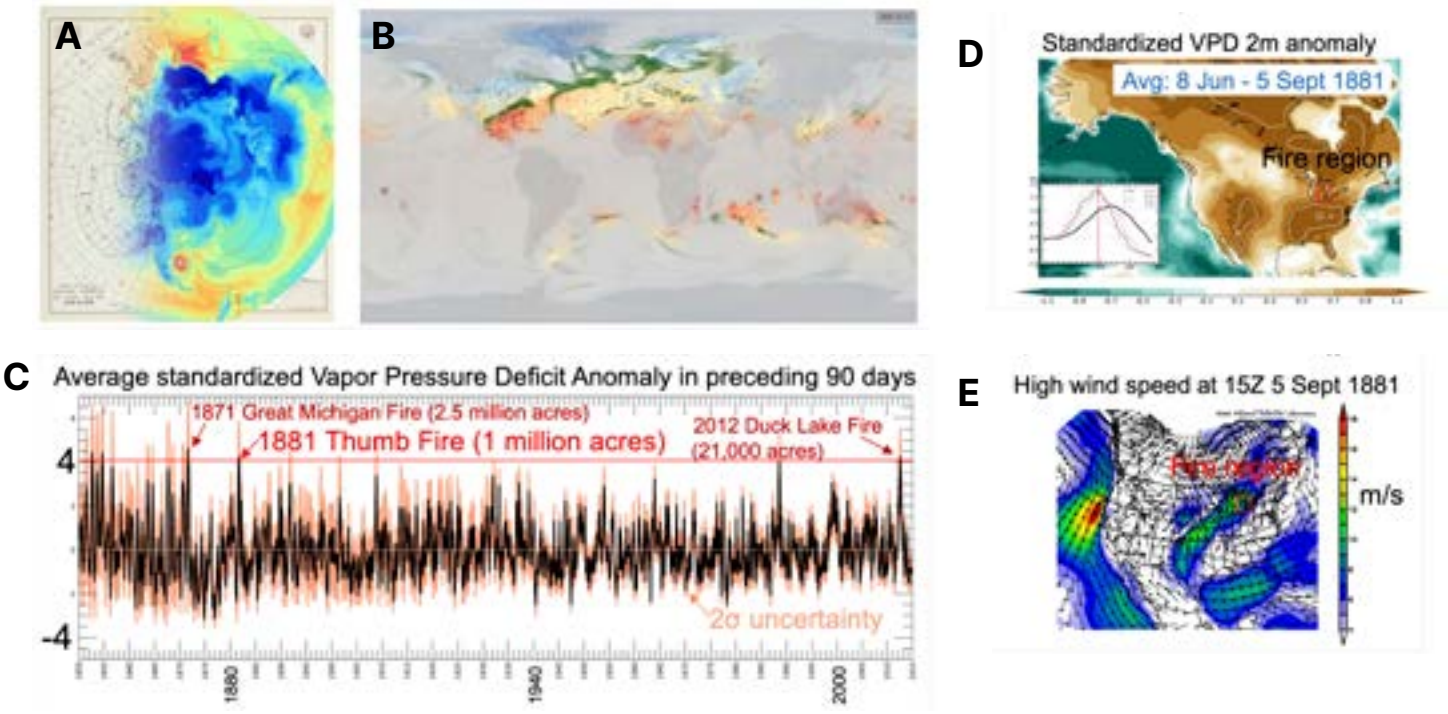
Relevance to NOAA: This project advances NOAA's mission to understand and predict fire weather and water availability by providing an observational subdaily weather dataset of key variables with quantified uncertainties spanning more than 200 years. The tool developed here has been used in thousands of studies relevant to the NOAA mission, on topics ranging from from severe storms to drought.

The Twentieth Century Reanalysis tool is a collaboration between NOAA, CIESRDS, and the Department of Energy. Using a state-of-the-art data assimilation system and surface pressure observations, the tool generates a four-dimensional global dataset of weather from 1806 to 2015 to place current atmospheric circulation patterns into a historical perspective.

Version 3 of the tool includes 80 estimates of global 3-hourly weather states. With these new data, such as near-surface vapor pressure deficit and wind speed, modern fire weather conditions contributing to high fire danger can be quantitatively compared to historical events to improve understanding and test prediction systems.

Since 2022, CIESRDS researchers have shown that the tool's fire weather variables can predict historical massive wildfires from seasonal to subdaily weather conditions and that its 80-member ensemble uncertainty is reliable. The project has generated two external grants, seven presentations, eight publications, and four publicly available datasets, including the near surface Hot-Dry-Windy fire weather index. Two previous papers have been awarded Highly Cited by Clarivate Web of Science during this period.

Over the next five years, the team will extend the tool to present and develop 200-year high-resolution datasets of hourly precipitation through machine learning and dynamical downscaling techniques. They will improve the algorithm and test NOAA's Unified Forecast System and machine learning models for their fidelity in reanalyzing fire weather and other key variables.



This graphic shows the capability of the 20th Century Reanalysis version 3 (20CRv3) to reconstruct historical fire weather conditions with quantified uncertainties, using Michigan's 1881 Thumb Fire as an example. The Thumb Fire was the fastest-spreading wildfire in United States history (1 million acres in 24 hours).

Panels A and B illustrate how 20CRv3 assimilates only surface pressure observations to reconstruct three-dimensional atmospheric fields such as column-integrated water vapor, global temperatures, wind, and precipitation for 1880 conditions. Panel C shows standardized seasonal 2-meter vapor pressure deficit anomalies from 1806 to 2015 for the region of the Thumb Fire. Two other major fires are highlighted. Panels D and E illustrate the seasonal drought conditions and extreme winds that combined to create catastrophic fire weather.

Credit: Laura Slivinski/CIESRDS and NOAA PSL

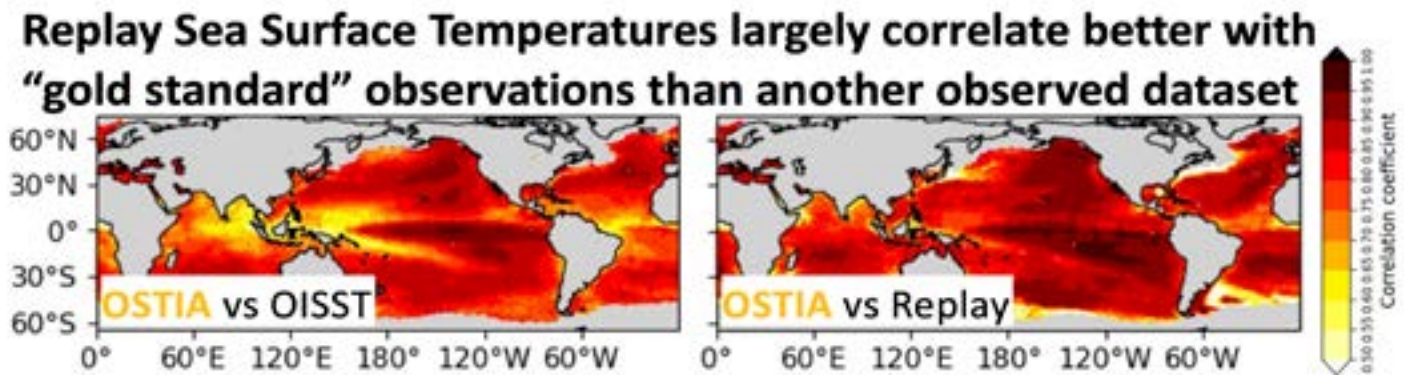
Project: Developing reanalysis tools for initializing reforecasts

CIESRDS contributors: Adam Schneider, Jessica Knezha, Sherrie Fredrick, Timothy Smith, Chesley McColl, Lawrence Spencer, Laura Slivinski, Joao de Souza, Ho-Hsuan Wei, Gilbert P. Compo, Henry Winterbottom, Peter Vaillancourt

Relevance to NOAA: NOAA's Global Ensemble Forecast System and new Seasonal Forecast System development within NOAA's Unified Forecast System (UFS) address top-priority national needs for subseasonal-to-seasonal forecasts of precipitation, temperature, drought, and flooding. The Replay dataset and coupled reanalysis development generated by this project provide initial conditions for UFS tests, reforecasts, and training NOAA-based AI-based weather prediction systems.

This project has developed a 30-year 3-hourly coupled ocean-atmosphere-land-sea-ice "Replay" dataset by nudging NOAA's Unified Forecast System (UFS) to uncoupled atmospheric weather and daily oceanic/sea ice datasets. The dataset and follow-on coupled earth system reanalysis will be used to initialize tests of the next version of NOAA's Global Ensemble Forecast System (GEFS) and new Seasonal Forecast System (SFS), significant tools for generating subseasonal to seasonal forecasts that inform decision-making.

Since 2022, CIESRDS researchers have completed the 30-year Replay dataset of 3-hourly estimates of the state of the weather, ocean, polar sea ice, snow cover, and soil. The project has generated a publication, two cloud datasets, two websites, four meeting presentations, and been awarded an external grant. Over the next five years, the team will develop NOAA's first coupled reanalysis in more than 15 years using new physical and AI models and advanced data assimilation. They will improve initial conditions for testing new GEFS, SFS, and other UFS systems, train AI prediction models, and deliver weather and ocean states for extreme weather and marine research.



Preliminary validation of the developing coupled reanalysis system using the new NOAA UFS model. (Left) An example map of the relative error of directly observed ocean temperature observations. (Right) Time series panels compare forecast and analysis root mean square error and bias between old (Climate Forecast System Reanalysis) and test (UFS coupled reanalysis) systems for (top) near-surface humidity and (bottom) air temperature, demonstrating smaller forecast RMSE and bias in the new test system..
Credit: Philip Pegion/NOAA PSL

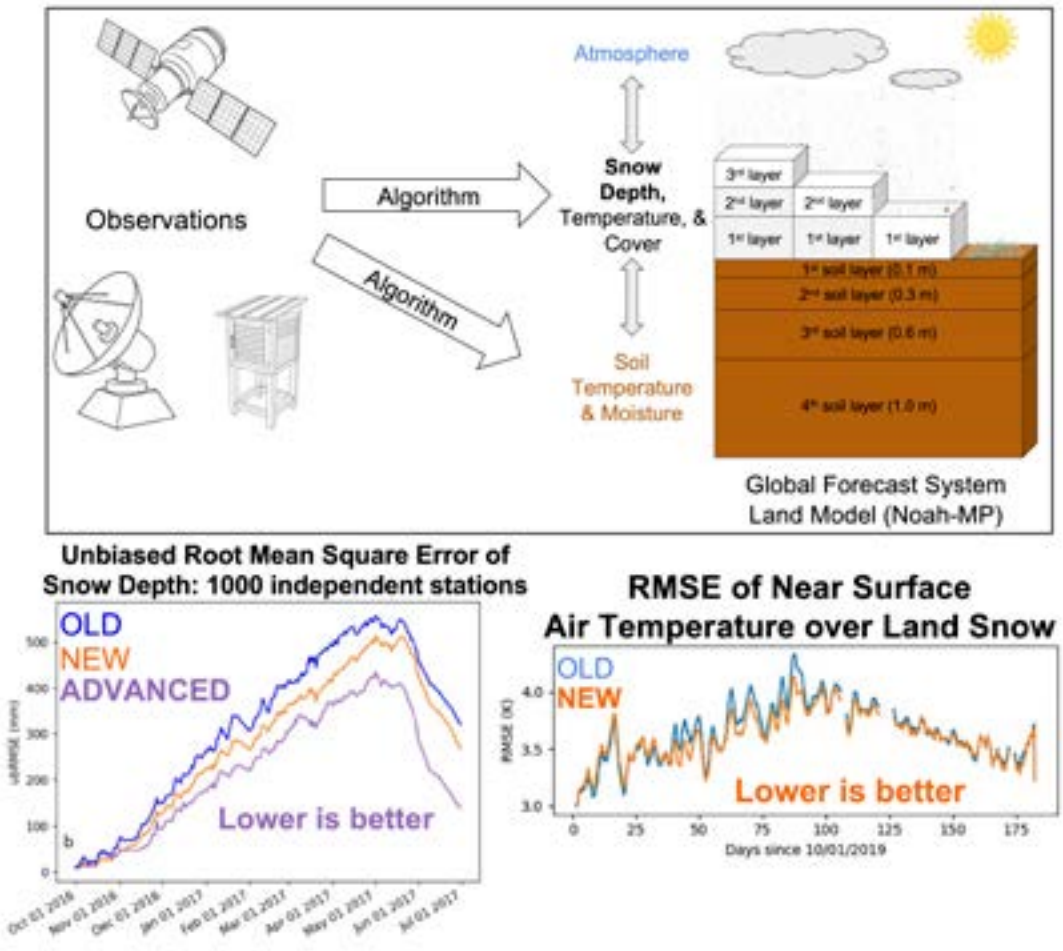
Project: Improving NOAA Unified Forecast System predictions through data assimilation of snow depth observations

CIESRDS contributors: Yanjun Gan, Tseganeh Gichamo

Relevance to NOAA: This project has substantially updated and improved NOAA snow depth and cover initialization in the Unified Forecast System, NOAA's flagship weather forecasting model. The new snow depth assimilation has been implemented in the latest NOAA system: Global Forecast System v17. It results in improved forecasts over snow-covered land regions of North America and the Northern Hemisphere, which are critical to planning for variations in water availability and flooding from melting snowpack.

This CIESRDS project team has substantially updated and improved NOAA snow depth and cover initialization in the Unified Forecast System using 2D variational assimilation of snow depth observations. The new snow analysis improves forecasts of near-surface sensible weather over snow-covered land areas. The researchers will make further improvements to land data assimilation algorithms, advancing NOAAs's forecast skill for key variables such as near-surface temperature and snow depth, which are crucial for water availability and flood forecasting.

Since 2022, this team's improved snow depth data assimilation algorithm has been implemented operationally in NOAA's newest Global Forecast System (version 17) and is included in the multi-institutional, international Joint Effort for Data Integration (JEDI) software system. Their work includes advancing the assimilation of other variables, such as snow temperature, that have been implemented and are ready for testing in the Global Forecast System. Over the next five years, the project team will develop simultaneous coupled initialization for the atmosphere and land using advanced data assimilation algorithms for snow depth, cover, and temperature. This could improve forecasts of variables crucial to society and to NOAA's goals to predict too much and too little water.



The new NOAA snow analysis system and its demonstrated improvements in forecast accuracy. (top) Illustration of how the snow analysis system assimilates observations from satellite and ground-based measurements. (lower left) The unbiased root mean square error of snow depth verified against 1000 independent observing stations, comparing the operational system before improvements (OLD), after the new method assimilates snow depth and snow cover observations (NEW), and with further advances in the snow analysis using an Ensemble Kalman Filter (ADVANCED). (lower right) Reduction in 6- to 24-hour near-surface temperature forecast error when initializing with the improved snow analysis (NEW) compared to the previous operational system (OLD). Note that (NEW) is now in NOAA operational forecasts.

Credit: Yanjun Gan/CIESRDS and NOAA PSL

Project: Use of short-term forecast errors to guide process-level improvements of the Madden-Julian Oscillation in the NOAA Unified Forecast System

CIESRDS contributors: Stefan Tulich, I-Kuan Hu

Relevance to NOAA: The Madden-Julian Oscillation (MJO) is a prominent type of large-scale tropical weather system that importantly affects temperature and rainfall patterns over the continental United States, but has proven difficult to fully capture in numerical forecast models, including the NOAA Unified Forecast System (UFS). This project seeks to improve the simulation and prediction of the MJO, which will allow NOAA to more accurately and reliably predict global weather patterns out to several weeks or more, enabling better planning and decision-making.

This project seeks to improve the NOAA Unified Forecast System (UFS), specifically in terms of its ability to simulate and predict the Madden-Julian Oscillation (MJO). The approach is to focus on short-term forecast errors of the MJO, which are used to guide adjustments in the model physics pertaining to unresolved convection and its interactions with resolved fluctuations in moisture. The specific refinements being tested are those that determine how unresolved thunderstorms interact with resolved fluctuations in atmospheric humidity. Since 2022, results of the ongoing project have been presented at several different scientific meetings and conferences. Over the next five years, the team will improve understanding about the types of adjustments in model physics needed to improve the depiction of the MJO in the NOAA UFS.

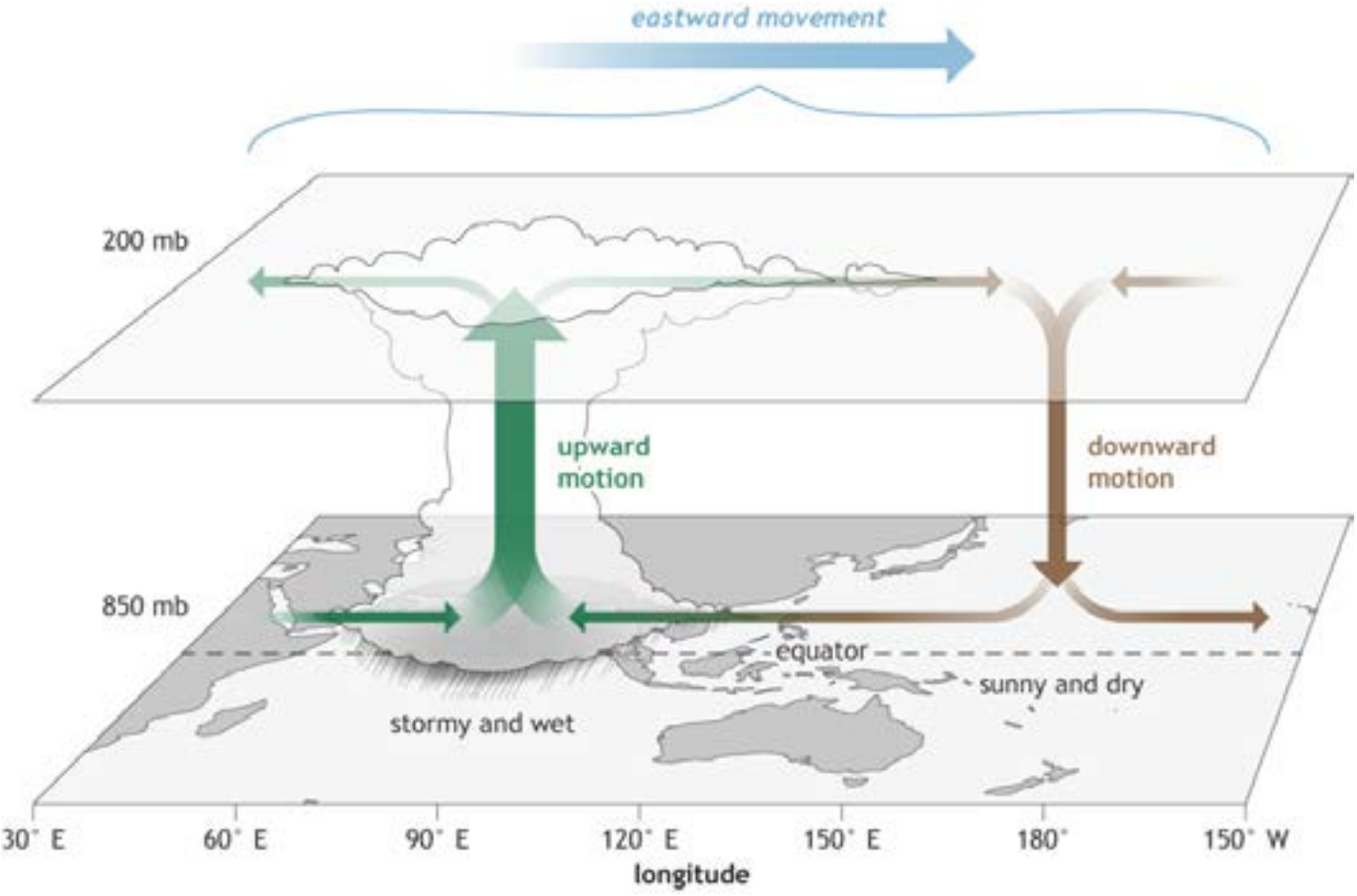


Diagram of the surface and upper-atmosphere structure of the Madden-Julian Oscillation (MJO) for a period when the enhanced convective phase (thunderstorm cloud) is centered across the Indian Ocean and the suppressed convective phase is centered over the west-central Pacific Ocean. Horizontal arrows pointing left represent wind departures from average that are easterly, and arrows pointing right represent wind departures from average that are westerly. The entire system shifts eastward over time, eventually circling the globe and returning to its point of origin.

Credit: NOAA climate.gov

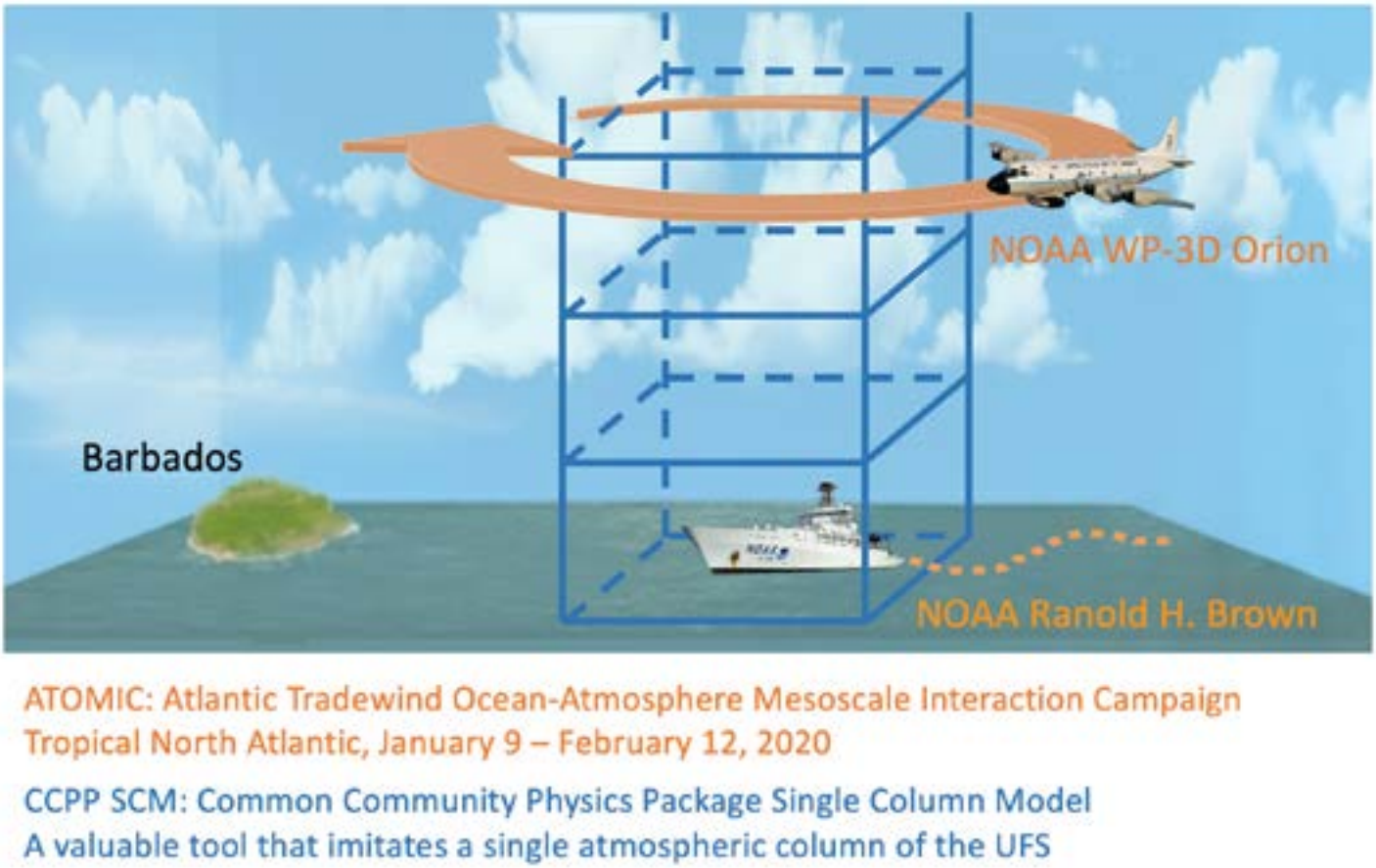
Project: Assessing marine shallow cumulus clouds in single-column models

CIESRDS contributors: I-Kuan Hu, Xuanyu Chen, Stefan Tulich

Relevance to NOAA: Knowledge gained from this project can be used to improve the depiction of shallow convection in various operational applications of the NOAA Unified Forecast System, potentially enabling NOAA to provide more reliable global forecasts of weather and extremes.

This CIESRDS project leverages observational data collected during the NOAA ATOMIC field campaign to construct a test case for assessing the representation of trade-wind shallow convection in various physics parameterization suites of the Common Community Physics Package (CCPP) Single-Column Model (SCM). The test case consists of several convectively active ("cloudy") and inactive ("clear") periods, enabling analysis of the environmental conditions associated with each regime and quantification of how well these regimes are captured by various physics suites employed in different applications of the NOAA Unified Forecast System.

Since 2022, the project team has published a manuscript describing the project and its outcomes. Next, they plan to use the constructed test case to evaluate modifications being made to the shallow convection convection scheme as part of another project.



Schematic of the basic idea behind the project, which is to use NOAA aircraft and ship-based observations (indicated by yellow annotation) collected during the ATOMIC field campaign to examine how the depiction of tropical marine shallow cumuli in the Common Community Physics Package (CCPP) Single-Column Model (indicated by the blue grid column) is affected by the choice of model physics suite.

Credit: NOAA CSL and PSL

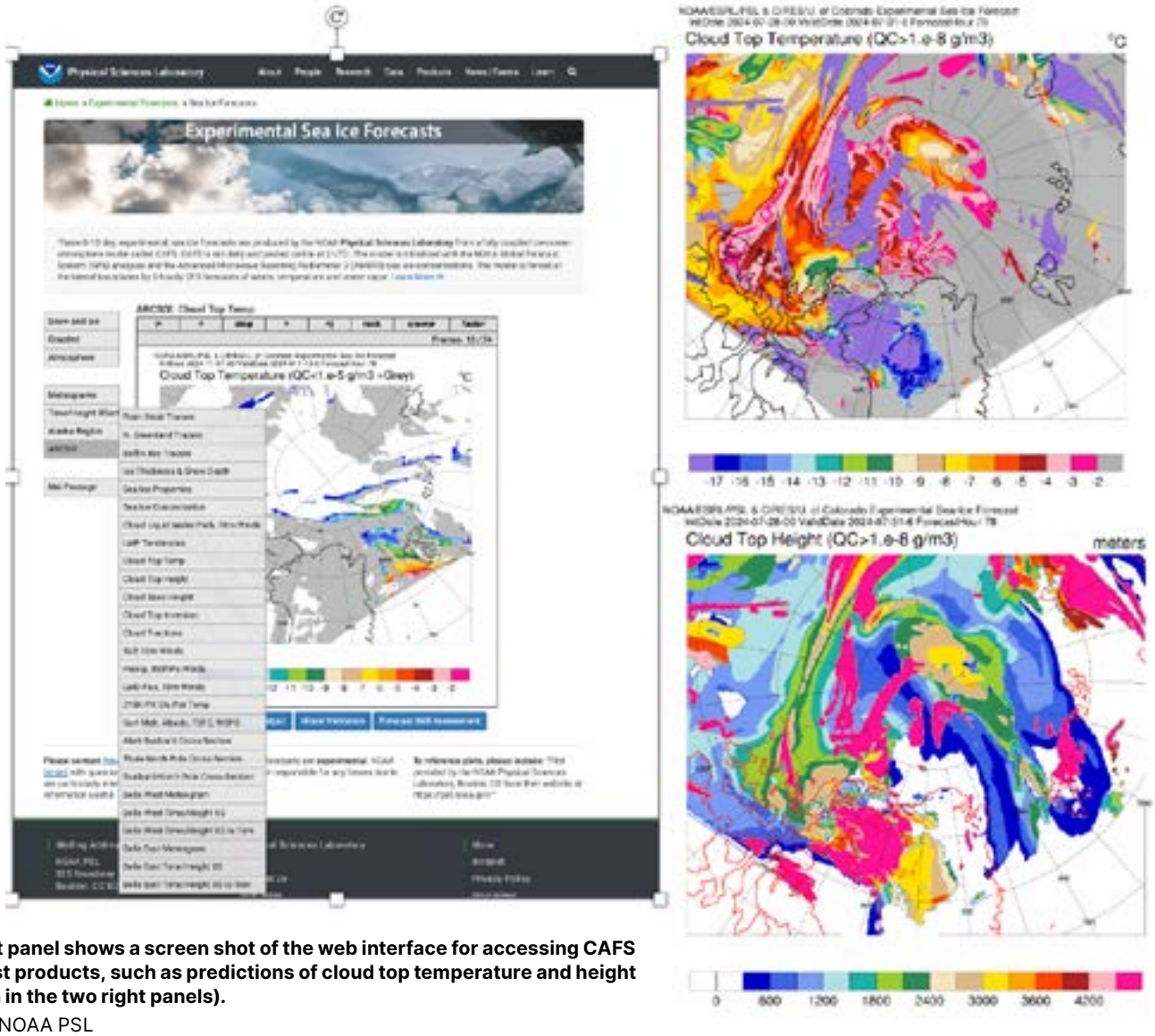
Project: Development of a Coupled Arctic Forecast System (CAFS)

CIESRDS contributors: Amy Solomon, Ola Persson, Matthew Schupe, Sergey Matrosov, Evelyn Grell, I-Kuan Hu

Relevance to NOAA: As the climate warms, the Arctic is becoming of increasing geopolitical importance, raising the need for accurate predictions of weather and climate in this region. This project aims to develop a Coupled Arctic Forecast System and associated products, advancing NOAA's mission to understand and predict changes in climate, weather, the ocean, and coasts.

CIESRDS researchers have developed aCoupled Arctic Forecast System (CAFS) to support NOAA field campaigns. Novel forecast products (such as cloud top temperature and height) have been developed to identify where measurements will support mission objectives. This project has an end-to-end strategy: observations from the campaigns are currently being used to evaluate parameterizations in the coupled system in order to provide more skillful forecasts.

Since 2022, a NOAA technical memorandum describing the CAFS and five peer-publications involving the use of the CAFS have been written. On a practical note, improved coupled Arctic system model products have been developed enabling forecasts of sea ice extent and atmospheric conditions to support navigation, coastal communities, and observational campaigns. Looking forward, a primary goal of the project is to contribute to the development of a Unified Forecast System-based version of the CAFS, to ensure even greater alignment with NOAA's strategic goals and priorities.



The left panel shows a screen shot of the web interface for accessing CAFS forecast products, such as predictions of cloud top temperature and height (shown in the two right panels).
Credit: NOAA PSL

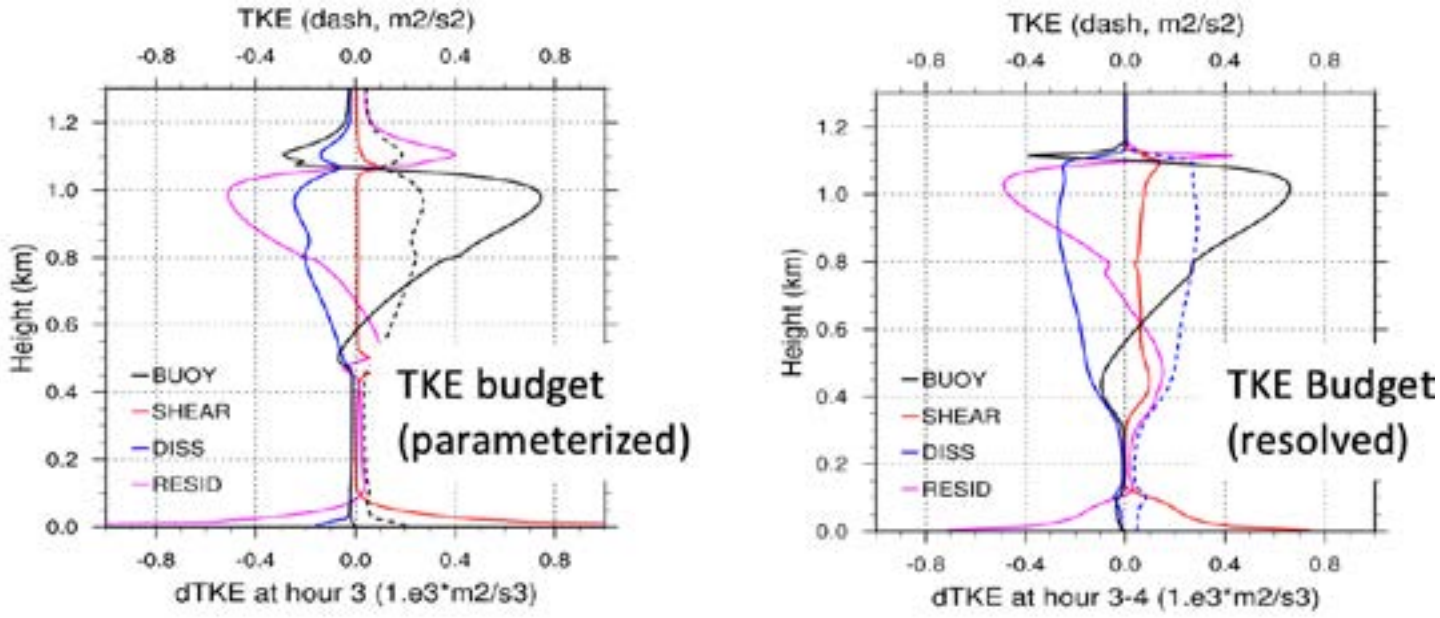
Project: Advancing predictions of mixed-phase Arctic cloud systems

CIESRDS contributors: Amy Solomon, Matt Shupe, Sergey Matrosov, Evelyn Grell, I-Kuan Hu

Relevance to NOAA: As the climate warms, the Arctic is becoming of increasing geopolitical importance, raising the need for accurate predictions of weather and climate in this region. This project aims to better simulate Arctic mixed-phase cloud systems in weather models, advancing NOAA's mission to understand and predict changes in climate, weather, the ocean, and coasts.

Mixed-phase cloud systems (consisting of both liquid water and ice) are ubiquitous over the Arctic, but are often poorly simulated in numerical weather models, thereby degrading predictions of sensible weather at higher latitudes. To address this problem, CIESRDS researchers are developing process-oriented diagnostics to evaluate the simulation of mixed-phase Arctic cloud systems in weather-scale models and then using results in conjunction with observations to develop parameterizatons with improved treatments of key physical processes.

Since 2022, the project team has conducted evaluations of sub-grid microphysical and boundary layer parameterizations in the NOAA Unified Forecast System (UFS) using observations from field campaigns. They have written several publications describing process studies that test hypotheses about cloud microphysical-turbulent processes. The gains in knowledge from this project have been used to develop new parameterizations to be implemented in the planned UFS-based version of the Coupled Arctic Forecast System.



The figure is taken from a published study by Amy Solomon and coauthors where they evaluate parameterizations of unresolved processes such as Turbulent Kinetic Energy (TKE) in the arctic boundary layer against high-resolution simulation data.
Credit: NOAA PSL

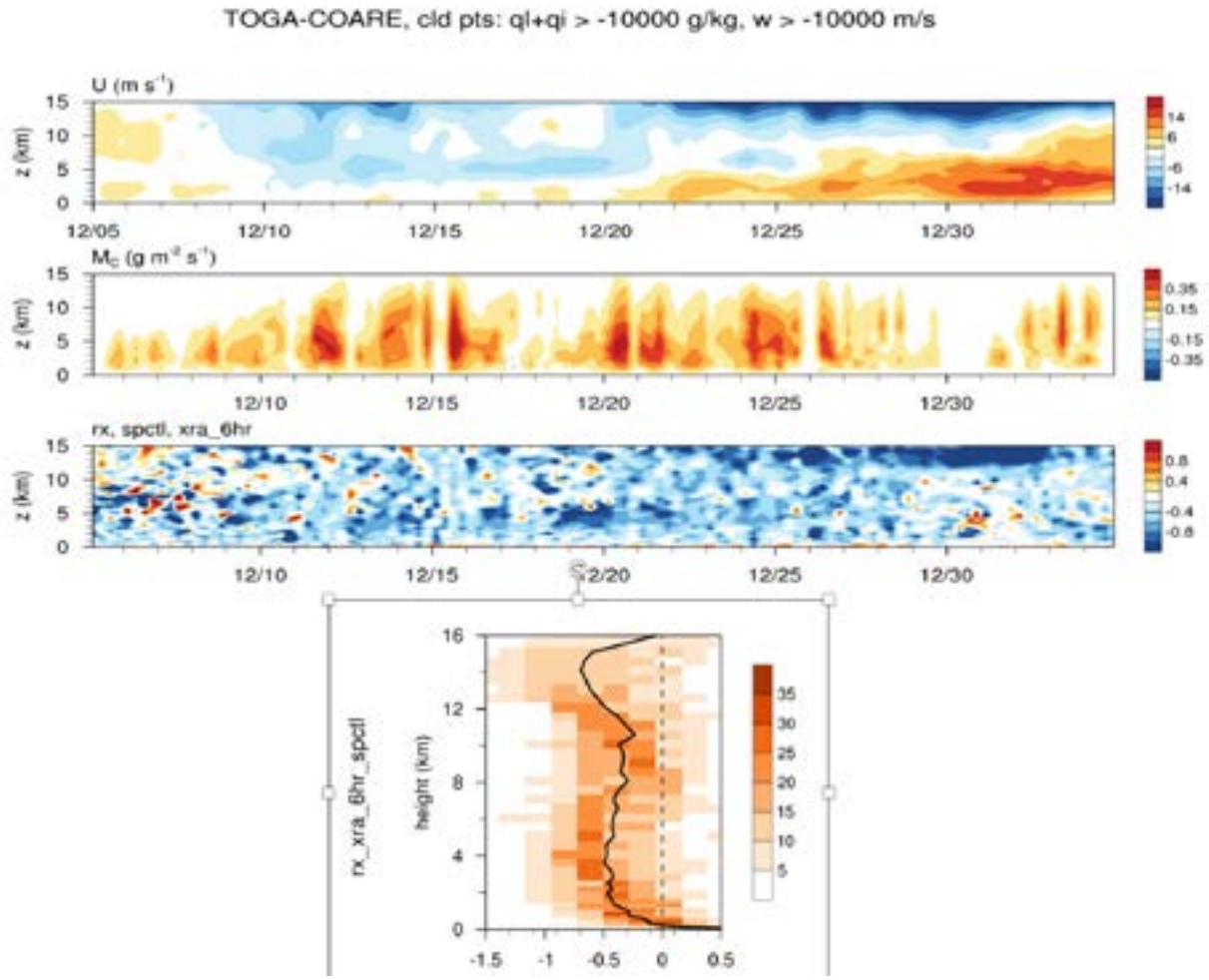
Project: Developing advanced methods for stochastic physics in the NOAA Unified Forecast System

CIESRDS contributors: Stefan Tulich, I-Kuan Hu

Relevance to NOAA: Results of this project are ultimately expected to improve NOAA's ability to provide reliable probabilistic forecasts of global weather and climate at lead times ranging from several weeks to several seasons, enabling better planning and decision-making.

This project seeks to improve upon the current method used to account for the stochastic nature of unresolved physical processes in the NOAA Unified Forecast System, with an initial focus on the process of convective momentum transport (CMT). The approach entails applying a stochastic perturbation to certain key physical parameters in the model's CMT scheme during runtime, where choices about the statistical nature of the applied perturbations are informed using output from high-resolution simulations of tropical convection.

Since 2022, the researchers have obtained estimates of the probability distribution of the aforementioned CMT parameters using output from a suite of high-resolution simulations of tropical convection, performed using the System for Atmospheric Modeling. Next, the team will evaluate the impact of the new stochastic treatment of CMT in NOAA's next-generation Seasonal Forecast System (SFS), which federal colleagues are currently developing.



Select results from a high-resolution simulation of tropical convection illustrating how the frequency distribution of one of the CMT parameters (depicted in the lowermost panel as a function of height) is estimated from the time series of this parameter (plotted in the third panel from the top). For reference, the upper two panels show the simulated time-series of background zonal wind and convective mass flux, which are used as part of the analysis.

Credit: NOAA PSL

Project: Developing a statistical picture of boundary layer, cloud, and radiation processes

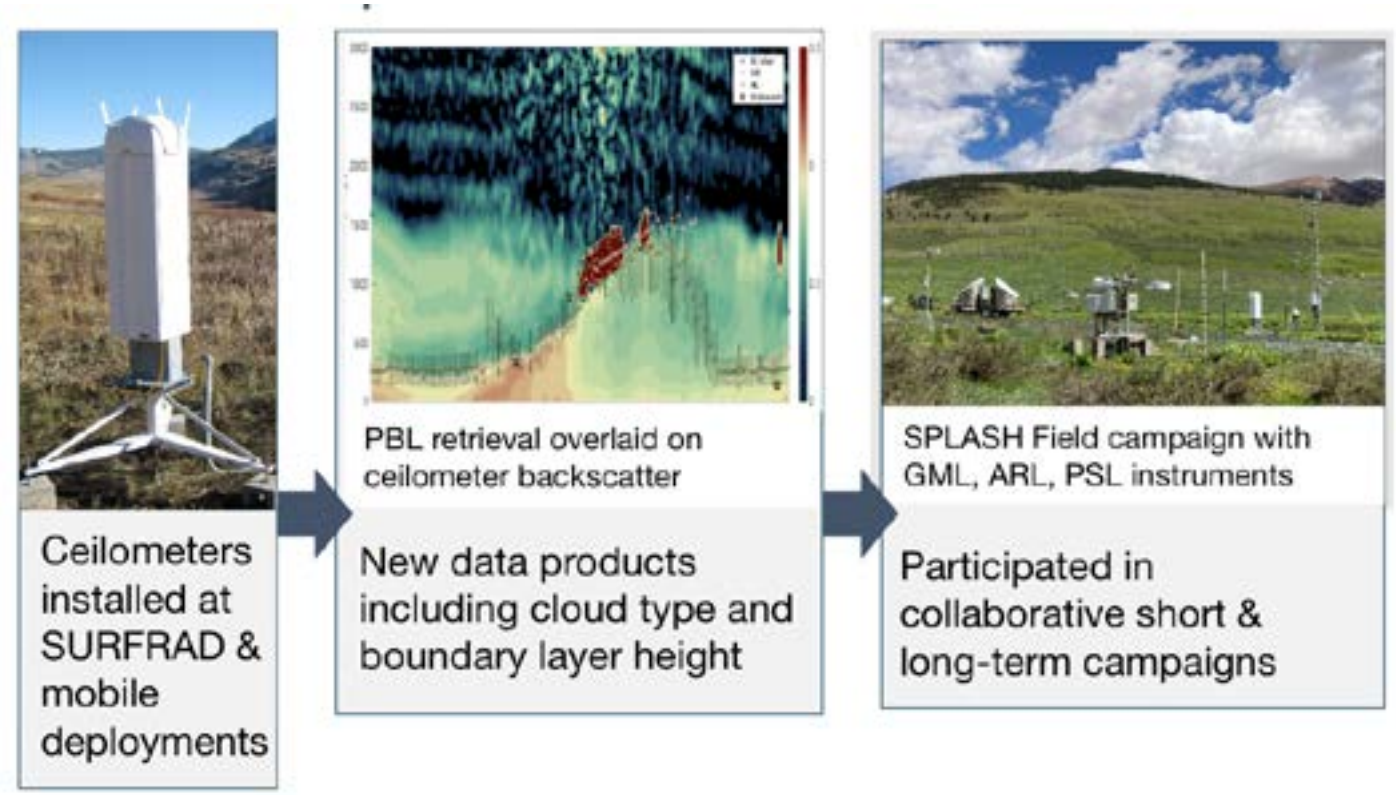
CIESRDS contributors: Laura Riihimaki, Joseph Sedlar, Vanessa Caicedo, Logan Soldo, Gary Hodges, Scott Stierle, Christian Herrera, Allen Jordan, Ben Sheffer

Relevance to NOAA: Surface radiation drives boundary layer processes that are critical for NOAA's weather and climate prediction capabilities. Better observational diagnostics of surface radiation will improve NOAA's weather prediction models.

NOAA operates seven Surface Radiation Budget Network (SURFRAD) sites that support climate research by providing accurate, continuous, long-term measurements of Earth's surface radiation budget over the United States. The seven SURFRAD stations operate in climatologically diverse regions: Montana, Colorado, Illinois, Mississippi, Pennsylvania, Nevada, and South Dakota.

This CIESRDS project team has added ceilometers to NOAA's fixed SURFRAD sites and mobile deployments and developed new products to collect additional cloud and boundary layer information. Ceilometers are lidar instruments that measure cloud base height, vertical visibility, and atmospheric aerosol concentrations.

The team uses SURFRAD data to build a catalog of cloud properties, boundary layer heights, and radiative properties in a range of climate regimes. This is a valuable new tool for process understanding and model evaluation, allowing for statistical comparisons between models and observations with additional insight into why there are model errors. Since 2022, the team has conducted four collaborative field campaigns, augmented two long-term sites with interdisciplinary measurements, completed 22 datasets, and finished seven publications.



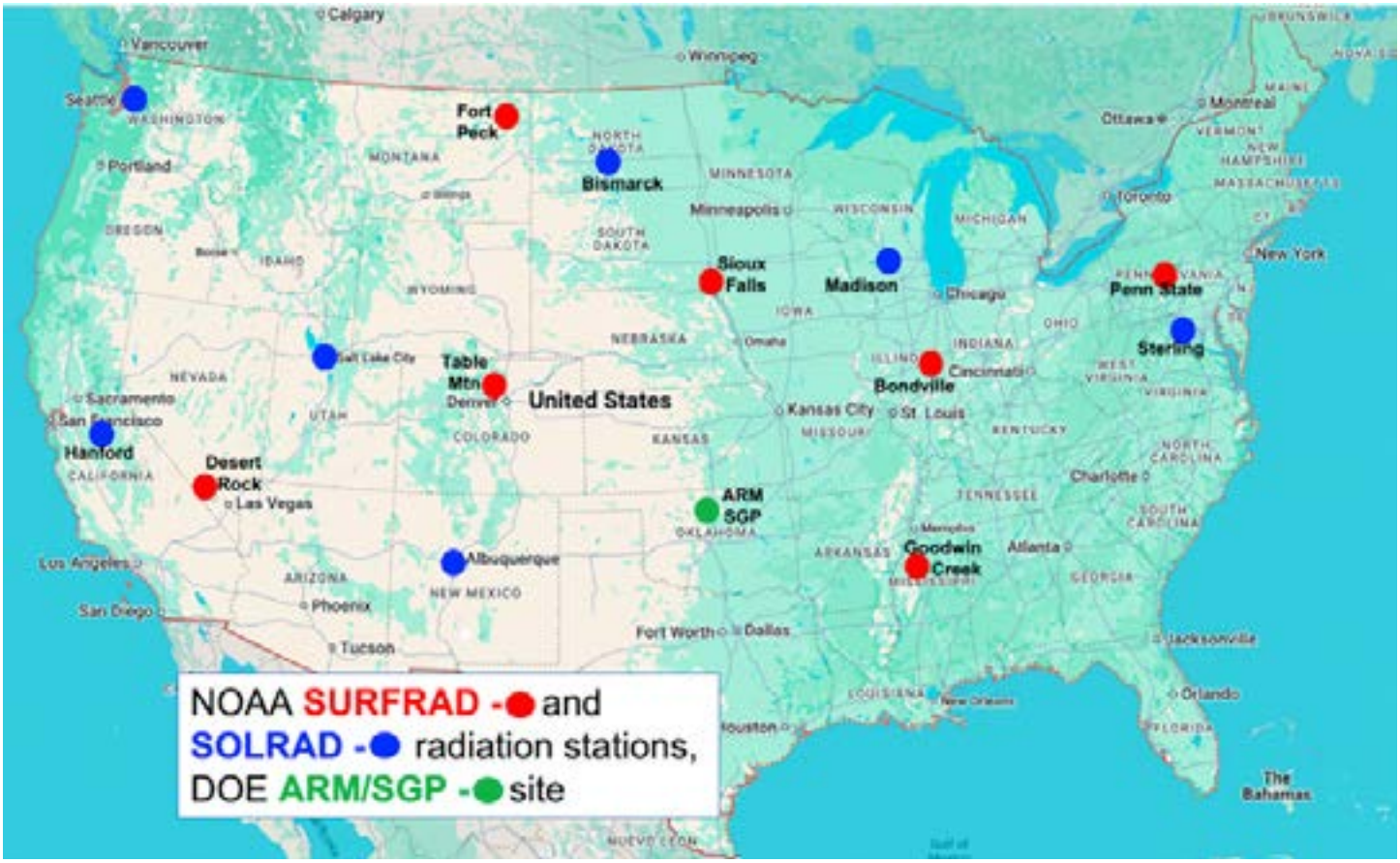
Examples of new instrumentation installed at NOAA SURFRAD sites, new products developed, and instruments deployed for field campaigns.
Credit: Laura Riihimaki/CIESRDS and NOAA PSL

Project: Using surface radiation measurements to evaluate and improve the NOAA High Resolution Rapid Refresh (HRRR) forecast model

CIESRDS contributors: Laura Riihimaki, Joseph Sedlar, Kelly Balmes, Stanley Benjamin

Relevance to NOAA: This project uses surface radiation measurements to evaluate and improve the NOAA High Resolution Rapid Refresh (HRRR) weather forecast model. Surface radiation is a critical diagnostic in numerical weather modeling because it provides the energy that drives weather.

The quality of surface radiation measurements provide the benchmark for evaluating and improving weather prediction models. This project team's work has reduced bias in subsequent versions of the NOAA High Resolution Rapid Refresh (HRRR) model by including NOAA Surface Radiation Budget Network (SURFRAD) measurements. Since 2022, the team has completed four collaborative projects and submitted three publications, with several more in progress. Over the next five years, the team intends to evaluate future versions of NOAA weather models and push the evaluation forward using the new cloud type dataset to better understand and focus development to reduce model errors.



Radiation measurement sites from the NOAA SURFRAD (red) and SOLRAD (blue) radiation station network from NOAA Global Monitoring Laboratory.

Credit: NOAA GML

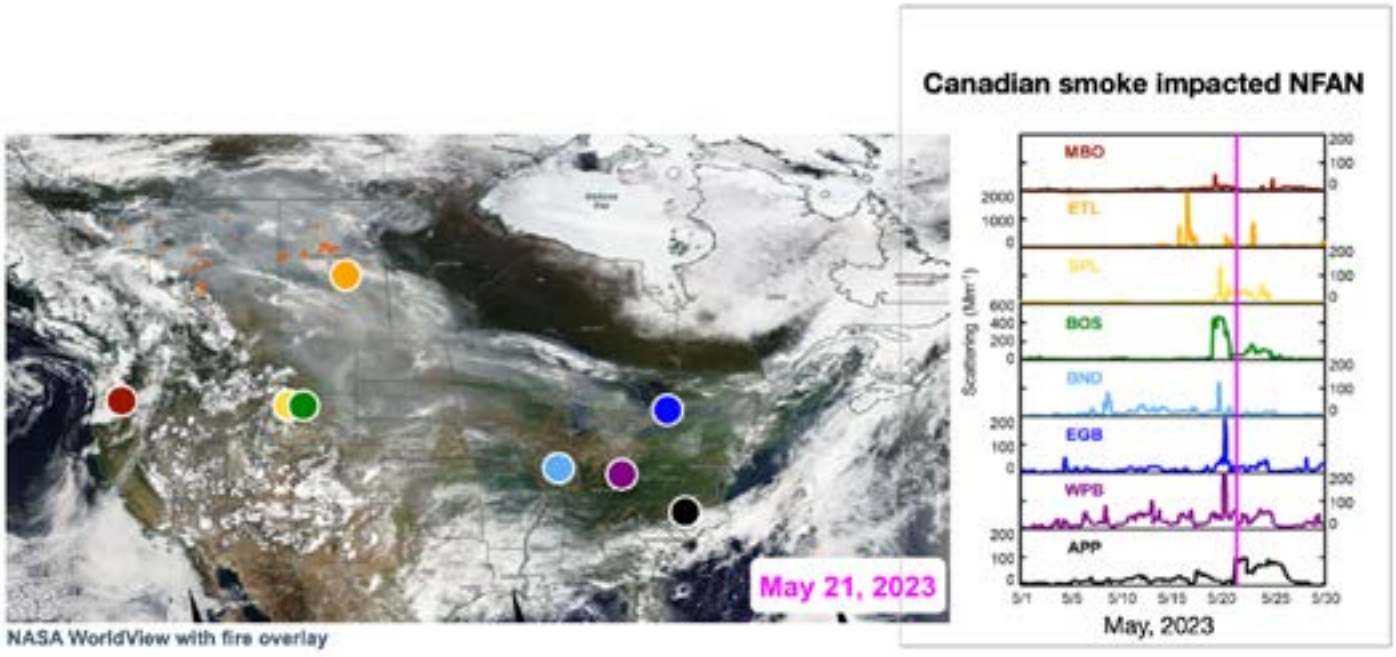
Project: Building networks and new stations quantify wildfire smoke impact

CIESRDS contributors: Joseph Sedlar, Elisabeth (Betsy) Andrews, Erin Boedicker, Vanessa Caicedo, Hagen Telg, Scott Stierle, Gary Hodges, Mark Kutchenreiter, Frank Smith, Ben Sheffer, Laura Riihimaki

Relevance to NOAA: Wildfire smoke impacts air quality, human health, and weather. This project's measurements will improve NOAA's understanding and forecasting of wildfire smoke and its relationship to weather. Understanding aerosol optical properties and how they are changing due to extreme events gives NOAA crucial information to provide to policymakers and the public.

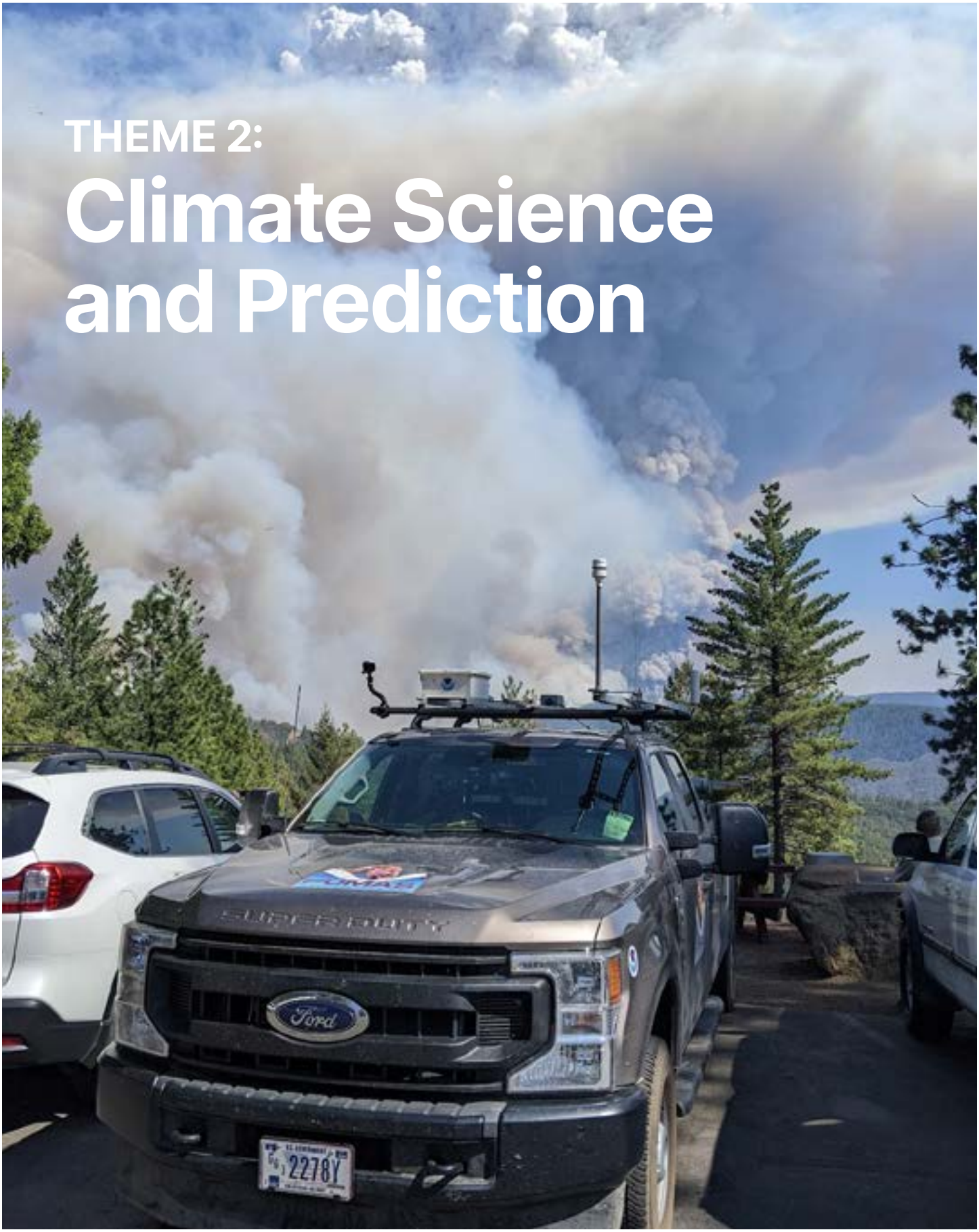
Permanent networks, like the NOAA Federated Aerosol Network (NFAN) and Surface Radiation Budget (SURFRAD) network, provide valuable information on the optical properties of smoke aerosols. This project team is developing new observational retrievals and analyses to optimize that information for detecting and understanding smoke impacts and providing a validation dataset for satellite and model data products. Additionally, they have been building new mobile and fixed sites more specifically targeted towards understanding smoke and the weather impacting wildfires.

Since 2022, the team has designed two new fixed sites and three mobile trailers outfitted with instruments for collecting wildfire smoke observations. Next, the team plans to continue monitoring aerosol optical properties and radiative effects at measurement sites. Since 2022, two new sites and 3 trailers have been designed for wildfire observations. Next, the team plans to continue monitoring aerosol optical properties and radiative effects at measurement sites to improve atmospheric composition forecasts.



Example showing how North American NOAA Federated Aerosol Network (NFAN) sites sampled wildfire smoke as it traveled across the U.S. from Canadian wildfires in 2023.

Credit: Elisabeth Andrews/CIESRDS and NOAA GML



THEME 2:

Climate Science and Prediction

While NOAA's Twin Otter flew above, researchers drove trucks around the perimeter of the Mosquito Fire in California to measure wind speed and air temperature.

Credit: Richard Marchbanks/CIESRDS and CSL

CLIMATE SCIENCE AND PREDICTION

CIESRDS research in this theme addresses the drivers of Earth's climate variability and extremes to provide better climate predictions across various time and spatial scales.

A key aspect of CIESRDS work on this theme has been monitoring and analyzing concentrations of ozone-depleting substances and greenhouse gases in Earth's atmosphere from a global network of air sampling sites. This work helps NOAA maintain a unified, traceable record of atmospheric gas measurements to support predictions, inform policy, and benefit society by enabling smarter decisions that protect the ozone layer and build resilience to climate-related health risks.

CIESRDS scientists have been heavily involved in studying the atmospheric effects of the January 2022 Hunga Tonga-Hunga Ha'api volcanic eruption, the most explosive volcanic event of the satellite era. They collected crucial atmospheric measurements in the days following the eruption and co-led a report released in December 2025 that describes how the massive amount of water vapor released from the eruption affected Earth's stratosphere, climate system, and ozone layer.

CIESRDS scientists and engineers are experts at designing and deploying compact, low-cost instruments to measure trace gases and aerosols from balloons and uncrewed aerial platforms. Most recently, they designed a custom ozone photometer and an ice spectrometer for deployment on balloons and uncrewed aircraft. Their work strengthens NOAA's atmospheric observational capabilities and advances low-cost air monitoring technologies.

CIESRDS scientists have also begun a pilot study to measure atmospheric gases from commercial aircraft in support of a NOAA partnership with United Airlines. They have designed a gas analyzer package and an air inlet that will be certified to fly on certain Boeing 737 commercial aircraft.

They have also developed a method for using uncrewed aircraft to deploy and recover an atmospheric sampling and measurement system from high altitude in controlled airspace. This work allows NOAA to deploy sampling instruments to locations where balloon retrieval would be nearly impossible or a payload would be lost or might come down in a populated area.

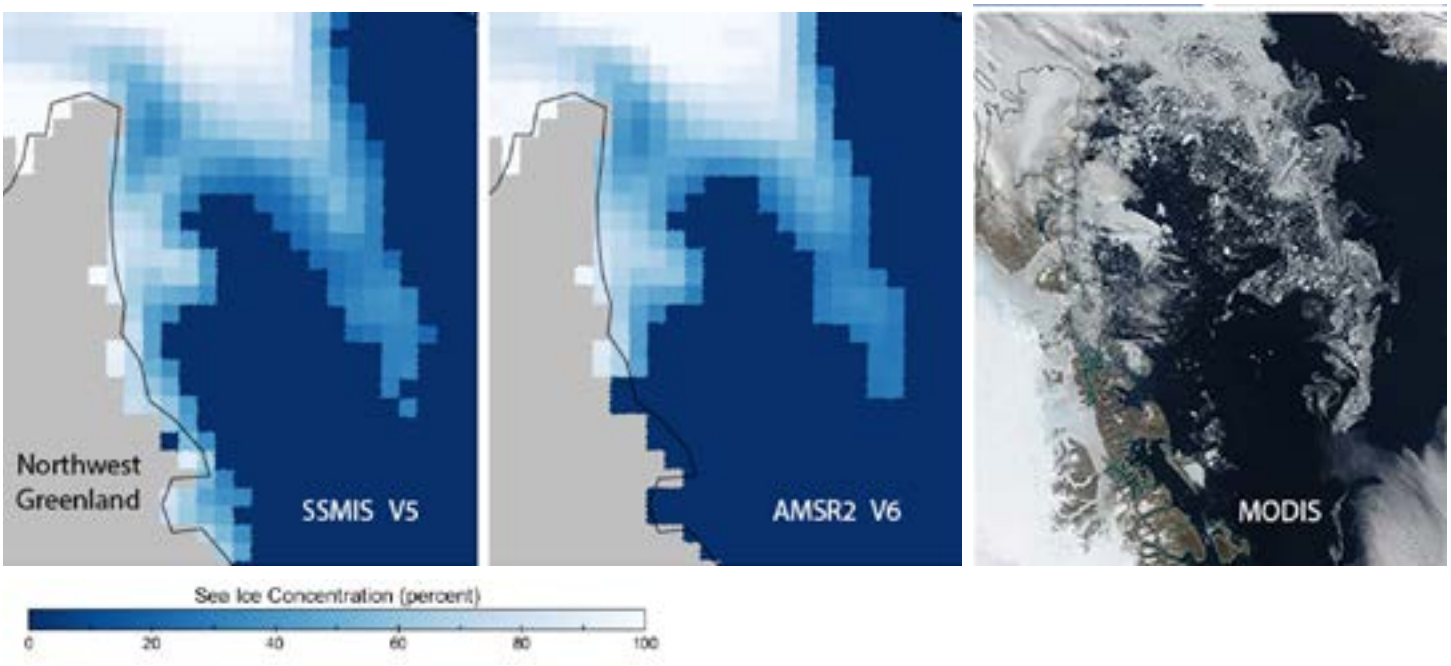
CIESRDS scientists have also published research on how aerosols from reentering satellites impact the middle atmosphere, informing discussions on the environmental effects of space activity.

Project: Maintaining the sea ice concentration climate data record

CIESRDS contributors: Ann Windnagel, Florence Fetterer, and Danica Cantarero

Relevance to NOAA: This project provides information on how sea ice is changing in a time series with the longevity, consistency, and continuity to assess and measure climate variability and change. NOAA climate data records are vetted using standards established by the National Research Council.

The Sea Ice Concentration Climate Data Record provides global daily and monthly fields of sea ice concentration from satellite passive microwave data starting in 1978. NOAA first released the product in 2011 and is tasked with updating and maintaining the product with support from CIESRDS. In 2025, anticipating the loss of data from the aging and unsupported Department of Defense Special Sensor Microwave Imager/Sounder (SSMIS) satellite series, this team transitioned to using Advanced Microwave Scanning Radiometer 2 (AMSR2) data. The climate data record now has over 800 registered users, with about 50,000 users downloading data in 2025 and many hundreds of citations. Over the next five years, the researchers will continue to maintain the sea ice CDR and likely transition to newer passive microwave instruments as AMSR2 grows older.



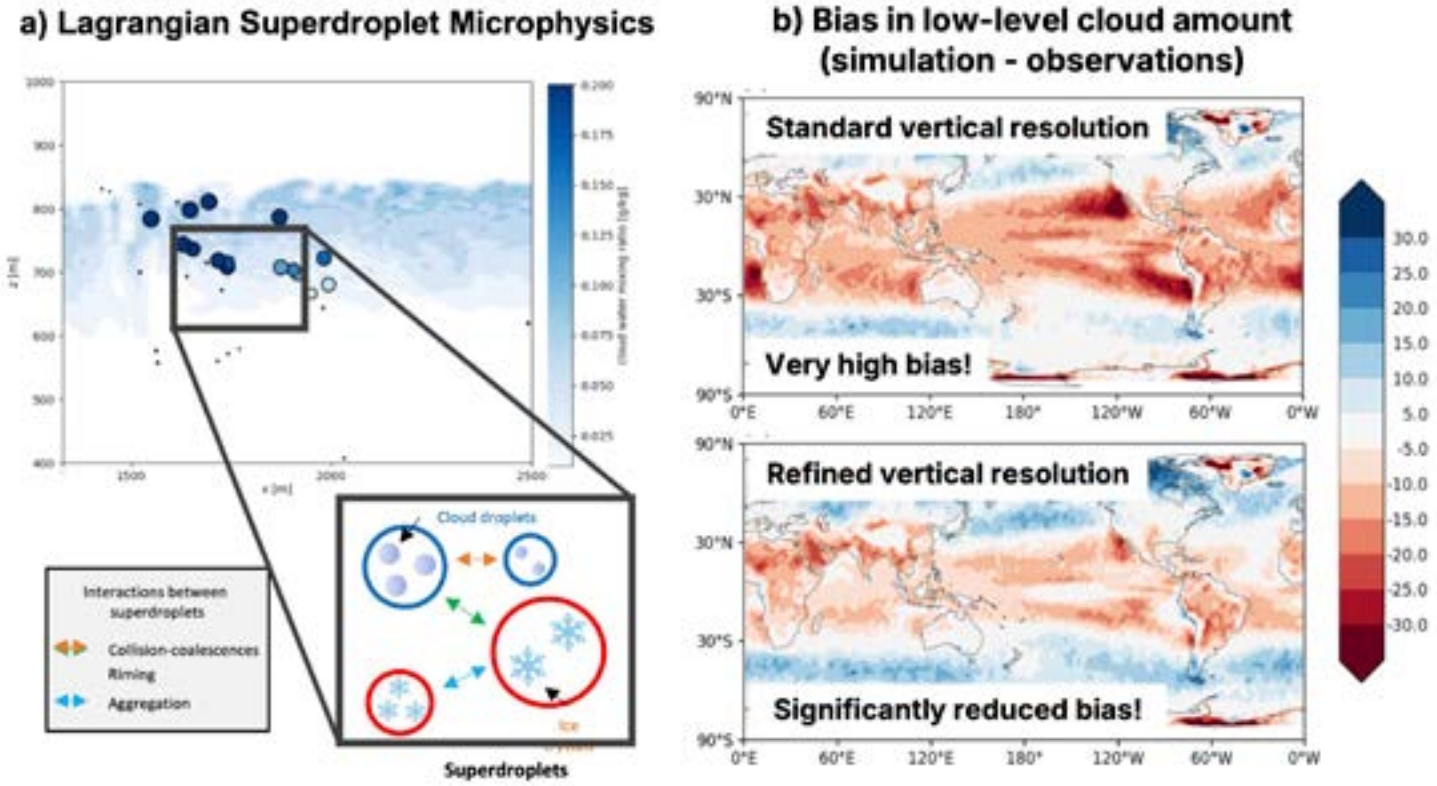
Sea ice concentration from V5 and V6 climate data record with a same-day MODIS image.
Credit: NOAA@NSIDC

Project: Advancing cloud representation in Earth system models

CIESRDS contributors: Jung-Sub Lim, Jake Gristey, Takanobu Yamaguchi, Jan Kazil

Relevance to NOAA: By advancing cloud representation across model scales, this work improves the realism and predictive skill of weather and climate simulations. These innovations enhance NOAA's ability to forecast high-impact weather, assess climate risks, and support science-based decision-making for society.

This team develops and advances cloud representation across model scales, from large-eddy simulations (LES) and storm-resolving models to global climate models. The researchers employ novel approaches to improve the realism and fidelity of simulated clouds, including Lagrangian superdroplet microphysics, AI-learned three-dimensional radiative transfer, and vertical-resolution enhancement methods. So far, they have published four journal papers and given two presentations. Over the next five years, they will advance microphysics schemes to better simulate mixed-phase cloud processes in LES and improve realism in cloud-radiation interactions with AI-learned three-dimensional radiative transfer in LES of, for instance, stratospheric aerosol injection-induced cloud brightening. The researchers will explore opportunities to advance their vertical-resolution enhancement method in global climate models.



Panel a): Large-eddy simulation of Arctic mixed-phase cloud with a Lagrangian microphysics scheme.
Credit: Jung-Sub Lim/CIESRDS

Panel b): Bias in low-level cloud amount with and without the vertical enhancement method used in the Department of Energy Energy Exascale Earth System Model.
Credit: Lee et al. 2022, *Geophysical Research Letters*

Project: Assessing drought in a changing climate

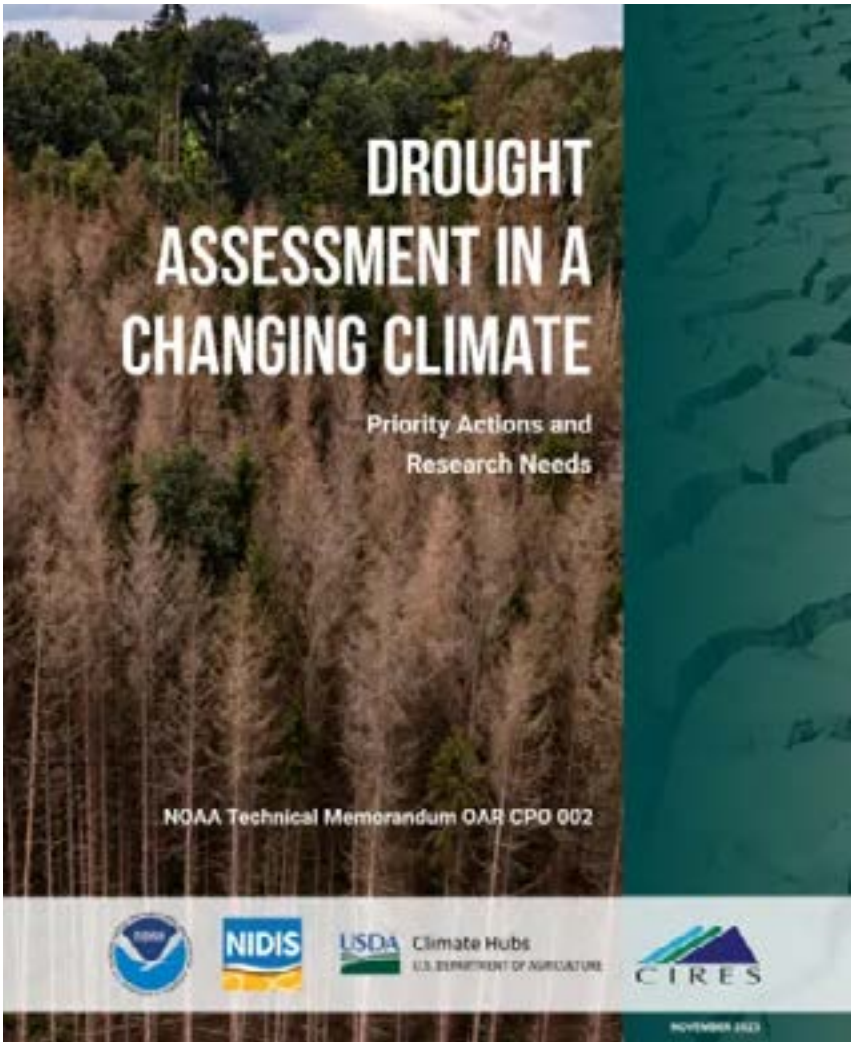
CIESRDS contributors: Britt Parker, Joel Lisonbee, Amanda Sheffield, Molly Woloszyn, Adam Lang, Kelsey Eigsti, Eleanor Hasenbeck, Gretel Follingstad

Relevance to NOAA: This effort supports the National Integrated Drought Information System's (NIDIS) mission (Public Law 109-430) to improve drought monitoring and forecasting capabilities. The 2023 workshop on outcomes not only identified priority actions and research questions, but also prioritized them. This information and future research will help the drought community account for a changing climate in our drought-assessment practices.

In a changing climate, the intensity, duration, and frequency of droughts may change. This poses new challenges for drought assessment. This effort, co-led by CIESRDS, helped fulfill the need to identify priority actions and outstanding research questions to address the issue.

A 2023 technical workshop organized by NIDIS and CIESRDS convened more than 100 experts on the topic and outcomes to guide NIDIS and partner activities and funding priorities going forward. Workshop outcomes led to one NOAA technical memorandum and two publications.

Over the next five years, workshop priority actions and research questions will continue to guide NIDIS and partner activities and priorities. Outcomes from this research and activities will improve our drought-assessment practices and water management, and thus our nation's drought planning and preparedness.



Report cover for "Drought assessment in a changing climate."
Credit: NIDIS/drought.gov

Project: Maintaining long-term observations of greenhouse gases and ozone-depleting substances

CIESRDS contributors: Scott Clingan, Molly Crotwell, Andrew Crotwell, Geoff Dutton, Stephen Devogel, Monica Madronich, Thomas Mefford, Ruth Mills, David Nance, Kyle Petersen, Aerin Searle

Relevance to NOAA: NOAA's Long-term Observations of Greenhouse gases and Ozone-depleting Substances (LOGOS) division makes long-term measurements of key atmospheric gases to provide the essential evidence base for understanding climate change and ozone recovery. This work advances that mission by maintaining a unified, traceable record of atmospheric gas measurements to support predictions, inform decision-makers, and benefit society through improved environmental resilience and public health protection.

This project conducts long-term global measurements of atmospheric gases that influence climate, stratospheric ozone, and human health, using both discrete sampling and continuous in situ observations. Since 2022, this project has continued to collect and publish more than 40 trace gas measurements. This work aims to advance NOAA's long-term atmospheric gas records by strengthening continuous measurements tied to LOGOS-maintained calibration scales. It also focuses on improving analytical techniques, enhancing data processing methods, and expanding high-quality, traceable observations across the Global Greenhouse Gas Reference Network. Through this effort, CIESRDS researchers deliver accurate, comparable datasets to support climate research, model evaluation, and policy-relevant assessments.

CIESRDS researcher Eric Moglia analyzes flasks of air samples that will be used to determine concentrations of key atmospheric gases.
Credit: Lauren Lipuma/CIESRDS

Project: LOGOS data processing framework

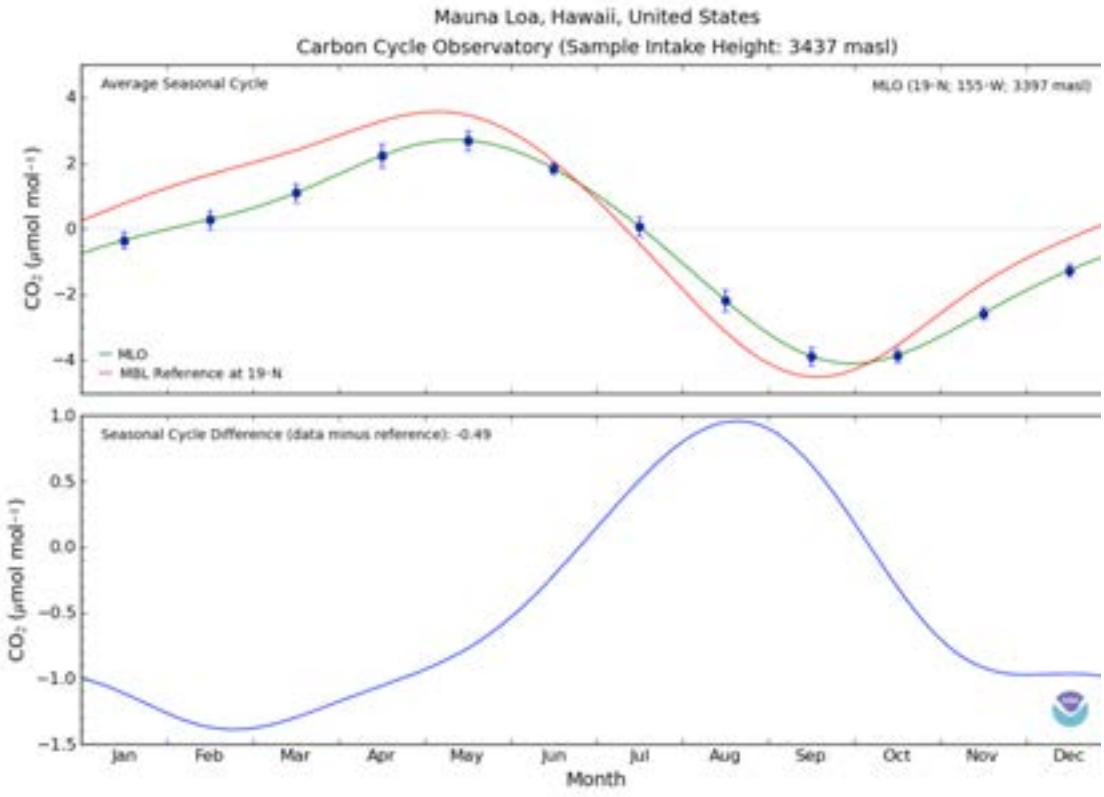
CIESRDS contributors: Scott Clingan, Molly Crotwell, Andrew Crotwell, Geoff Dutton, David Nance, Kyle Petersen, Aerin Searle

Relevance to NOAA: This project strengthens NOAA's long-term atmospheric records by modernizing LOGOS data processing and ensuring all measurements are recorded in a robust modern framework. These improvements enhance data quality, comparability, and accessibility.

This team transitions and modernizes LOGOS data processing systems by developing a unified framework built around NOAA/GML relational databases. The project enhances the handling of continuous and discrete measurements, integrates calibration-scale updates, and streamlines QA/QC and archiving.

These improvements ensure the long-term consistency, traceability, and accessibility of NOAA's atmospheric records, supporting climate monitoring, emissions verification, and broader scientific and societal applications. Tangible outcomes since Sept 2022: We transitioned all next-generation LOGOS instruments to the GML relational database, enabling standardized data acquisition and long-term archiving. The team develped new Python-based processing and QA/QC tools to interface directly with this system, improving reliability and reproducibility. Work is ongoing to ingest and modernize legacy datasets.

The team also created a unified data-tagging and flagging framework and leveraged existing GML software to streamline processing across multiple instruments and measurement programs. Over the next five years, the team plans to maintain and improve the software developed in the last couple of years.



Top panel: The average seasonal cycle determined from the observations is shown (solid line). Monthly means are computed from a detrended smooth fit to the observations. The monthly means for all Januarys, Februarys, etc. are aggregated and statistics are determined with monthly resolution. The standard deviation (whisker) of each aggregated monthly mean value is a measure of the year-to-year variability in the monthly mean values. The average seasonal cycle determined from the reference Marine Boundary Layer (MBL) time series at the same latitude is also shown (solid line).

Bottom Panel: The difference between the average seasonal cycle derived from the data and that derived from the MBL reference. The average offset in the two time series has been preserved in the difference. For a description of the reference MBL time series, see the Marine Boundary Layer web page.

Credit: NOAA GML

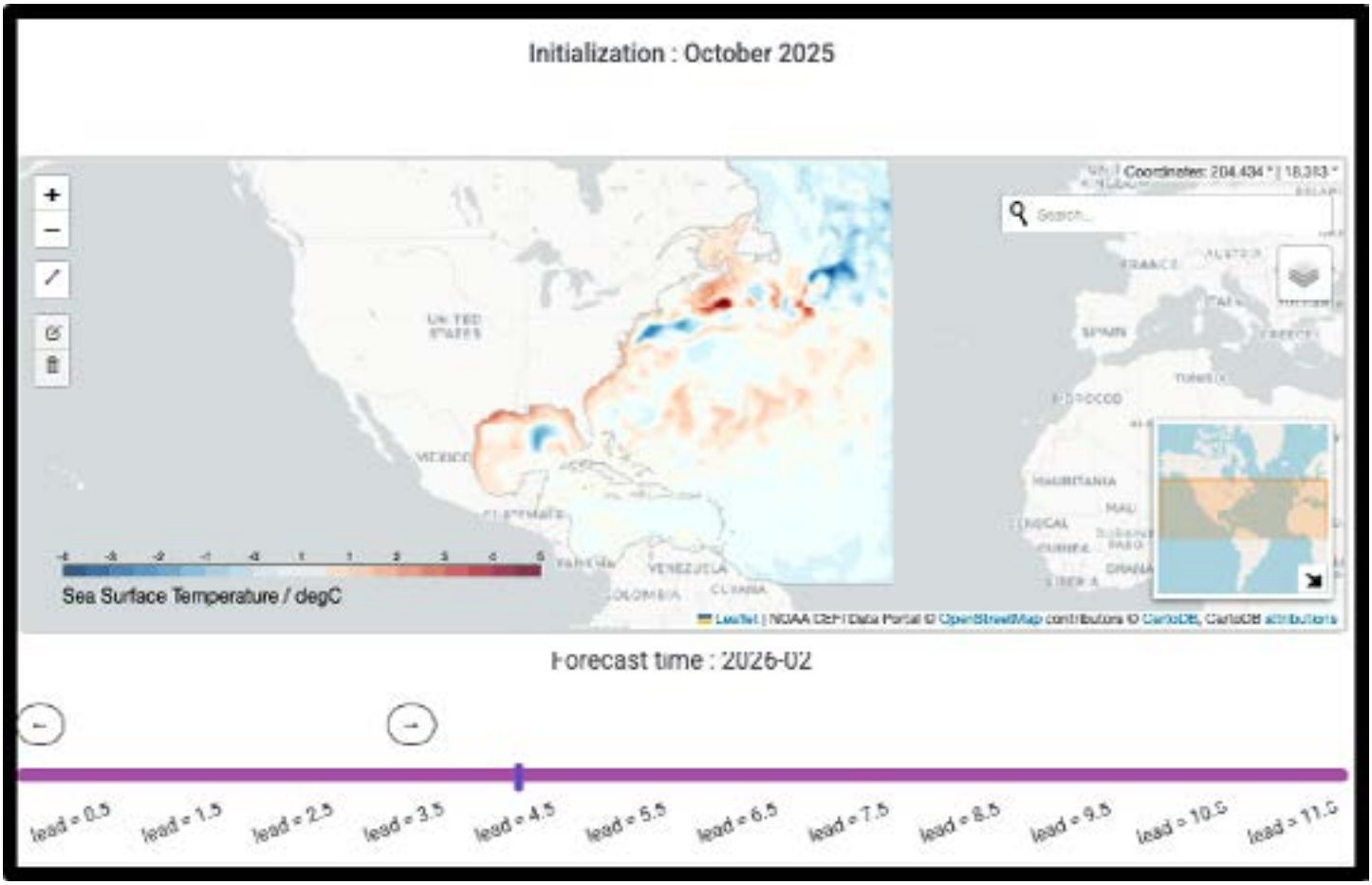
Project: Changing Ecosystems and Fisheries Initiative (CEFI)

CIESRDS contributors: Cathy Smith, Kevin Counts

Relevance to NOAA: The Changing Ecosystems and Fisheries Initiative (CEFI) is a cross-NOAA program designed to help marine/Great Lakes resources, communities, and economies adapt to rapidly changing ocean conditions. This project supports NOAA's requirements for marine resource management. It improves how NOAA understands the ocean/atmosphere system and creates decision-making products in marine resources and related areas.

The Changing Ecosystems and Fisheries Initiative (CEFI) is designed to meet NOAA's growing needs for high-resolution, region-specific information to support marine resource management. By running fine-scale ocean models over areas of particular importance to NOAA's resource managers, CEFI provides tailored variables and products that strengthen both scientific understanding and decision support. Each region receives customized outputs that reflect its unique oceanographic and ecological characteristics, helping managers interpret conditions, anticipate changes, and make informed choices. To ensure broad accessibility, the CEFI project includes a web portal that allows users to download, subset, and analyze data—including tools for plotting monthly forecasts alongside observed conditions.

To date, CEFI has produced three regional ocean models with accompanying hindcasts and forecasts, along with an information hub that catalogs useful fisheries-related resources. These efforts represent critical new investments in understanding the ocean–atmosphere system and in developing products that directly support decision-making for marine resources and related sectors. As the initiative continues to expand, additional products will be added based on user needs, and the portal will remain a central platform for accessing high-resolution model output across diverse ocean regions. Together, these capabilities position CEFI as a key component of NOAA's strategy for advancing marine resource management in a changing environment.



The image shows one of the model's sea surface temperature forecasts available for Changing Ecosystems and Fisheries Initiative users. Credit: NOAA PSL

Project: Balloon rapid response to understand disruptive atmospheric events

CIESRDS contributors: Elizabeth Asher, Alex Fritz and Emrys Hall

Relevance to NOAA: Upper atmospheric water vapor, ozone, and aerosol impact Earth's radiative budget and can influence surface temperatures. Rapid response measurements after an energetic and unusual volcanic eruption in 2022 provided insights into atmospheric chemistry and dynamics.

Targeted balloon launches carrying water vapor, ozone, and aerosol sondes provide critical in situ observations for understanding the evolution of volcanic and large wildfire plumes. These rapid-response measurements are especially important following major eruptions, which can perturb Earth's radiative balance through injections of sulfur dioxide into the stratosphere that subsequently form sulfate aerosol. Such observations help constrain both the mass of sulfur injected and the lifetime of sulfur dioxide in the stratosphere—key parameters for improving aerosol microphysics in climate models and for assessing the impacts of natural or potential anthropogenic sulfur injections.

The 2022 Hunga Tonga–Hunga Ha'apai (HT-HH) eruption offered a rare opportunity to observe an exceptionally energetic plume. CIESRDS researchers launched Bballoon-borne instruments from Réunion Island, which intercepted the plume 7–10 days after the eruption, capturing detailed measurements of aerosol number and size distributions, sulfur dioxide, and water vapor. These observations revealed an unexpected abundance of large particles and constrained the total sulfur injection to roughly 0.2 Tg. They also showed that sulfuric acid aerosol formation was completed within about three weeks—approximately three times faster than typical stratospheric conditions—likely accelerated by unusually high water vapor concentrations. Enhancements in stratospheric water contributed up to ~30% of the ambient aerosol surface area, amplifying aerosol extinction and influencing radiative impacts.

Because upper-atmospheric water vapor, ozone, and aerosol strongly affect Earth's radiative budget and can influence surface temperatures, continued monitoring is essential. NOAA GML observations are now tracking the removal of the ~145 Tg of water vapor injected into the stratosphere by the HT-HH eruption and evaluating how well climate models capture its evolution. Together, these targeted balloon measurements and long-term monitoring efforts deepen understanding of atmospheric chemistry and dynamics following extreme natural events and strengthen predictive capabilities for future climate impacts.

A view of the 2022 Hunga volcanic eruption, which injected an unprecedented amount of water vapor into the stratosphere.
Credit: Tonga Geologic Services

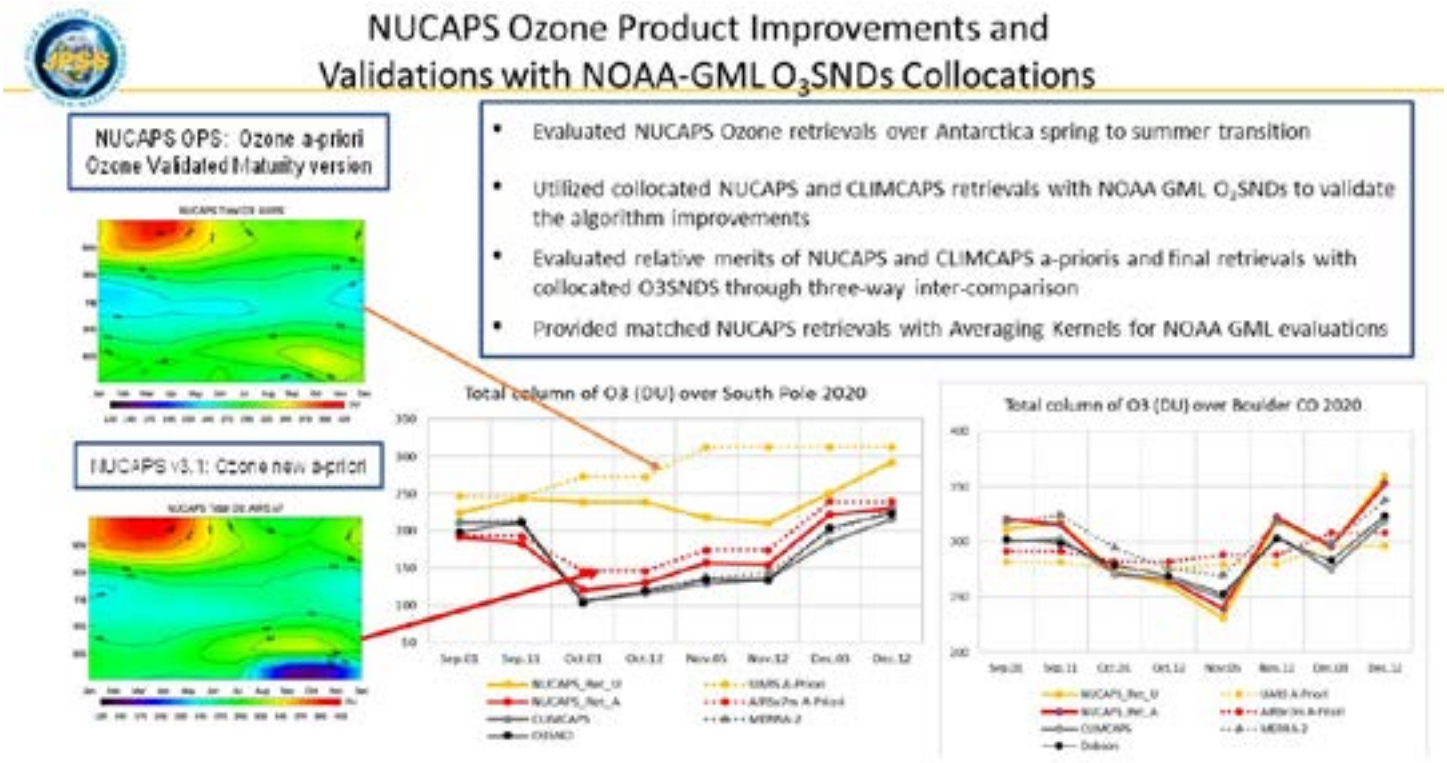
Project: Satellite ozone product validation

CIESRDS contributors: Peter Effertz, Brandon Noirot, Glen McConville

Relevance to NOAA: Ground-based observations serve as a benchmark for combining short-term satellite ozone records for tracking atmospheric composition change vital for climate research and predicting sustainability of the U.S. economy and mitigation of the impacts of ozone on human health and food production.

Validation of ozone and water vapor retrievals from satellite-borne instruments is essential for ensuring the accuracy, stability, and long-term usefulness of NOAA's atmospheric composition products. This work includes near-real-time evaluation of JPSS NPP, NOAA-20, and NOAA-21 ozone products against high-quality Dobson and ozonesonde observations collected by NOAA and CIESRDS. Each week, findings are reported to NESDIS, providing continuous insight into product performance, potential biases, and long-term drift. The importance of this collaboration was highlighted in the 2023 JPSS Annual Science Digest, which summarized the 2020–2023 partnership between NESDIS and GML and confirmed the consistency of NESDIS ozone records through rigorous comparison with GML's benchmark ground-based measurements.

These observations—spanning ozone columns, vertical profiles, and water vapor—are foundational for merging short-term satellite datasets into coherent long-term records needed to track atmospheric composition change, support climate research, and anticipate future conditions that affect the U.S. economy, human health, and food production. The validation process involves acquiring satellite overpass data for ozone columns and profiles, developing software for data formatting and processing, comparing satellite retrievals with ground-based observations in both near-real-time and multi-year analyses, and presenting results during monthly coordination meetings. These evaluations also inform maturity assessments for new product versions and reprocessing cycles, ensuring that NOAA's satellite ozone products remain robust, traceable, and climate-relevant.



Validation of satellite ozone and water vapor products from the NOAA-Unique Combined Atmospheric Processing System (NUCAPS) (left) with NOAA Global Monitoring Laboratory ozonesonde data (right). NUCAPS combines observations from the Cross-track Infrared Sounder (CrIS) and Advanced Technology Microwave Sounder (ATMS) aboard NOAA's JPSS and EUMETSAT's Metop polar-orbiting satellites. NUCAPS data consist of vertical atmospheric profiles detailing the temperature and moisture at multiple elevations. The two graphs on the right show NUCAPS observations plotted alongside ozonesonde observations.

Credit: NOAA and NASA Joint Polar Satellite System

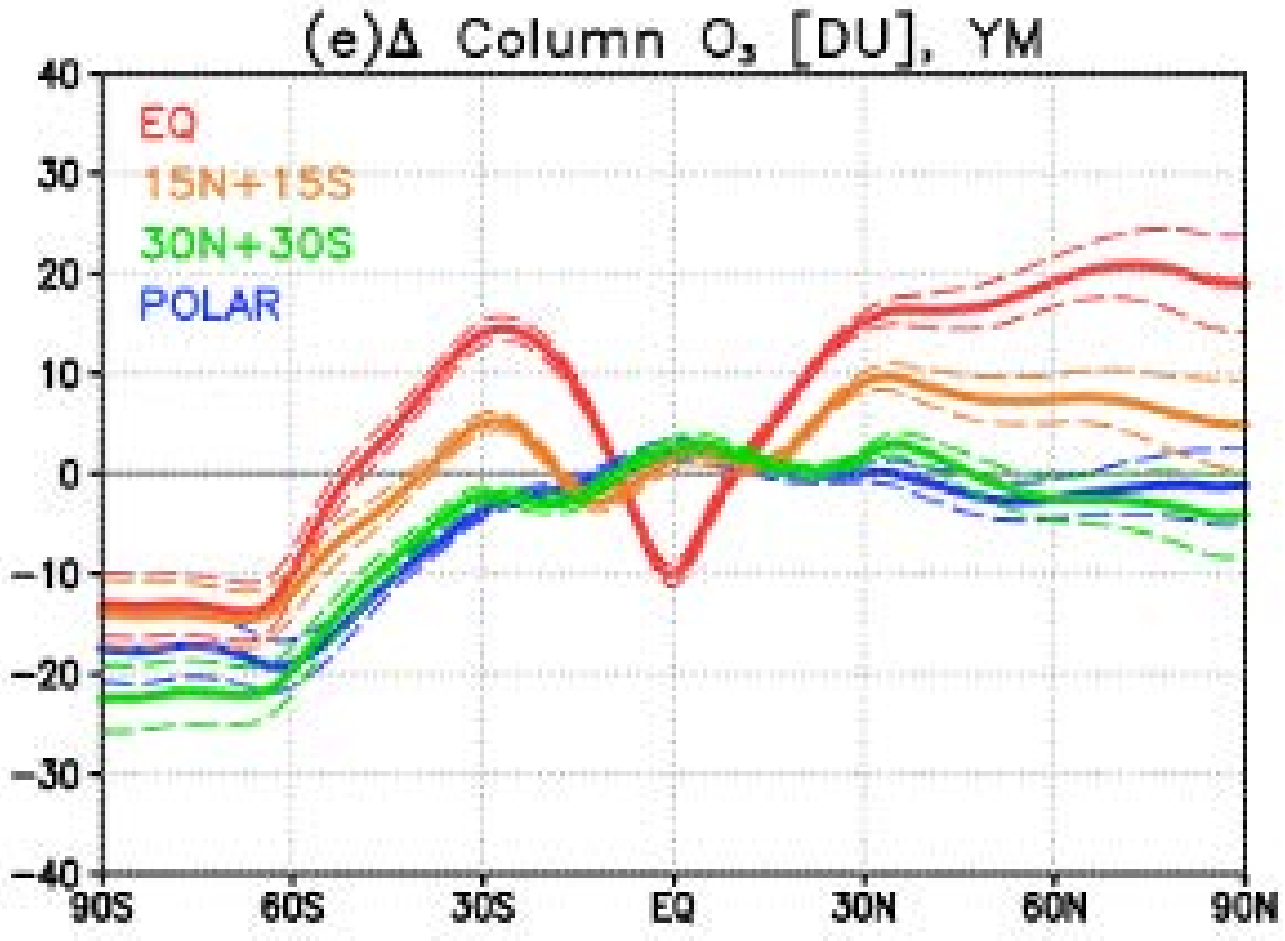
Project: Modeling stratospheric aerosol injection

CIESRDS contributors: Ewa Bednarz

Relevance to NOAA: This project is of key importance to the wider NOAA mission of understanding processes driving changes in atmospheric composition and climate.

This team models the atmospheric and climate impacts of climate intervention strategies, particularly stratospheric aerosol injection (SAI). Over the past five years, the researchers have published 20 peer-reviewed papers on SAI and co-authored a chapter of the upcoming World Meteorological Organization/United Nations Environment Program Ozone Assessment report for 2026. Their results have shown the air quality impacts of SAI are likely small and mainly driven by changes in climate, not aerosol settling.

Over the next five years, they plan to publish a multi-model assessment study of SAI impacts on stratospheric ozone recovery and related changes in stratospheric climate using the new GeoMIP G6-SAI-1.5K experiment.



Annual mean total column ozone response to different SAI strategies achieving the same level of global mean surface cooling via SO2 injection at either the equator (red), tropics (orange), sub-tropics (green), or polar regions (blue)
Credit: Bednarz et al. 2023, *Atmospheric Chemistry and Physics*

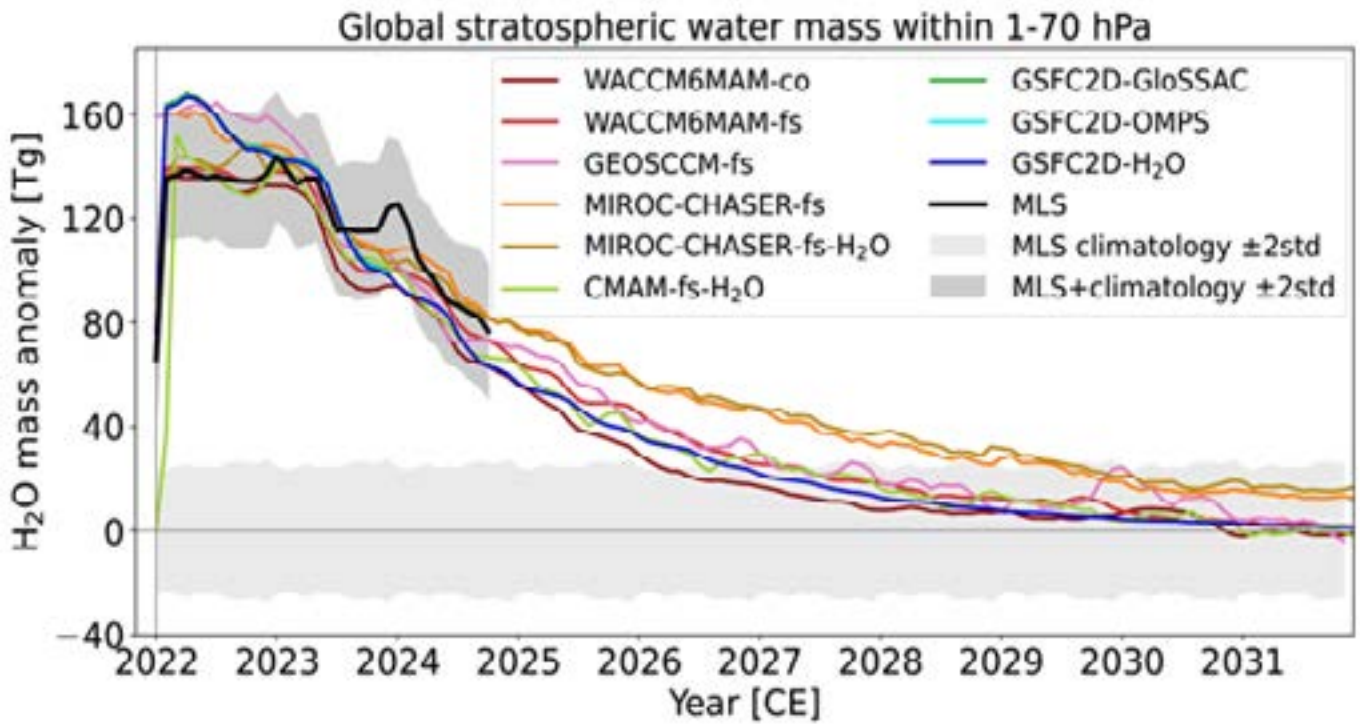
Project: Understanding the climate impacts of the 2022 Hunga Tonga-Hunga Ha'apai eruption

CIESRDS contributors: Yunqian Zhu, Ewa Bednarz

Relevance to NOAA: Results from the project will improve our understanding of the ozone and other impacts to current climate caused by large volcanic eruptions. This project falls under the goals of NOAA's Earth's Radiative Budget (ERB) program.

This CIESRDS project team models how the unprecedented amount of water vapor injected into the stratosphere from the 2022 Hunga Tonga-Hunga Ha'apai eruption impacted Earth's stratosphere. So far, they have published 18 journal articles, 1 book chapter, and given 12 presentations. One team member also led production of the Hunga Atmospheric Impact Report that was released in December 2025. Results from this report will be incorporated into the World Meteorological Organization/ United Nations Environment Program ozone assessment for 2026. Their results show that while the eruption significantly altered the chemical composition and radiative budget of the stratosphere, if it impacted surface climate, the effects are small, and more research is needed before definitive statements on the role of the eruption in contributing to surface climate and weather events in the following years are made.

Over the next five years, the team plans to lead the Hunga Tonga-Hunga Ha'apai Volcano Impact Model Observation Comparison (HTHH-MOC) Project and release data to the public.



Simulated and observed global stratospheric H_2O mass anomalies within the 1–70 hPa range following the Hunga eruption. The colored lines represent the ensemble mean anomalies relative to the control run, while the black line and gray shading depict the observed anomaly from the Microwave Limb Sounder (MLS) water vapor mass, along with its ±2 standard deviation range from the 2012–2021 climatology period.

Credit: Zhuo et al. 2025, *Atmospheric Chemistry and Physics*

Project: Studying the stratospheric impacts of rocket and satellite re-entry emissions

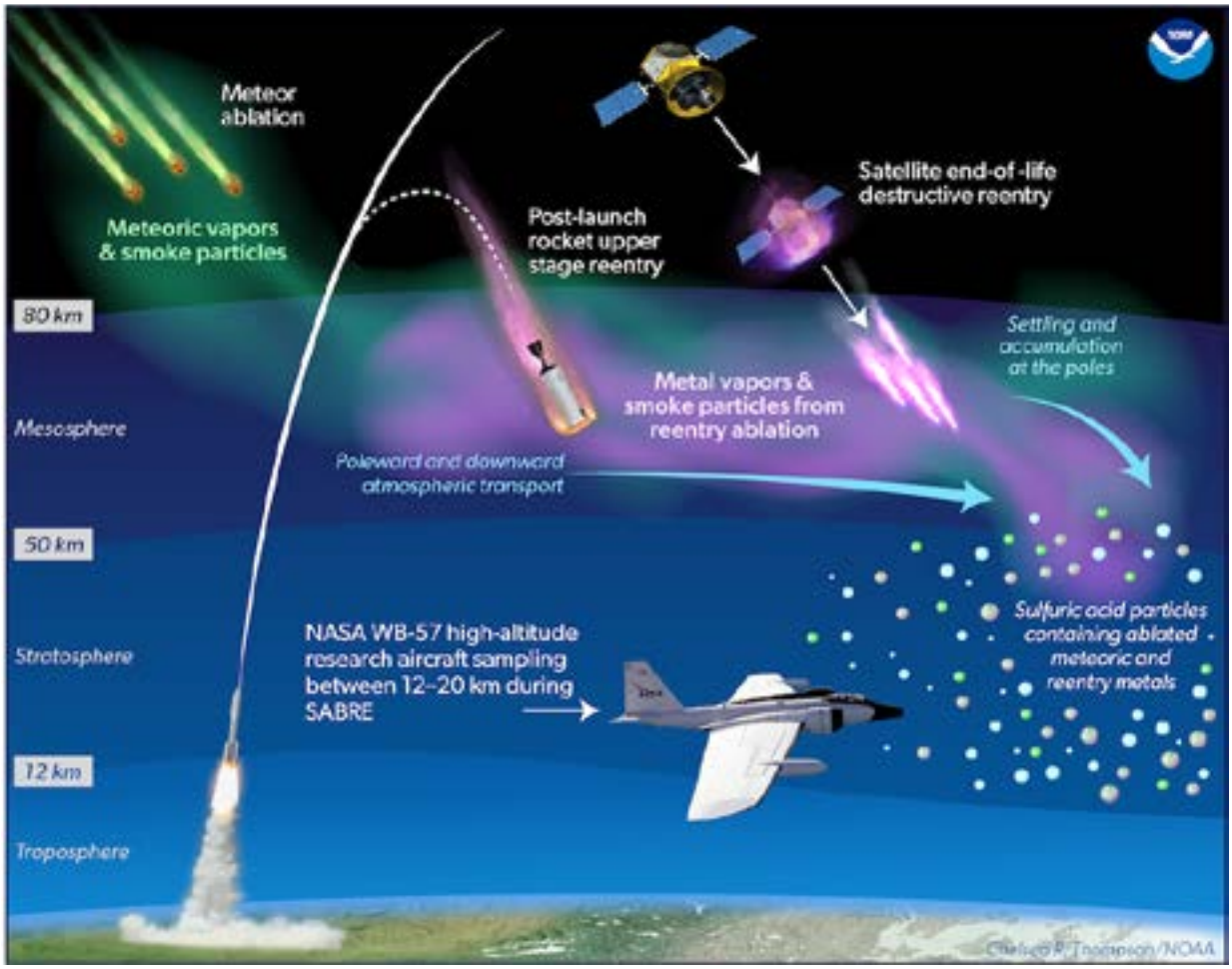
CIESRDS contributors: Christopher Maloney

Relevance to NOAA: This project strengthens NOAA's ability to monitor and understand stratospheric composition and aerosol impacts on climate, radiation, and ozone. The project shows human activity influences the composition of stratospheric aerosols, and although the result of this changing composition is unknown, it is likely to increase in importance as space launches increase in frequency.

CIESRDS researchers on this project use global climate model simulations of projected rocket launch and satellite re-entry scenarios to estimate how this emerging aerosol emission source in the middle atmosphere may influence the stratospheric environment, ozone, and Earth's radiative balance.

Since September 2022, the researchers have authored several publications highlighting the first-ever observations of satellite re-entry material mixed with aerosols in the stratosphere, given several talks and conference presentations, and contributed to the upcoming 2026 World Meteorological Organization/United Nations Environment Program Ozone Assessment. Their results so far show that by 2040, the amount of aerosolized aluminum and other particles from burning satellites could equal the amount of dust that naturally accumulates in the atmosphere from falling meteors. That much alumina could alter polar vortex speeds, heat up parts of the mesosphere by as much as 1.5 degrees Celsius, and impact the ozone layer.

Over the next five years, the researchers plan to develop a new model version to better represent satellite re-entry aerosols and contribute to an international collaboration to produce a pathways-style emissions inventory dataset for rocket launches.



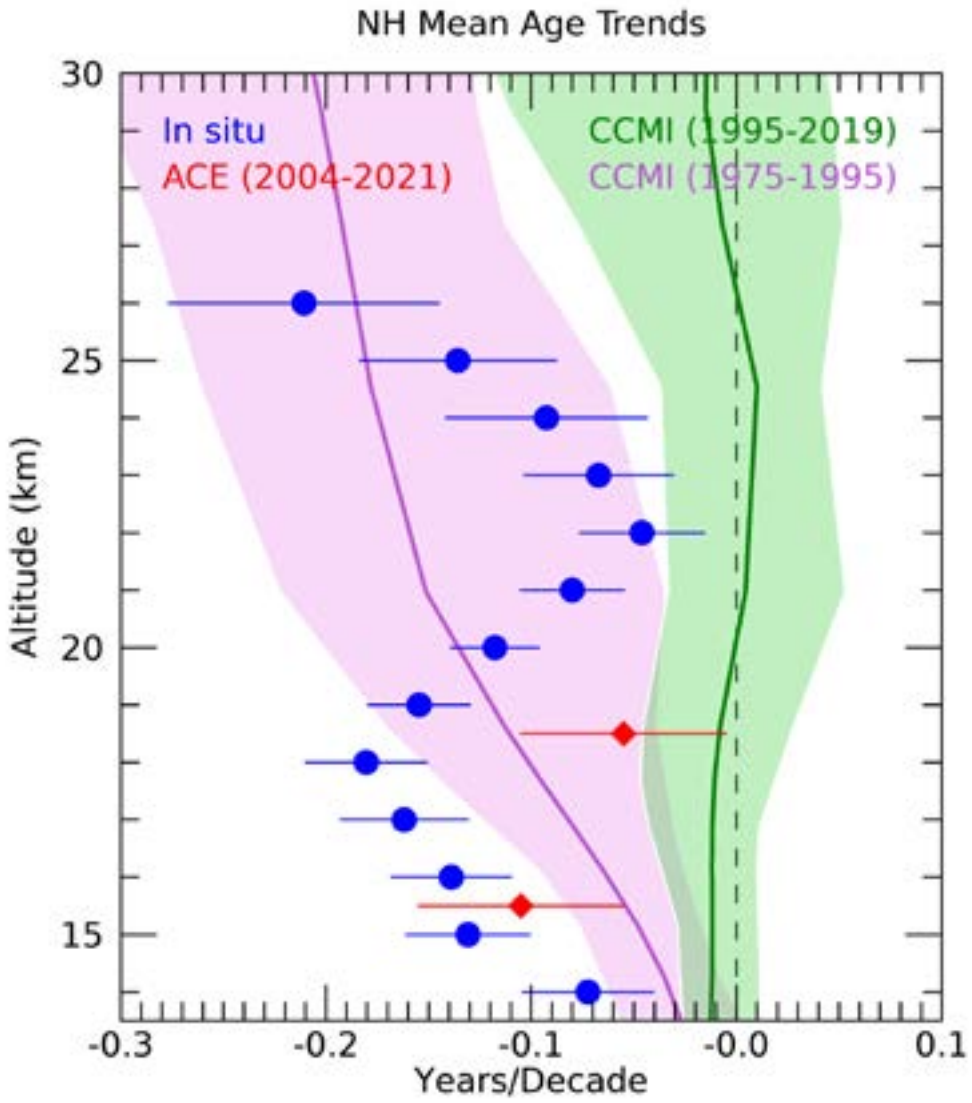
Overview of how satellite re-entry contributes metal particles to the stratoshere. Satellite vaporization in the upper atmosphere during re-entry emits metallic particles that may change the heating profile of the mesosphere and upper stratosphere and affect with stratospheric ozone chemistry.
Credit: Chelsea Thompson/NOAA CSL

Project: Determining stratospheric circulation strength through age of air

CIESRDS contributors: Eric Ray

Relevance to NOAA: This work helps clarify how the changing climate affects stratospheric circulation. The researchers have developed an updated technique to be used to calculate mean age from in situ trace gas measurements over the past 30 years, resulting in a new stratospheric mean age climatology and trend estimates.

This team uses in situ measurements to determine stratospheric age of air, the primary observed indicator of stratospheric circulation strength and decadal time scale changes. Mean age can also be used to place other in situ trace gas or aerosol measurements in dynamical context in the stratosphere. A recent reevaluation of mean age trends from in situ measurements shows a significant discrepancy with model trends over the most recent several decades. So far, the researchers have given 13 presentations at scientific conferences and published 11 journal papers. Two additional publications are expected from this project.



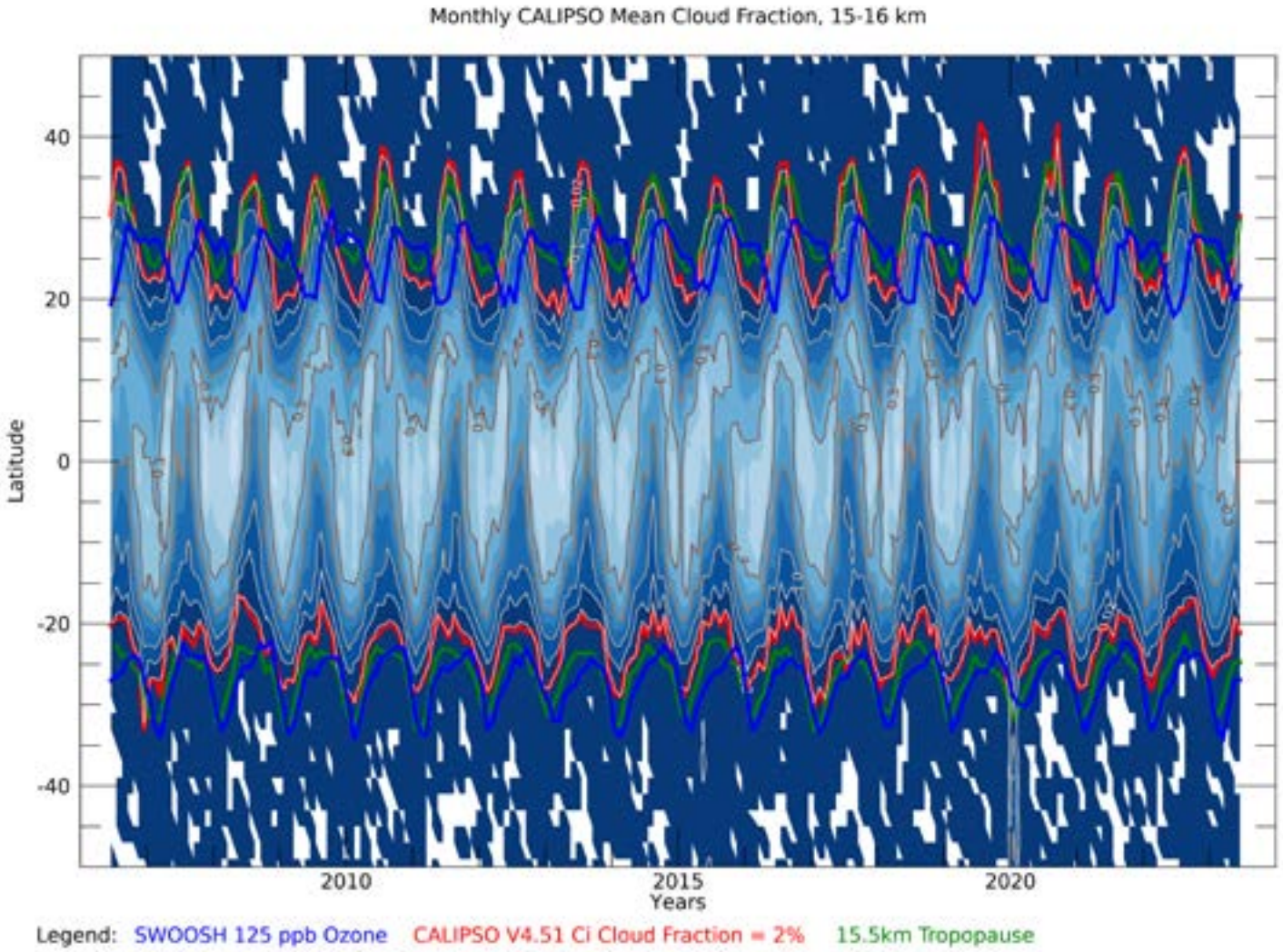
Northern Hemisphere mean age trend profiles from in situ data (blue), satellite data (red) and model output over two time periods (green and purple).
Credit: Eric Ray/CIESRDS

Project: Determining tropical width from cloud, aerosol, and trace gas measurements

CIESRDS contributors: Melody Avery

Relevance to NOAA: The tropical tropopause region is a critical area for transport of gases and aerosols from the troposphere into the stratosphere. Independent evaluation of model predictions using observations improves model forecasts of change.

This team defines new metrics for the width of the tropics that are derived from observations. Models predict change in the latitude of the edge of the tropics that may vary with altitude. High spatial resolution observations of clouds and aerosols provide a means to verify tropical edge parameters derived from reanalysis models. These can be used to evaluate model processes and predictions. So far, the researchers have defined new tropical edge metrics, published six journal articles, and given eight conference presentations. Over the next five years, they plan to continue documenting new tropical edge metrics in a scholarly paper and begin work using machine learning to speciate ice clouds and aerosol types in the upper troposphere/lower stratosphere using satellite data.



Contoured time series of the monthly zonal mean cloud fraction between 15 and 16 km, as observed by the CALIPSO Lidar. The 2% contour (red), 15.5 km tropopause (green) and 125 ppb zonal mean contour (blue) coincide well, showing that the tropical "edge" can be observed quite well by looking at the disappearance of thin clouds in the tropical tropopause layer.
Credit: Melody Avery/CIESRDS

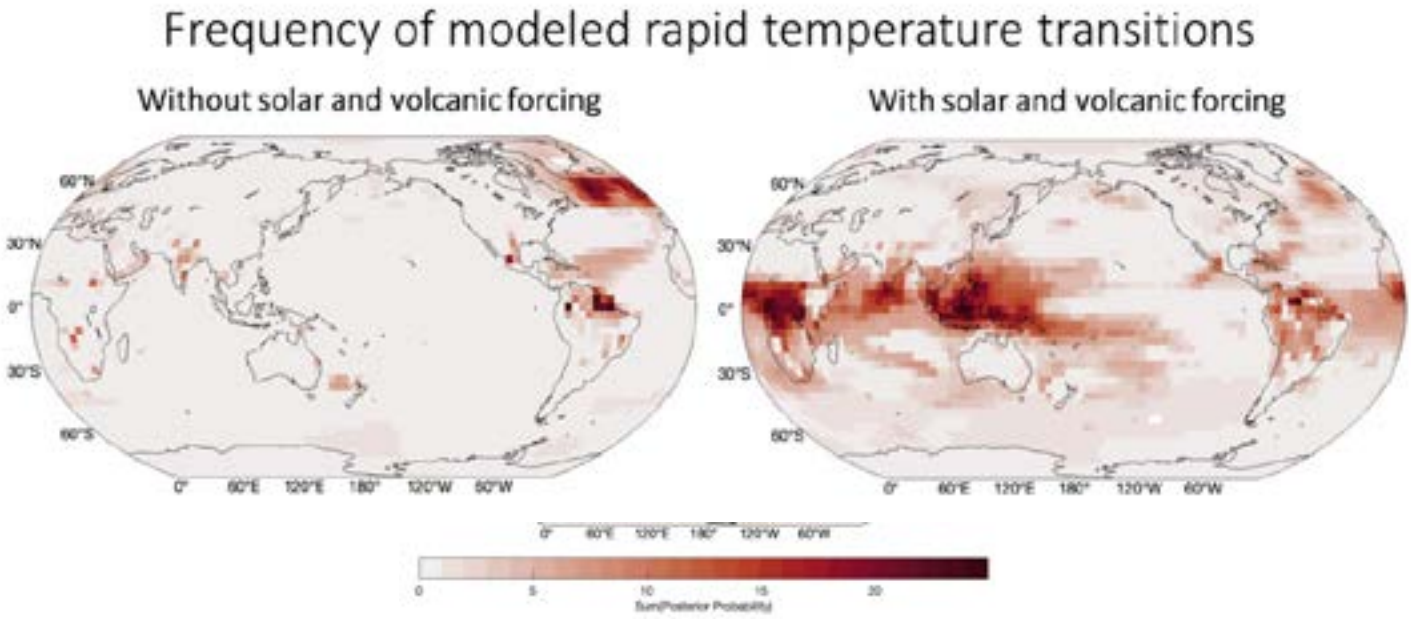
Project: Identifying rapid climate changes in high-resolution paleoclimate records and model simulations of the last 8,000 years

CIESRDS contributors: Allison Lawman, David Harning, Christopher Guiterman, Edward Gille, Anastacia Werner

Relevance to NOAA: Paleoclimate records provide the only multi-centennial and longer records of climate variability. This information is critical for improving model performance and predictions.

Past research has shown that state-of-the-art climate models tend to underestimate multi-decadal and longer-term climate variability and are less capable of producing the very rapid temperature and hydroclimate transitions evident in the paleoclimate record. One key limitation is that the full influence of solar and volcanic forcing on climate variability has not been fully represented in many model simulations.

This project addresses that gap by comparing the spatial patterns and frequency of abrupt climate changes recorded in paleoclimate archives with those produced by climate models that include solar and volcanic forcing. Paleoclimate records provide the only multi-centennial to millennial-scale perspective on natural climate variability, making them essential for improving model performance and enhancing predictions of future climate behavior. To date, the project team has presented initial analyses at five scientific conferences and has two manuscripts in preparation. Supported by an NSF grant to CIRES, this work is scheduled for completion in September 2026 and will contribute important insights into how external forcing shapes long-term climate variability and the likelihood of abrupt transitions.



The result of a Bayesian model; the sum of posterior probability translates to the likely number of abrupt temperature changes over the approximately 2000-year period of analysis.
Credit: Allison Lawman/CIESRDS

Project: Understanding aerosol-cloud interactions

CIESRDS contributors: Jianhao Zhang, Jung-Sub Lim, Eshkol Eytan, Yaosheng Cheng, Takanobu Yamaguchi, Jan Kazil, Xiaoli Zhou, Prasanth Prabhakaran, Isabel McCoy

Relevance to NOAA: This work reduces one of the largest sources of uncertainty in climate prediction by improving fundamental understanding of aerosol-cloud interactions across diverse regimes. These advances directly strengthen NOAA's ability to make more reliable climate projections and inform societal planning related to air quality, climate change, and environmental policy.

This group investigates aerosol-cloud interactions, including fundamental processes such as the diurnal evolution of stratocumulus clouds, cloud water adjustment timescales to aerosol perturbations, the potential for cloud darkening regimes, Arctic mixed-phase clouds, and the influence of aerosols and smoke on the stratocumulus-to-cumulus transition. The team explores these questions using satellite remote sensing, high-resolution modeling, and machine-learning-based analysis. So far, they have published more than 20 journal articles and participated in one workshop report.

Over the next five years, the researchers plan to investigate Arctic mixed-phase clouds and the role that their wintertime radiative cooling plays in protecting Arctic ice. They will also continue to advance core research themes, with particular emphasis on understanding meteorological covariability and its role in controlling marine cloud responses to aerosol perturbations.

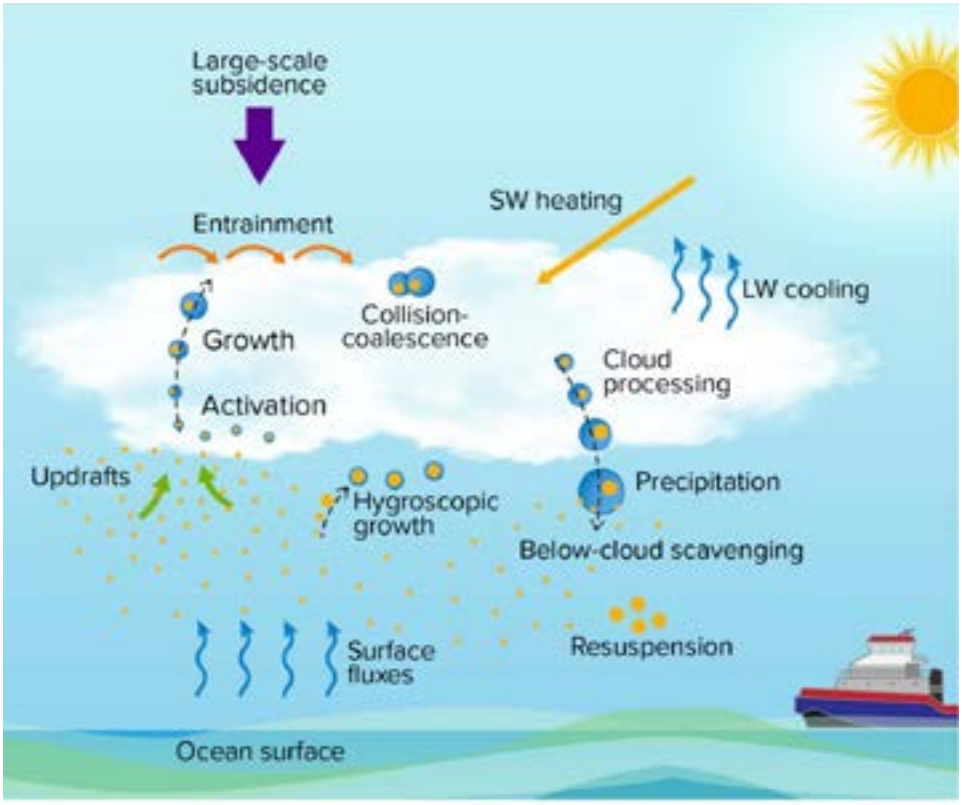


Diagram of the key aerosol, cloud, dynamics, and radiation processes in the marine boundary layer.
Credit: Feingold et al. 2024, *Science Advances*

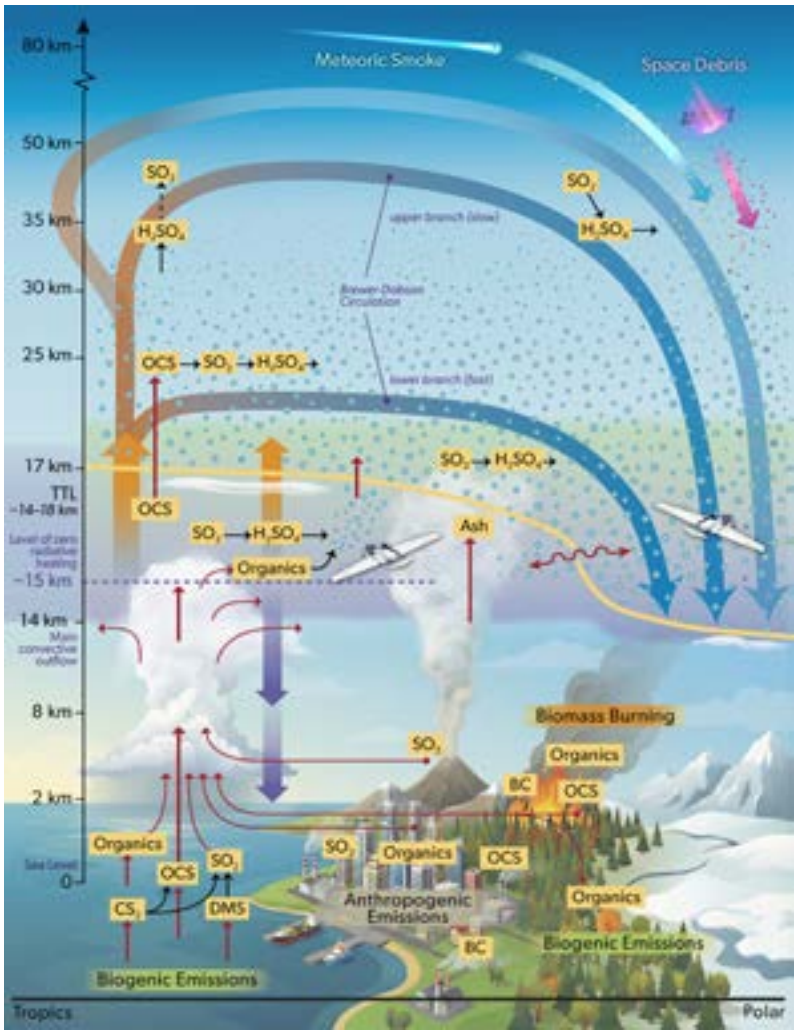
Project: Understanding stratospheric aerosol processes, budget, and radiative effects

CIESRDS contributors: Colin Gurganus, Samantha Delone, Georgia Michailoudi, Eleanor Waxman, Matthew Forbes, Zach Decker, Daun Jeong, Gordon Novak, RuShan Gao, Alex Baron, Katie Smith

Relevance to NOAA: This project strengthens NOAA's ability to monitor and understand stratospheric composition and aerosol impacts on climate, radiation, and ozone. The measurements improve climate and air quality models, support informed environmental policy decisions, and enhance preparedness for volcanic and human-driven changes to the atmosphere, ultimately benefiting public health, climate resilience, and long-term environmental stewardship.

The Stratospheric Aerosol processes, Budget, and Radiative Effects (SABRE) project uses NASA's WB-57 high-altitude aircraft to collect comprehensive measurements of stratospheric aerosols, trace gases, and dynamics. These data establish baseline stratospheric conditions, improve understanding of aerosol chemistry, microphysics, and radiative effects, and assess responses to natural and human perturbations. The results will strengthen climate and atmospheric models and inform policy decisions on emissions, ozone protection, and potential climate intervention strategies.

The SABRE project conducted two major field deployments (Alaska 2023 and Houston 2025), achieving the first deep in situ stratospheric aircraft sampling in more than two decades. These measurements revealed significant changes in stratospheric composition, including long-range impacts of the 2022 Hunga volcanic eruption. To date, CIESRDS researchers have produced 15 publicly available datasets from these campaigns and supported three journal papers that are published or currently under review. Over the next five years, the researchers will collect more data, including from a 2026 deployment to Panama and a 2027-2028 mission to the Southern Hemisphere.



An artist's rendering of the different sources of aerosols in Earth's stratosphere.
Credit: Chelsea Thomson/NOAA CSL

Project: Understanding stratospheric aerosol abundance and variability

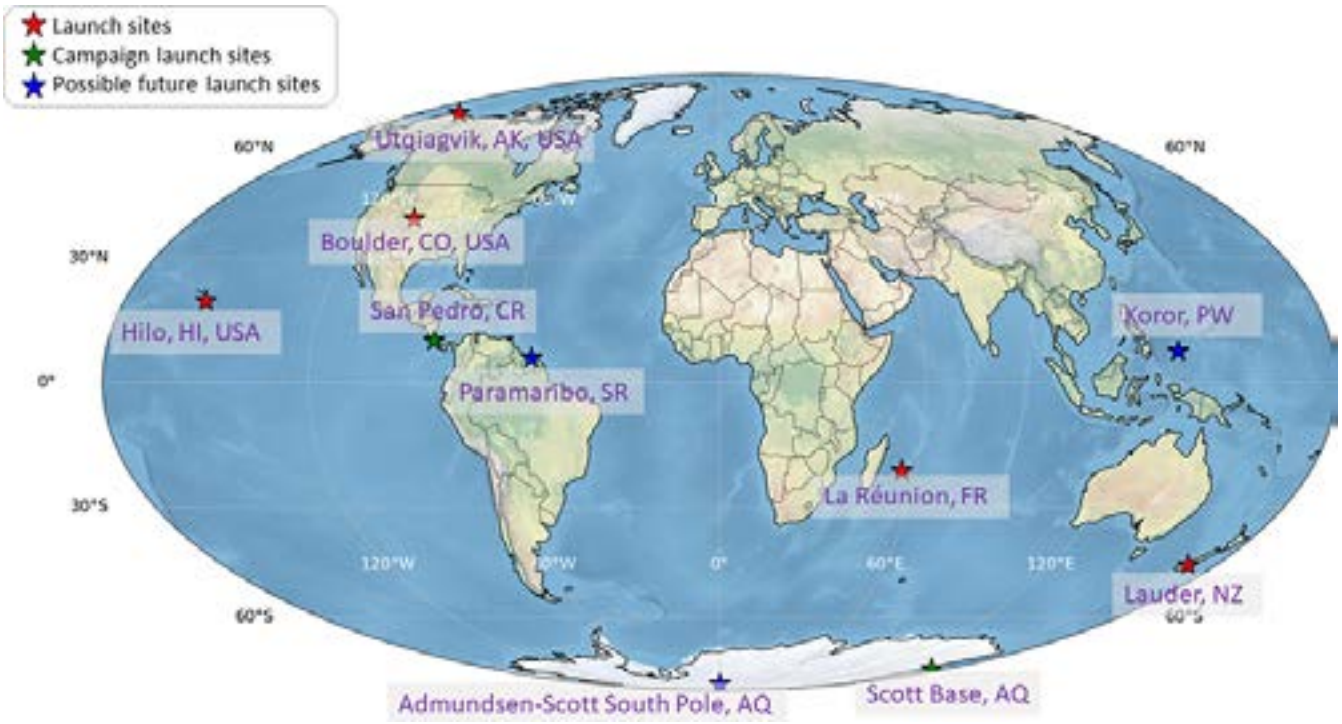
CIESRDS contributors: Alex Baron, Katie Smith

Relevance to NOAA: This project enhances NOAA's ability to monitor and interpret atmospheric composition and aerosols, improving climate, weather, and air quality predictions. It provides critical reference datasets for satellite validation and models, supports international collaboration, informs environmental policy, and strengthens society's resilience to climate change, volcanic impacts, and human-driven atmospheric disturbances.

This project collects baseline stratospheric aerosol profiles by using balloon-born instrumentation to characterize the background stratospheric aerosol abundance and variability and improve our understanding of how perturbations to the aerosol layer will impact the Earth's energy balance.

Since September 2022, the project has completed over 100 successful profiles across four new sites spanning multiple latitudes, creating a critical reference dataset for satellites and models. The project includes six international partners and over 30 collaborators, resulting in six publications (with seven more in preparation or submitted) and more than ten scientific presentations.

Over the next five years, the project will add new international launch sites and increase launch frequency. This growth will strengthen the spatial and temporal coverage of stratospheric observations, enhancing their value for understanding stratospheric dynamics, improving satellite validation, and supporting more accurate atmospheric and climate research.



Baseline Stratospheric Aerosol Profiles (B2SAP) launch locations.
Credit: NOAA GML

Project: Developing compact, low-cost atmospheric instruments

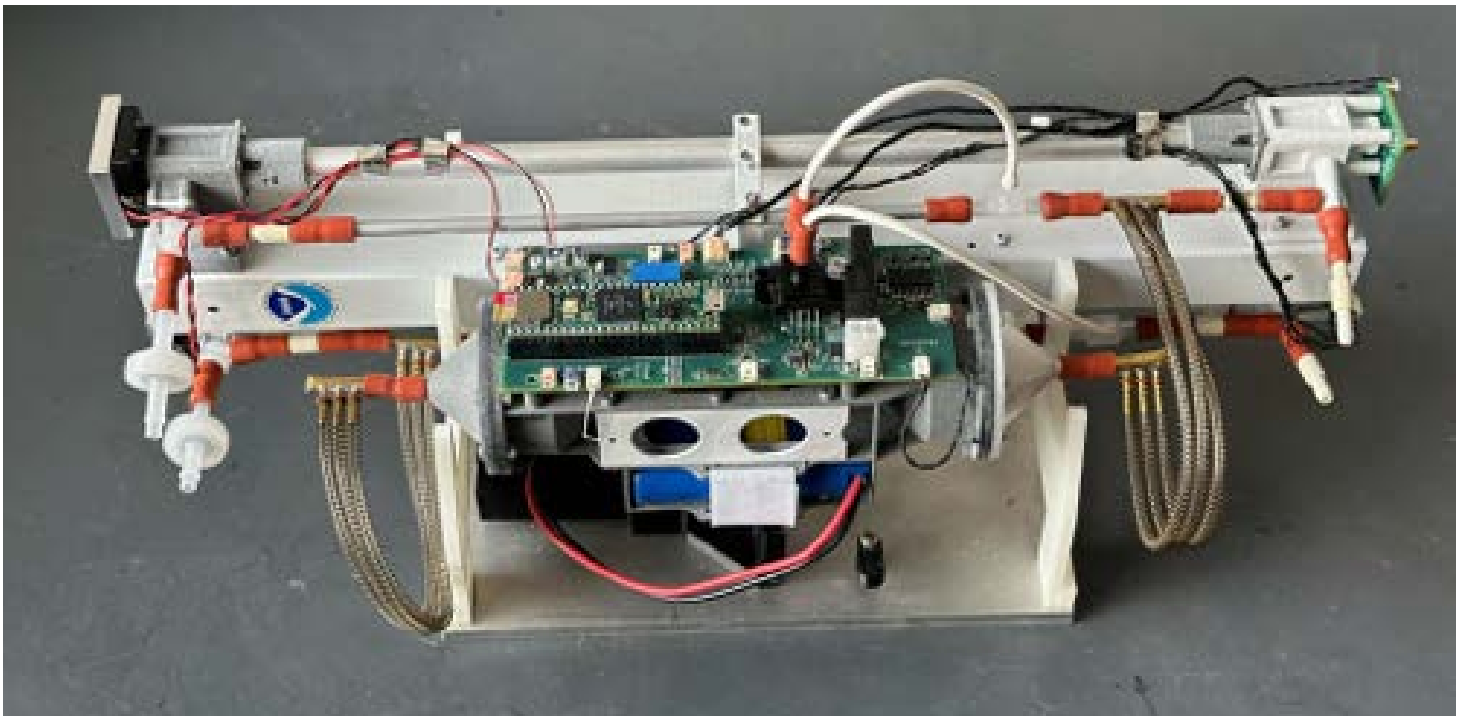
CIESRDS contributors: Rushan Gao, Matthew Forbes, Samantha Delon

Relevance to NOAA: This project advances NOAA's mission by delivering affordable, innovative tools for monitoring atmospheric composition. Improved access to high-quality data strengthens weather and climate modeling, supports air quality management, and enhances hazard and environmental assessments. These capabilities help communities more effectively respond to pollution, climate change, and evolving environmental risks.

NOAA has more than a decade of experience designing and deploying compact, low-cost scientific instruments for balloon and uncrewed aerial platforms to measure trace gases and aerosols in the upper atmosphere. This project builds on that legacy to develop innovative, lightweight monitoring technologies that expand observational access while reducing costs. A notable success is the Portable Optical Particle Spectrometer (POPS) spectrometer, now commercialized by Handix Inc. and widely used on balloon-borne payloads for atmospheric research.

Since September 2022, this team has expanded its development of compact, robust instruments for measuring climate- and air quality–relevant trace gases and aerosols. Two patents have been filed: one for an ozone photometer for UAS/balloon studies (OPUS) and one for an in situ balloon-borne ice spectrometer (IBIS). Multiple deployments of these instruments have been completed using drone and tethered balloon platforms. In partnership with NOAA GML, coordinated launches on weather balloons have resulted in more than three successful flights, strengthening NOAA's observational capabilities and advancing low-cost atmospheric monitoring technologies.

Over the next five years, the team will continue instrument development and balloon-borne stratospheric testing, with the goal of commercialization and rapid operational deployment. Working closely with other stratospheric sampling networks will expand global coverage, increase data availability, and accelerate adoption of low-cost, high-impact atmospheric monitoring technologies.



CIESRDS scientist Ru-Shan Gao designed the Ozone Photometer for UAS/balloon-based Studies (OPUS) instrument shown here to address the need of a fast and lightweight ozone sensor for scientific studies on moving platforms.
Credit: NOAA CSL

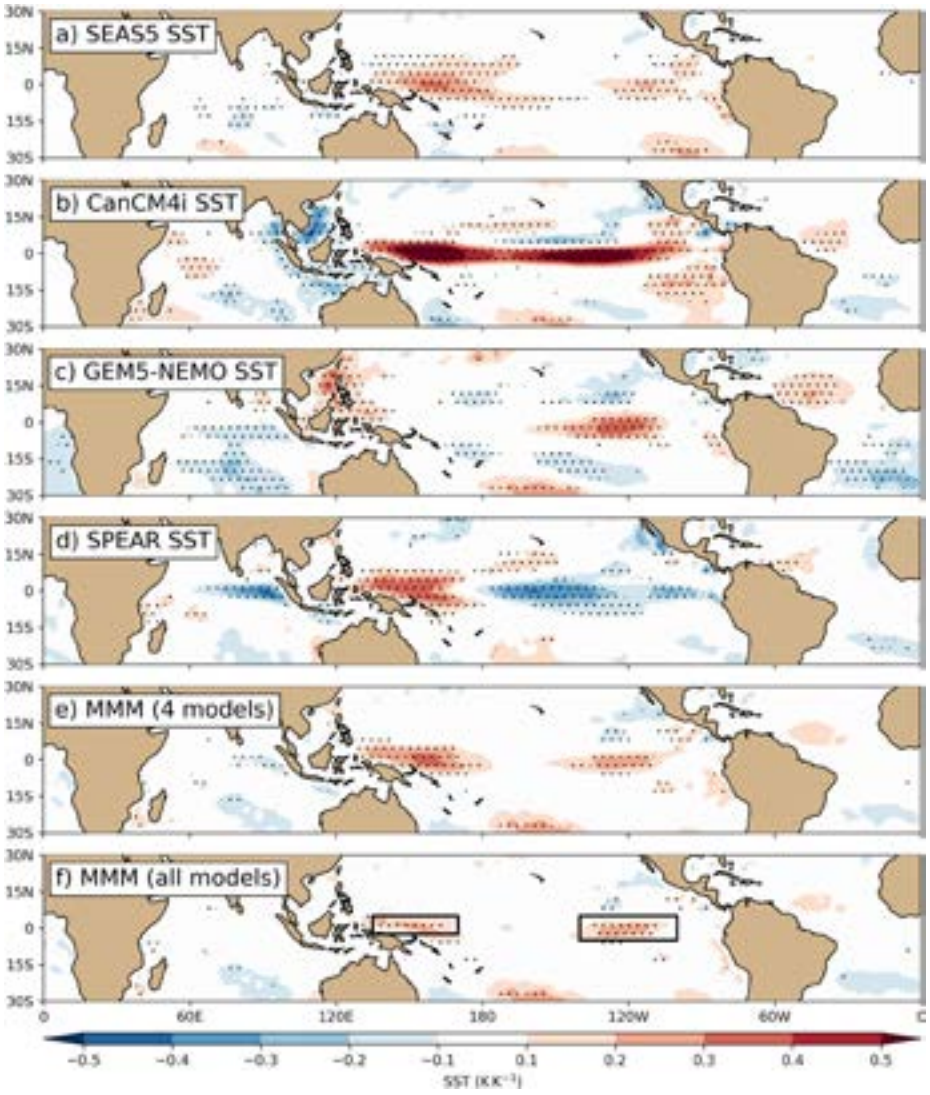
Project: Examining model errors and sources of predictability in subseasonal to decadal weather forecasts

CIESRDS contributors: Jonathan Beverley, Antonietta Capotondi, David Marsico, Joe Barsugli

Relevance to NOAA: Subseasonal to multi-year forecasts are a vital tool for disaster preparedness and water resources management in many regions. Improving the skill of forecasts on these timescales is therefore critical for forward planning of resource management, as well as mitigation and adaptation purposes.

This project aims to advance weather prediction tools on timescales ranging from weeks to decades, with a focus on improving precipitation predictions. This includes developing model analogs, evaluating coupled subseasonal and seasonal forecast model and climate model data, and utilizing more idealized and empirical models and machine learning techniques to diagnose the causes and impacts of model errors on prediction skill.

Publications from this project have led to a better understanding of errors in El Nino-Southern Oscillation (ENSO) (a major source of seasonal predictability) in seasonal forecasts, causes of errors in long-term trends in seasonal forecasts and climate model simulations alike, and improved understanding of sources of subseasonal forecast skill, aiding the model development process and operational forecasting. Over the next five years, this project will continue to examine sources of subseasonal-to-seasonal forecast model errors, including analysis of coupled ENSO and Madden-Julian Oscillation (MJO) errors. This will help identify areas for model improvement. Subsequent goals include exploring the relative importance of these errors vs biases in extratropical basic state circulation on North American precipitation forecasts.



December–January–February El Niño–Southern Oscillation (ENSO)-related sea surface temperature error for forecasts initialized in October for (a–d) four representative seasonal forecast models, (e) the multi-model mean of these four models and (f) the multi-model mean of all 11 models. Stippling indicates significance based on 1000 Monte Carlo samples.

Credit: Jonathan Beverley/CIESRDS and NOAA PSL

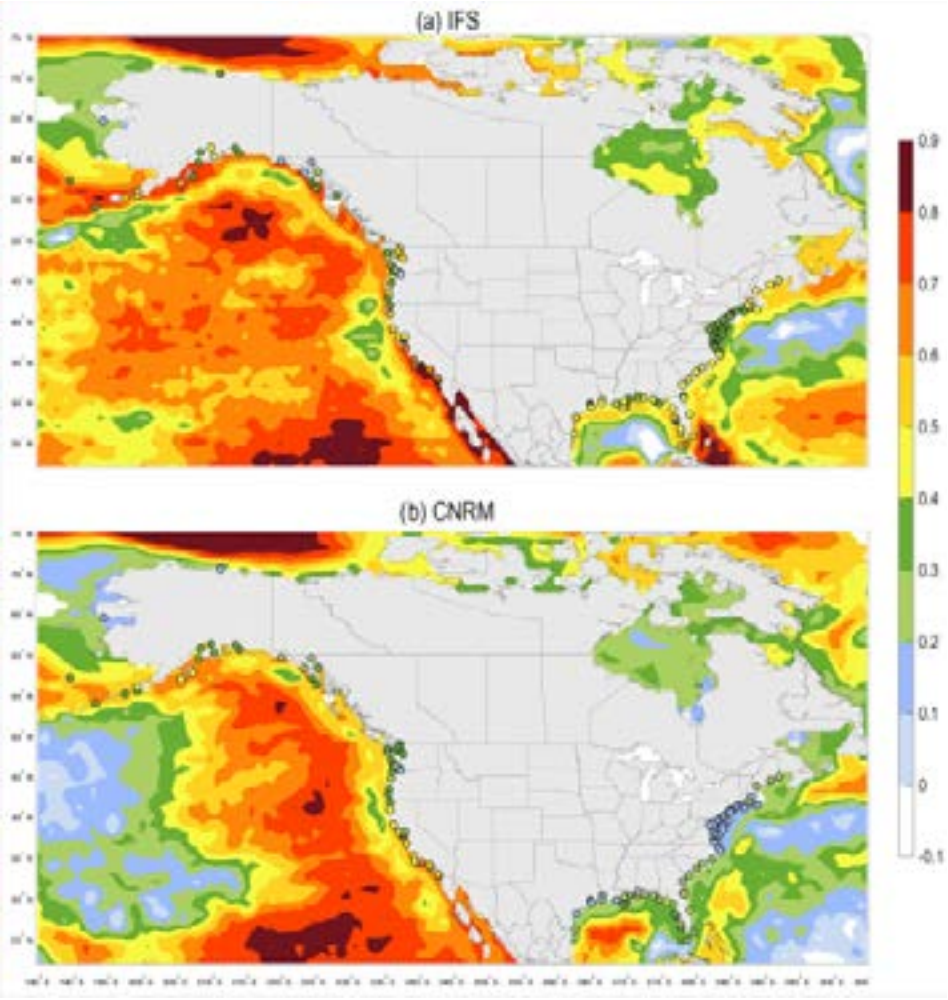
Project: Enhancing NOAA operational forecast systems for predicting U.S. coastal flooding on subseasonal to annual timescales

CIESRDS contributors: Sang-Ik Shin, Xiaoyu Long, Yan Wang, Tongtong Xu

Relevance to NOAA: This project supports NOAA's mission by advancing operational high- tide flooding monthly outlooks. Statistical downscaling techniques are integrated into NOAA's forecasting framework to improve coastal sea surface height predictions at tide gauges, enhancing early warning capabilities and supporting a climate-ready nation through improved coastal hazard preparedness and risk mitigation.

This project aims to enhance U.S. coastal sea surface height prediction across subseasonal-to-annual timescales through two main tracks: (1) evaluating and improving global climate model forecasts via bias correction, postprocessing, and downscaling to produce actionable regional predictions, and (2) developing empirical and deep -learning models to provide probabilistic forecasts with lower computational costs and comparable skill. These efforts address key challenges in bridging large-scale climate forecasts with coastal applications, advancing NOAA's operational flood prediction capabilities.

Since September 2022, the project has developed an empirical framework that reduces model dimensionality while maintaining comparable prediction skill. In addition, this project led to a major Bipartisan Infrastructure Law-funded proposal, which has since produced several major publications. Over the next five years, with support from the Bipartisan Infrastructure Law, this project will transition improved downscaling, postprocessing, and machine learning techniques into NOAA's operational forecast systems. These efforts will deliver actionable, high-resolution forecasts and enhance NOAA's coastal flooding prediction skill and reliability.



Year-round (2000–2017) week 3 anomaly correlation skill between Global Ocean Reanalysis and Simulations (GLORYS) Sea Surface Height (SSH) anomalies and SSH reforecasts (color contours), and week 3 anomaly correlation skill between NOAA gauge station anomalies and SSH reforecasts (colored circle markers), for reforecasts from the (a) Integrated Forecast Styem (IFS) and (b) Centre National de Recherches Meteorologiques climate model CNRM. While the sample years used in the anomaly correlation calculation (2000–2017) are the same, the dates are slightly different because of different initialization dates. All dates are used in both datasets, regardless of whether they overlap with the other dataset, because otherwise there are too few samples.

Credit: Albers et al. 2025, *Ocean Science*

Project: Collecting in situ stratospheric data using AirCore and StratoCore instruments

CIESRDS contributors: Tim Newberger, Markus Jesswein, Sonja Wolter, Fred Moore

Relevance to NOAA: The AirCore and StratoCore instruments provide some of the only in situ data available on trace gases present in the upper atmosphere. These data are crucial to understanding atmospheric composition and advancing NOAA's priorities of understanding changes in climate and weather.

CIESRDS scientists on this project use the AirCore and StratoCore balloon-borne instrument packages to collect air samples from Earth's troposphere and stratosphere. They use these samples to derive vertical profiles of carbon dioxide, methane, carbon monoxide, nitrous oxide, sulfur hexafluoride, and other ozone-depleting substances throughout the atmosphere. This ongoing, 13-year data collection effort is unique to NOAA's Global Monitoring Laboratory and provides the only routine *in situ* data available for understanding stratospheric dynamics in a changing climate.

So far, the team has published a novel, cost-effective analytical method for measuring high-resolution vertical profiles of stratospheric trace gases using a gas chromatograph coupled with an electron capture detector and has continued to add data to the AirCore/StratoCore dataset.

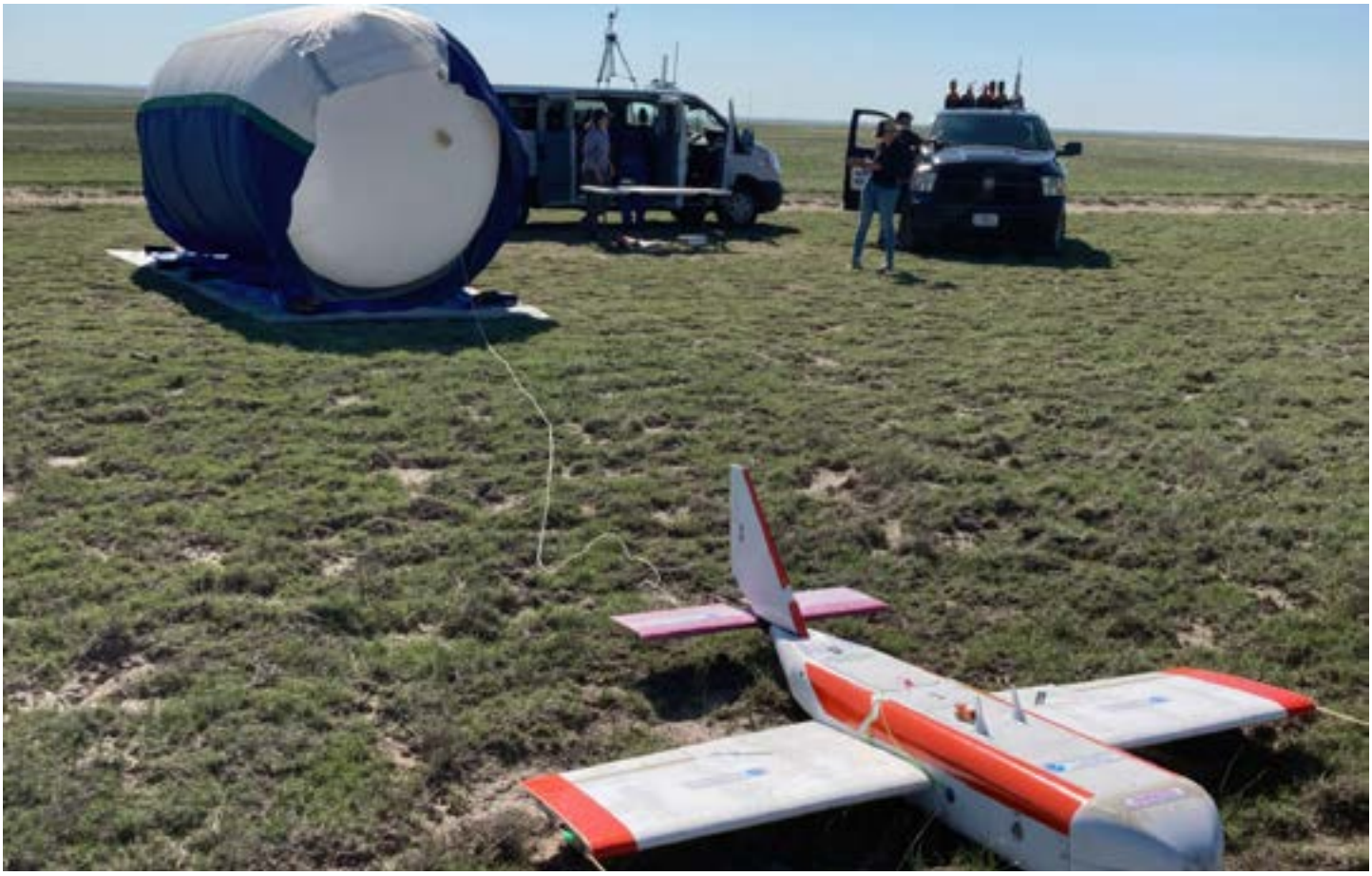
The AirCore atmospheric sampling system flying on a weather balloon.
Credit: NOAA GML

Project: Developing an uncrewed aerial system to steer balloon payloads back to their launch location

CIESRDS contributors: Steve Borenstein, Tim Newberger

Relevance to NOAA: This project will allow NOAA to deploy weather balloon payloads to locations where balloon retrieval would be nearly impossible, a payload would be lost, or where the payload might come down in a populated area. This work ultimately expands the range of places where NOAA can collect important weather data.

The High-altitude Operational Returning Uncrewed System (HORUS) for AirCore is an uncrewed aerial system designed to steer weather balloon payloads back to their original launch location. HORUS provides weather balloons with a predictable and trackable trajectory back to their launch location, making it easy for scientists to recover their payloads and for FAA air traffic control to ensure the safety of other aircraft. In 2023, the HORUS glider system completed its first sampling mission to 90,000 feet. The next version of HORUS, HORUS2, has an invention disclosure application and transition plan filed and is under development to be able to deploy and sample wildfire smoke plumes that propagate high into the atmosphere and have downwind air quality effects on other regions.



The HORUS glider and balloon prepared for a test flight on May 17, 2023 in Colorado's Pawnee National Grasslands. HORUS is a low-tech, cost-effective balloon-glider system for hosting a small payload of specialized atmospheric instruments to the edge of space, and then guiding it back to its launch location after its flight is complete.
Credit: NOAA

Project: Collecting shipborne measurements of carbon dioxide

CIESRDS contributors: Dave Munro, Anna McAuliffe, Tim Newberger

Relevance to NOAA: This project provides some of the only measurements of in situ atmospheric carbon dioxide and partial pressure of carbon dioxide in the surface ocean, which are necessary to understand the oceanic sink of carbon dioxide from the atmosphere. This work expands NOAA Global Monitoring Laboratory's land-based carbon dioxide observational network to the sea surface.

This shipborne carbon dioxide data collection project takes measurements of surface ocean and atmospheric carbon dioxide and process-associated variables (e.g., carbonate chemistry, nutrients, temperature, salinity, etc.). This project expands NOAA Global Monitoring Laboratory's land-based carbon dioxide observational network to the sea surface. Over the next five years, the team will collect data and make the data publicly available for these ongoing datasets and publish a manuscript in a peer-reviewed journal.

View from the Wallenius Wilhelmsen car carrier *M/V Tysla* during an open-ocean transit. The vessel serves as a ship of opportunity for atmospheric and surface-ocean observations.
Credit: Anna McAuliffe/CIESRDS

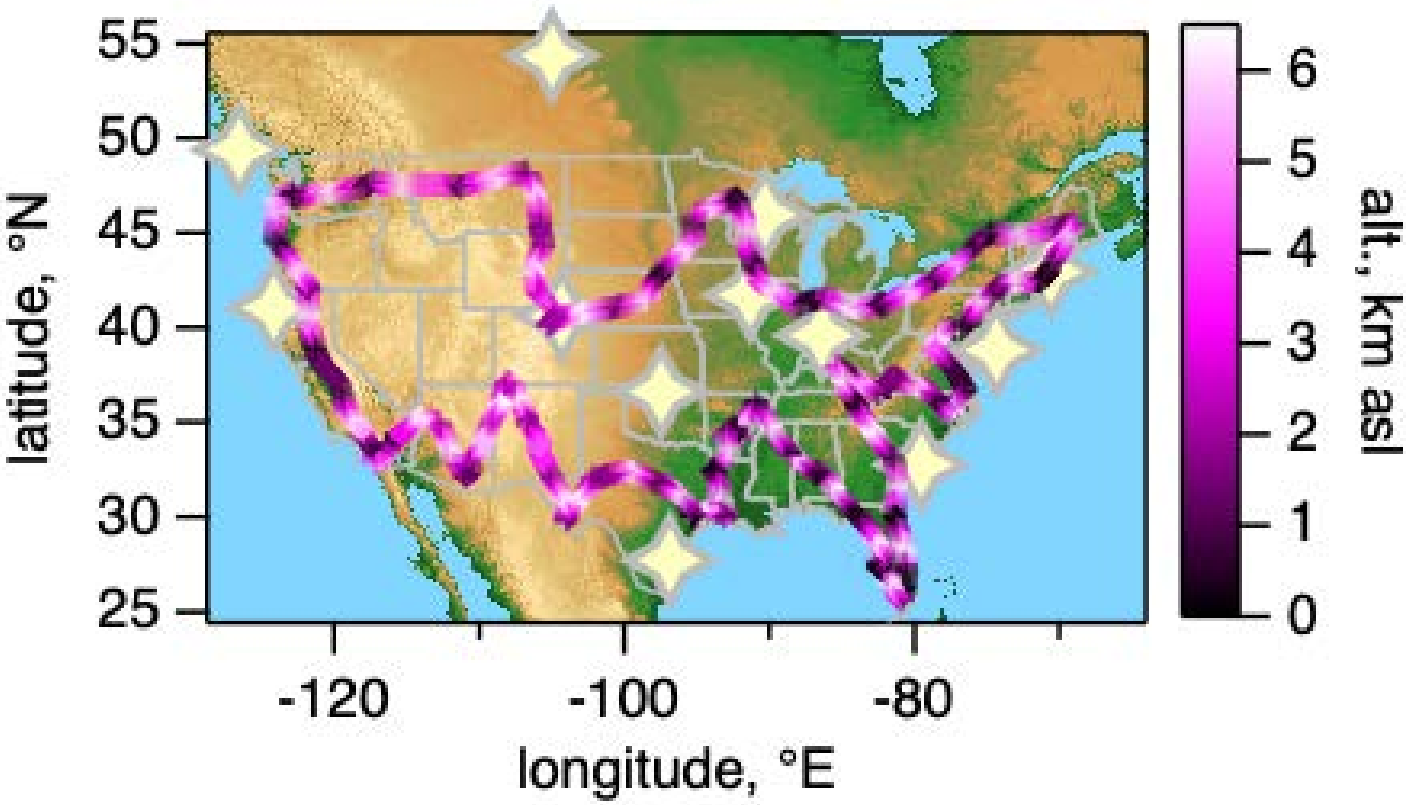
Project: National observations of greenhouse gases using aircraft profiles (NOGAP) project

CIESRDS contributors: Tim Newberger, Anna McAuliffe, Steve Borenstein, Sonja Wolter, Jeff Peischl

Relevance to NOAA: The data from this project will improve our understanding of atmospheric composition and improve computer models of atmospheric carbon dioxide and methane, advancing NOAA's priorities of understanding changes in climate and weather.

The National Observations of Greenhouse gases using Aircraft Profiles (NOGAP) project uses aircraft to collect vertical profiles of carbon dioxide, methane, carbon monoxide, water vapor, ozone, and more than 60 trace gases.

The NOGAP project started in November 2023 and has deployed an instrumented aircraft eight times across the United States, collecting up to 96 vertical profiles per deployment, from 500 feet above ground level up to 20,000 feet. The project provides broad spatial in situ measurements in locations far from GML-network tower and aircraft vertical profile measurement sites. Eight NOGAP deployments have been completed to date, and successful test flights on the NOAA King Air aircraft were completed in 2025, which will provide an alternative platform for the NOGAP project. Over the next five years, the team will collect data for these ongoing datasets and publish a manuscript in a peer-reviewed journal.



An aircraft flight track around the United States with vertical profiles represented in black-magenta-white showing where measurements are made in the spatial regions between NOAA GML aircraft vertical profile sites (yellow stars).

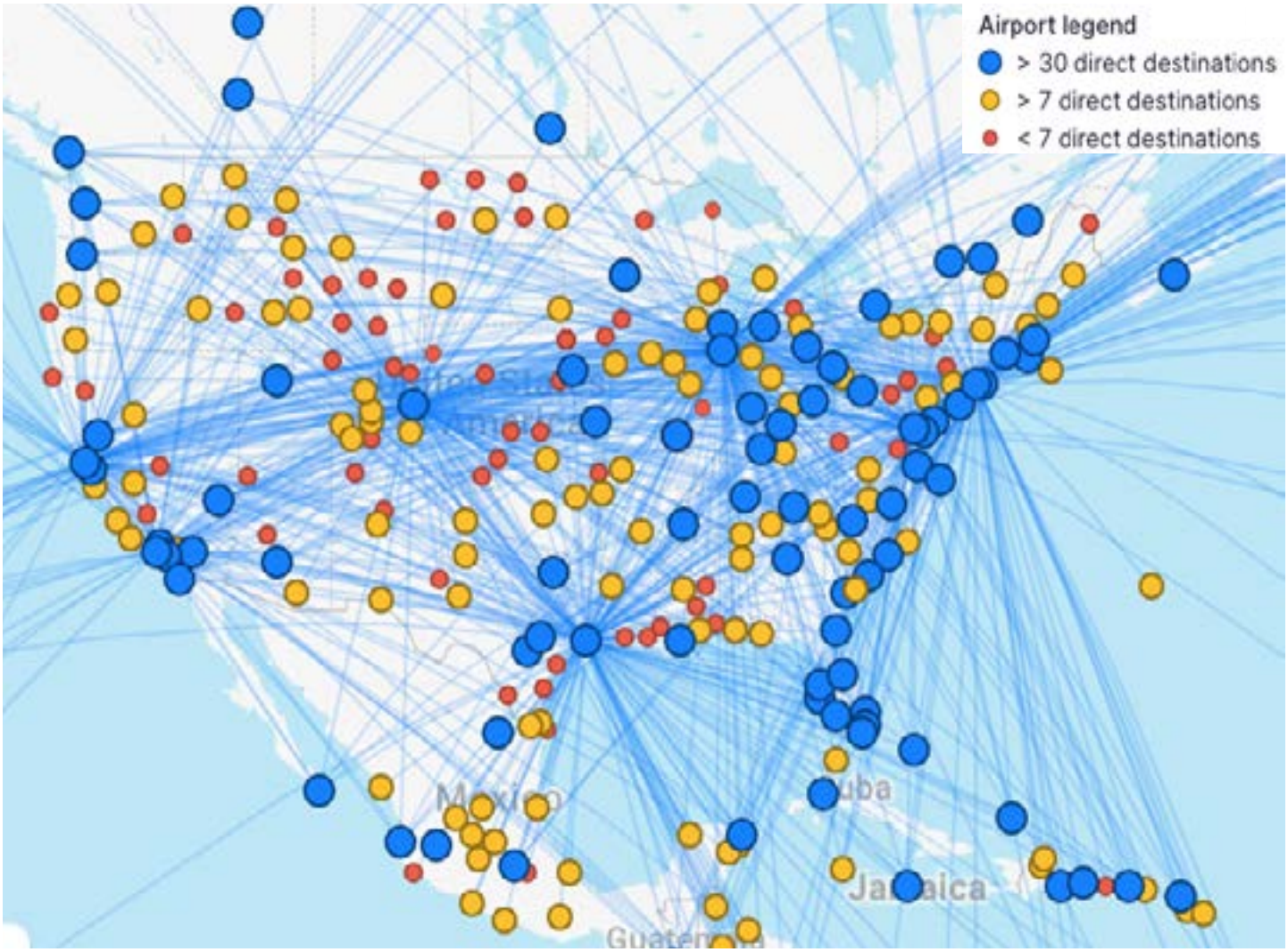
Credit: NOAA GML

Project: Measuring trace gases on commercial airplanes

CIESRDS contributors: Steve Borenstein, Tim Newberger, Anna McAuliffe, Jeff Peischl

Relevance to NOAA: This project will allow NOAA to collect atmospheric composition measurements without using NOAA aircraft or resources.

This project involves installing a greenhouse gas analyzer aboard a United 737 beginning in spring 2026. Several years of work have resulted in modifications of a commercial analyzer for robust, autonomous operation on the aircraft for 8 to 12 months. Additional work has been done for certification from both European and United States aviation administrations. The project will result in atmospheric profiles above up to five cities per day, approximately 1,300 flights per year, and up to 10,000 profiles per year. Over the next five years, the team plans to continuously operate a trace gas analyzer aboard a 737 aircraft.



Map showing where randomly selected United 737 aircraft fly in a year, showing where data can be expected to be collected with the trace gas analyzer.
Credit: Colm Sweeney NOAA GML

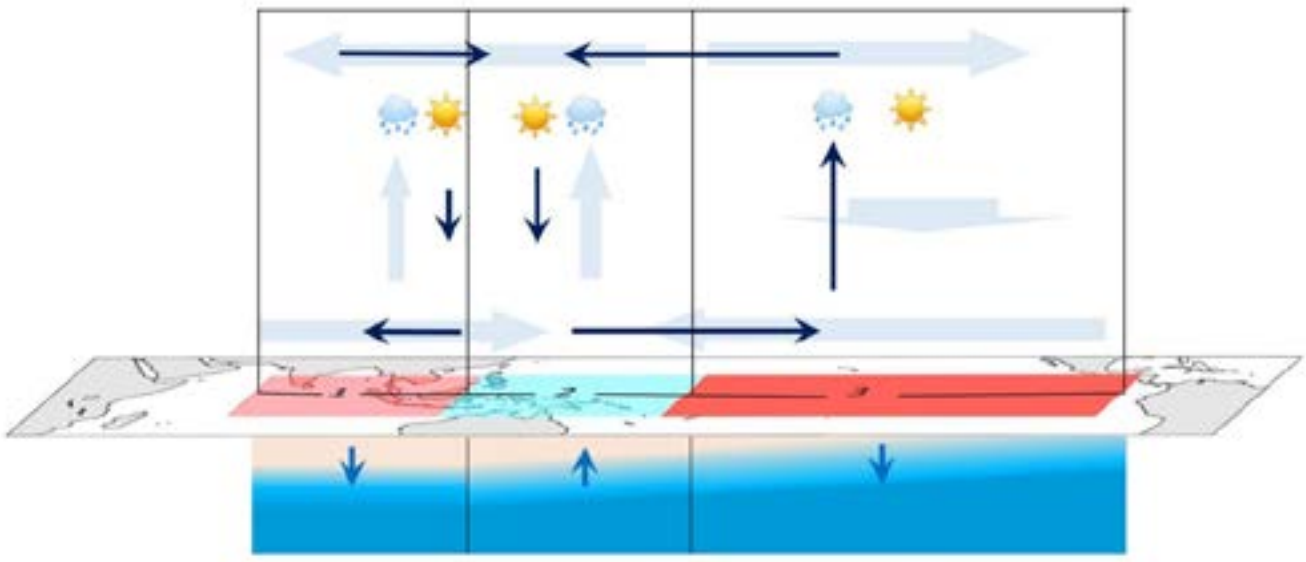
Project: Diagnosing key El Niño feedbacks and model errors using reanalyses

CIESRDS contributors: Gilbert P. Compo, Prashant D. Sardeshmukh

Relevance to NOAA: The project's results suggest that errors in key processes related to cloud-shielding, e.g., in cloud or boundary layer parameterizations, are compromising model ENSO predictions, and negatively affecting seasonal and longer-term forecasts worldwide. Improving such forecasts is a key component of the NOAA mission for its new Seasonal Forecast System.

Tropical El Niño Southern Oscillation (ENSO) events provide the source for much of the predictability in seasonal climate anomalies. Using observational atmospheric and oceanic reanalysis data, this project diagnoses, for the first time, the relative roles of the dominant positive and negative feedbacks on predictable ENSO event magnitudes, patterns, and durations. The project goal is to estimate these feedbacks observationally to diagnose and correct process errors in NOAA's and other forecasting and climate models.

Since September 2022, the project's diagnosis has provided a clear picture of the dominant competition between the destabilization of ENSO by positive near-surface zonal wind and subsurface oceanic feedbacks and its stabilization by a negative surface shortwave flux feedback associated with cloud shielding in cloudy areas. The results suggest that primarily this negative feedback renders ENSO asymptotically stable and is likely misrepresented in climate models. The work has resulted in one publication, three presentations, and two invited seminars. Over the next five years, this diagnosis provides a quantitative target for AI and physical models. The diagnosed feedbacks will be compared to new NOAA reanalyses and to model output from NOAA's Unified Forecast System and the developing Seasonal Forecast System to identify and correct the model errors.



Schematic illustration of atmospheric and oceanic anomalies in the equatorial vertical plane during the mature warm El Niño phase of ENSO. The anomalous zonally overturning Walker circulation (thick black arrows) is associated with a weakening of the mean Walker Circulation (light blue arrows). The thick blue vertical arrows in the ocean indicate displacements of the thermocline associated with the strong surface warming in the eastern Pacific (dark red), cooling in the western Pacific (cyan), and warming in the eastern Indian ocean (light red). The anomalies during the mature cold La Niña phase are generally opposite.

Credit: John Albers and Matthew Newman/NOAA PSL

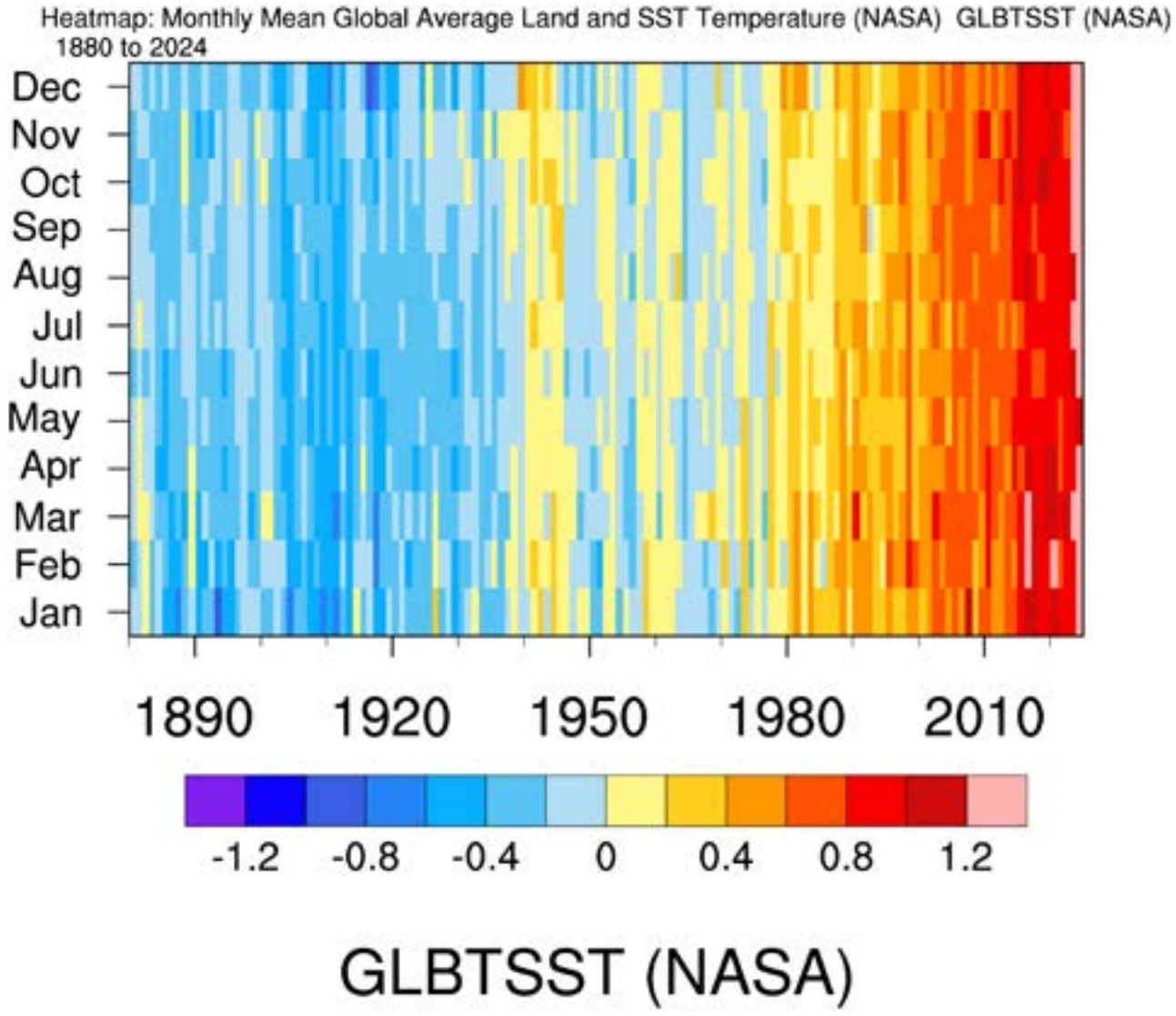
Project: Developing web-based weather and climate data analysis tools

CIESRDS contributors: Cathy Smith, Don Hooper, Don Murray, Lesley Smith

Relevance to NOAA: The tools developed here allow researchers to investigate weather and climate processes to improve weather forecasts and climate models.

This project created a set of web pages that allow researchers to quickly obtain global to regional plots of historic or forecasted weather and climate data. Users can also perform exploratory analysis of the many datasets to come up with testable hypotheses and examine relationships between variables.

Since September 2022, the webpages have been used extensively by researchers in NOAA's Physical Sciences Laboratory and in the research community. Plots generated via this project have been used in talks and publications. There have been over 1.4 terabytes of products downloaded through interactive pages. The speed at which ideas can be tested allows researchers to be more productive. Over the next five years, the team aims to improve the webpage interfaces and site security, add more datasets to the tools, and add the ability to analyze different processes.



This plot shows the global monthly mean averaged temperature using combined land and ocean values from 1880 to near the present. The monthly values are included and show how the annual cycle varies for each year.

Credit: NOAA PSL

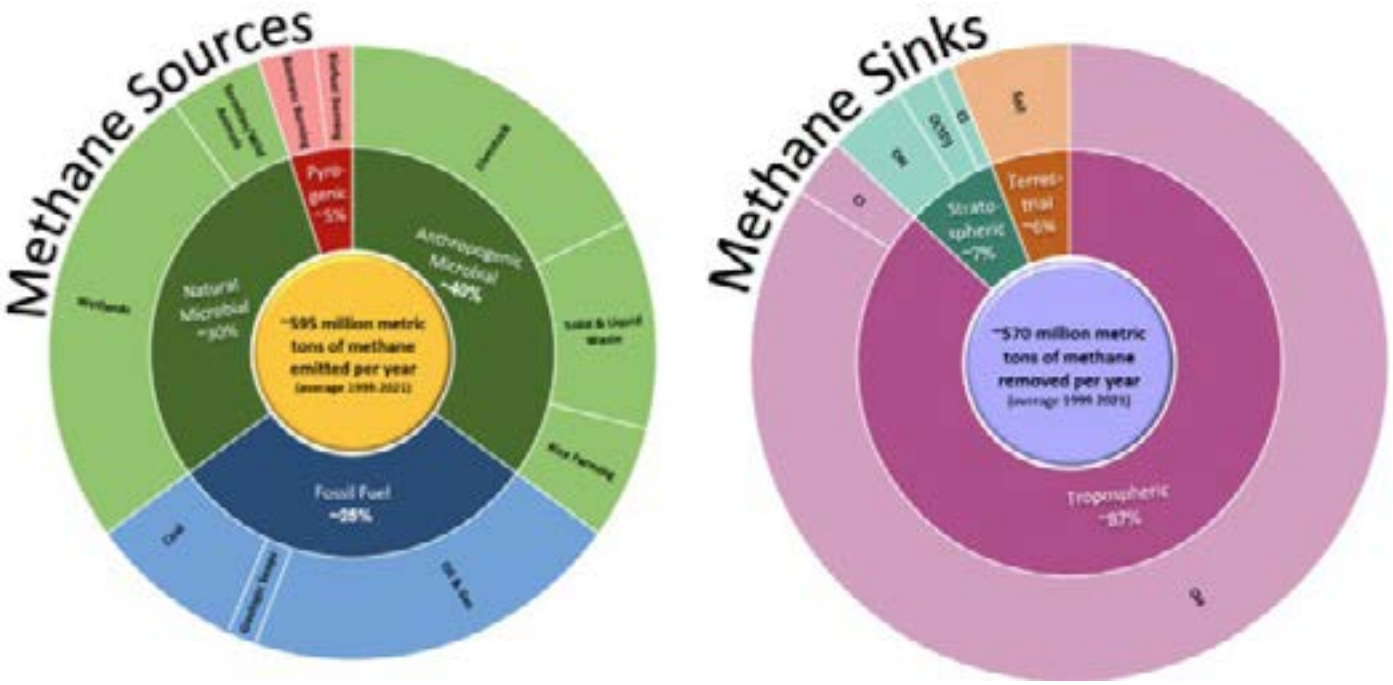
Project: CarbonTracker-Methane

CIESRDS contributors: Youmi Oh, Ashley Pera, Kenneth Schuldt, Andy Jacobson

Relevance to NOAA: CarbonTracker-Methane advances understanding of methane sources and sinks by combining atmospheric observations with modeling to improve trace gas monitoring and inform mitigation strategies. This work is vital to the interpretation of Global Monitoring Laboratory measurements and supports NOAA's mission to provide the science needed for climate policy and public health.

CarbonTracker-Methane is a global model of atmospheric methane and its isotopes. It provides estimates of regional surface emissions of this potent greenhouse gas, which are vital to the interpretation of NOAA Global Monitoring Laboratory measurements.

CarbonTracker-Methane has been operational since 2023 and has released two datasets of surface emissions. Over the next five years, researchers will further operationalize this model, improve the estimation of surface fluxes, and transition to a unified carbon dioxide/methane assimilation system based on the ensemble Kalman filter.



Left: Pie chart of global mean methane emissions from microbial, fossil, and pyrogenic source sectors.
Right: Pie chart of global mean methane oxidation from tropospheric, stratospheric, and terrestrial sink sectors.
Credit: NOAA GML

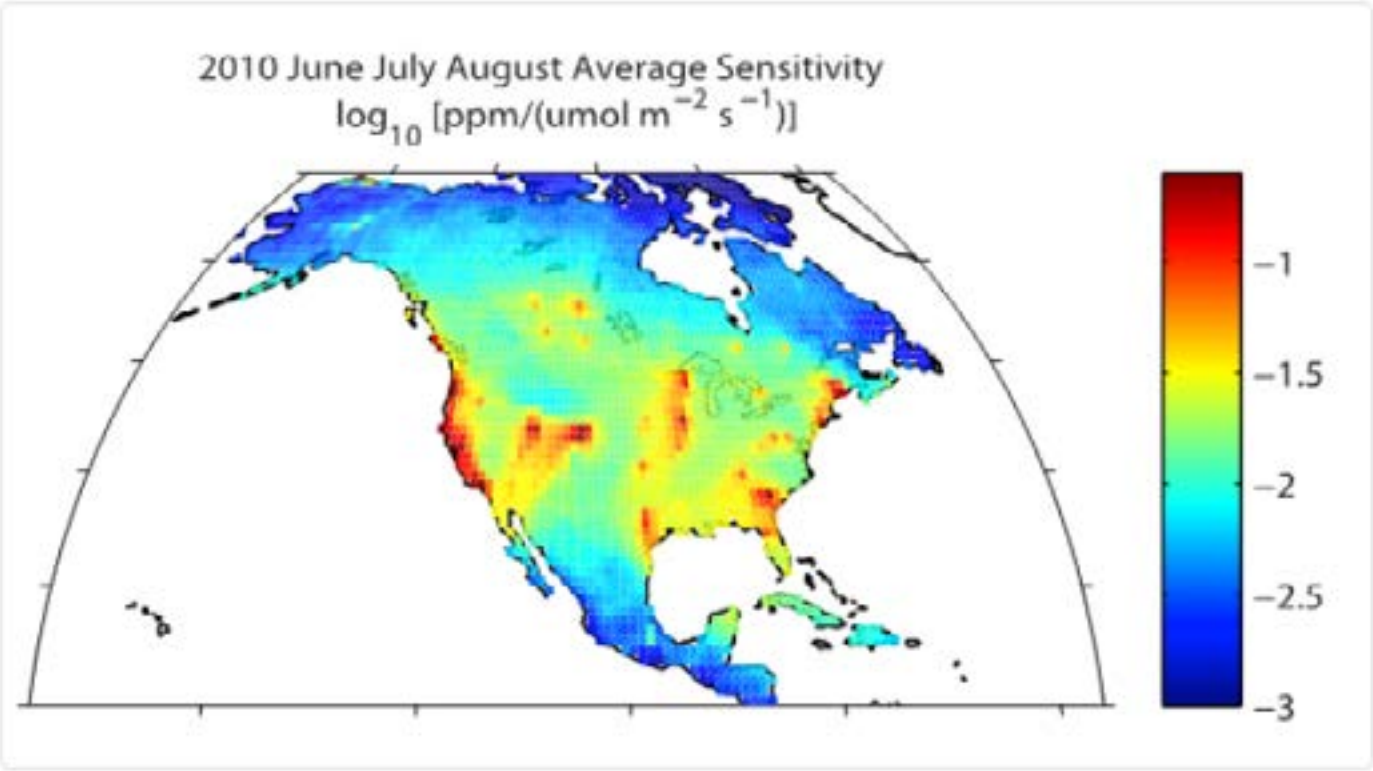
Project: CarbonTracker-Lagrange

CIESRDS contributors: Sergio Ibarra-Espinosa, Kenneth Schuldt

Relevance to NOAA: CarbonTracker-Lagrange permits high-resolution interpretation of NOAA's extensive greenhouse gas observations over North America. Through inverse modeling, it enables the estimation of emissions for discrete geographic sectors of the United States, which enhances trace gas monitoring and informs mitigation strategies.

CarbonTracker-Lagrange is a modeling system designed for regional inverse modeling over North America to evaluate U.S. methane emissions.

Since September 2022, the team has published a paper investigating the impacts of the COVID-19 pandemic on United States methane emissions. Over the next five years, researchers will continue to produce operational estimates of regional greenhouse gas and ozone-depleting substances emissions.



Sensitivity to surface emissions and uptake fluxes for summer 2010 representing the combined footprints for continuous in situ and discrete (flask) carbon dioxide measurements that are linked to the World Meteorological Organization carbon dioxide calibration scale.
Credit: NOAA GML

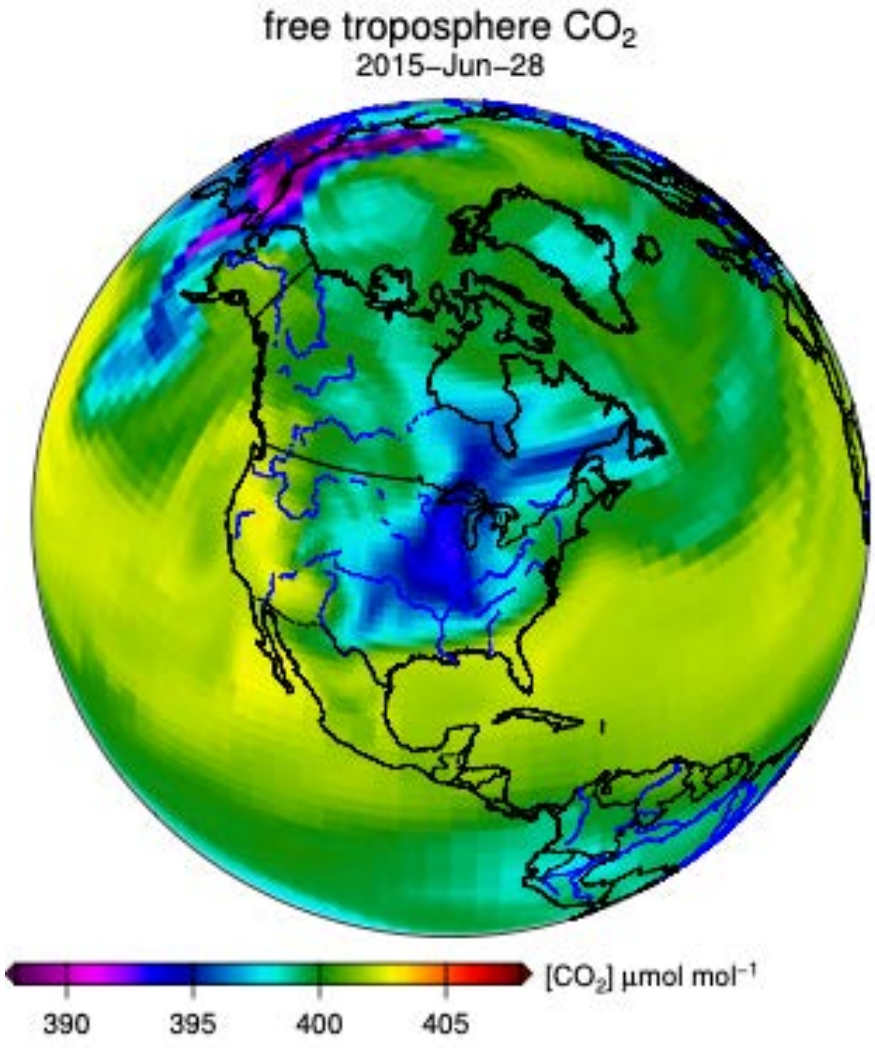
Project: CarbonTracker CO_2

CIESRDS contributors: Andrew Jacobson, Kenneth Schuldt, Ashley Pera, John Mund

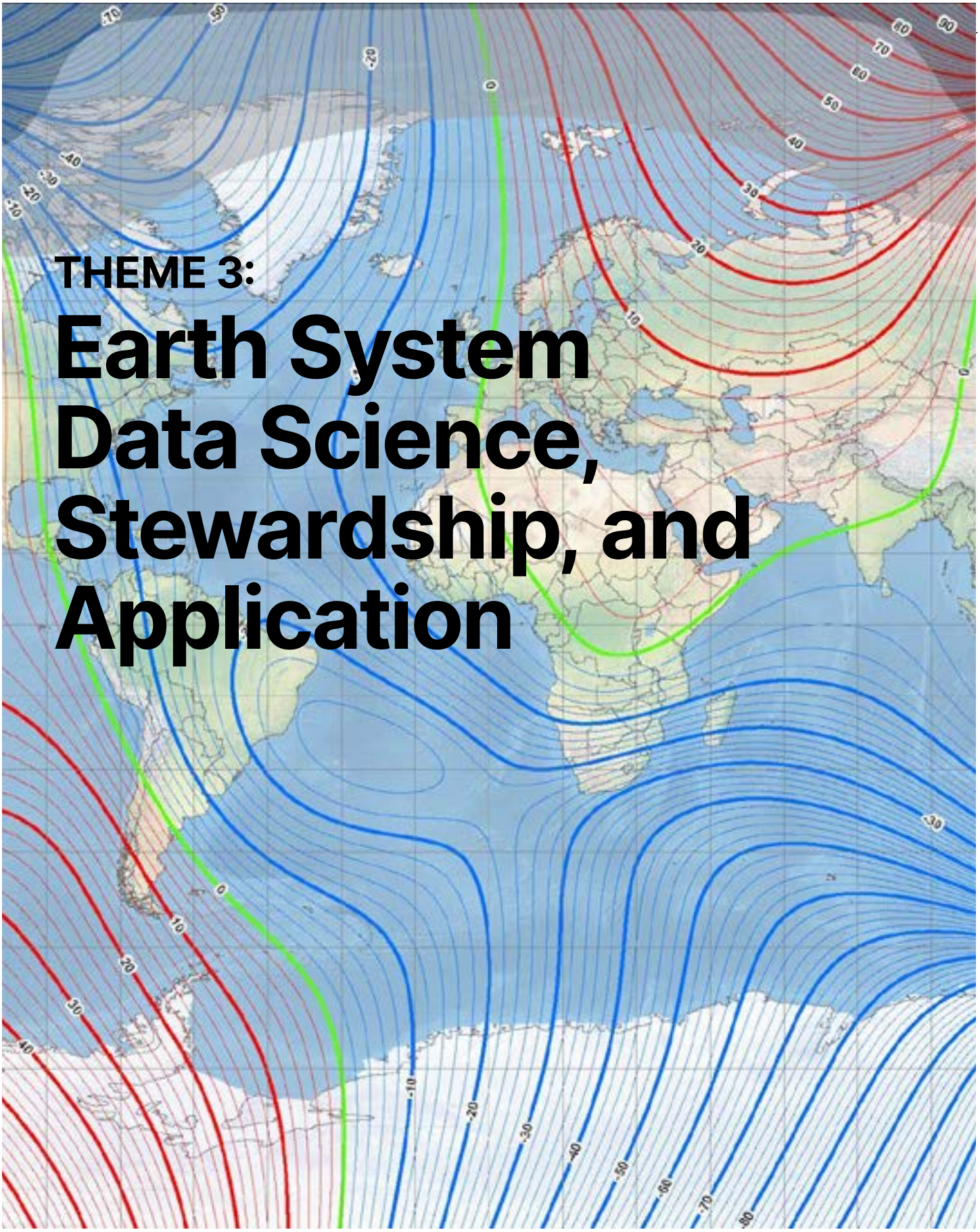
Relevance to NOAA: CarbonTracker provides a global view of the impact of NOAA's greenhouse gas measurements. The model fulfills a vital role in the Global Monitoring Laboratory's observing system by assessing the strengths and weaknesses of the observing network and permitting a more sophisticated analysis of measurement quality than previously available.

CarbonTracker is a modeling and data assimilation system that quantifies how much carbon dioxide is taken up and released at the Earth's surface over time. It works from an atmospheric perspective: carbon dioxide mole fractions measured in the air reflect the combined influence of all natural and human-driven surface exchanges, making them the most complete record of greenhouse gas dynamics. CarbonTracker compares model predictions of atmospheric carbon dioxide with real-world observations, and the differences between them reveal where initial assumptions about sources and sinks—its "first guess"—diverge from reality. Using numerical optimization, the system adjusts surface fluxes until the modeled atmosphere aligns with the observed one, drawing on weather-forecast–driven atmospheric transport and modules representing ocean exchange, terrestrial photosynthesis and respiration, and emissions from fires and fossil fuel combustion.

Developed and maintained by CIESRDS scientists, CarbonTracker has become a widely used tool for carbon cycle science, currently cited in more than 800 publications. Its operational estimates of surface sources and sinks support research on carbon budgets, climate feedbacks, and long-term trends in atmospheric carbon dioxide. Over the next five years, researchers plan to enhance the system with higher-resolution atmospheric transport, an improved state vector for assimilation, and continued operational releases—advances that will sharpen CarbonTracker's ability to diagnose carbon fluxes in a changing climate.



Carbon dioxide concentrations in the free troposphere for June 28, 2015 calculated by CarbonTracker. Warm colors indicate high atmospheric carbon dioxide concentrations, and cool colors indicate low concentrations. As the summer growing season takes hold, photosynthesis by forests and crops draws concentrations ofcarbon dioxide down, opposing the general increase from fossil fuel burning. The resulting high- and low-carbon dioxide air masses are then moved around by weather systems to form the pattern shown here.
Credit: NOAA Global Monitoring Laboratory



THEME 3:

Earth System Data Science, Stewardship, and Application

A CIESRDS team helps develop the World Magnetic Model and its data products, maintains supporting software and online calculators, and researches the use of commercial-satellite magnetometer data.

Credit: https://www.ncei.noaa.gov/products/world-magnetic-model

EARTH SYSTEM DATA SCIENCE, STEWARDSHIP, AND APPLICATION

CIRES has been managing NOAA Earth system data for more than 50 years, using state-of-the-art technologies and products to make data findable, accessible, interoperable, and reusable. CIESRDS scientists have used their significant expertise in building and enhancing software and data ingest pipelines to bring data into NOAA's archive at the National Centers for Environmental Information (NCEI).

They have skilfully collected, organized, distributed, and analyzed datasets from the surface of the Sun to the bottom of the ocean, including tsunami and hazards data, ocean acoustics data, precise geodetic measurements, paleoclimate data, biological data, and worldwide geomagnetic, solar, and ionospheric measurements.

A key accomplishment in this realm is the analysis and archive of seafloor topography maps. CIESRDS scientists led the analysis of more than 3 million square kilometers of seafloor data that helped the U.S. Department of State determine the outer limits of the U.S. Extended Continental Shelf. This work granted the United States sovereign rights over a million square kilometers of additional seafloor.

CIESRDS scientists also analyze and improve geomagnetic reference field models that improve health and safety in directional drilling operations and safer navigation for airplanes, ships, and satellites. They have developed high-resolution magnetic anomaly maps to support Department of Defense research into magnetic navigation and developed the 2025 High-Definition Geomagnetic Model for use by the oil and gas industry for directional drilling.

CIESRDS scientists also steward water column sonar and passive acoustic data that support fisheries stock assessments and endangered species monitoring.

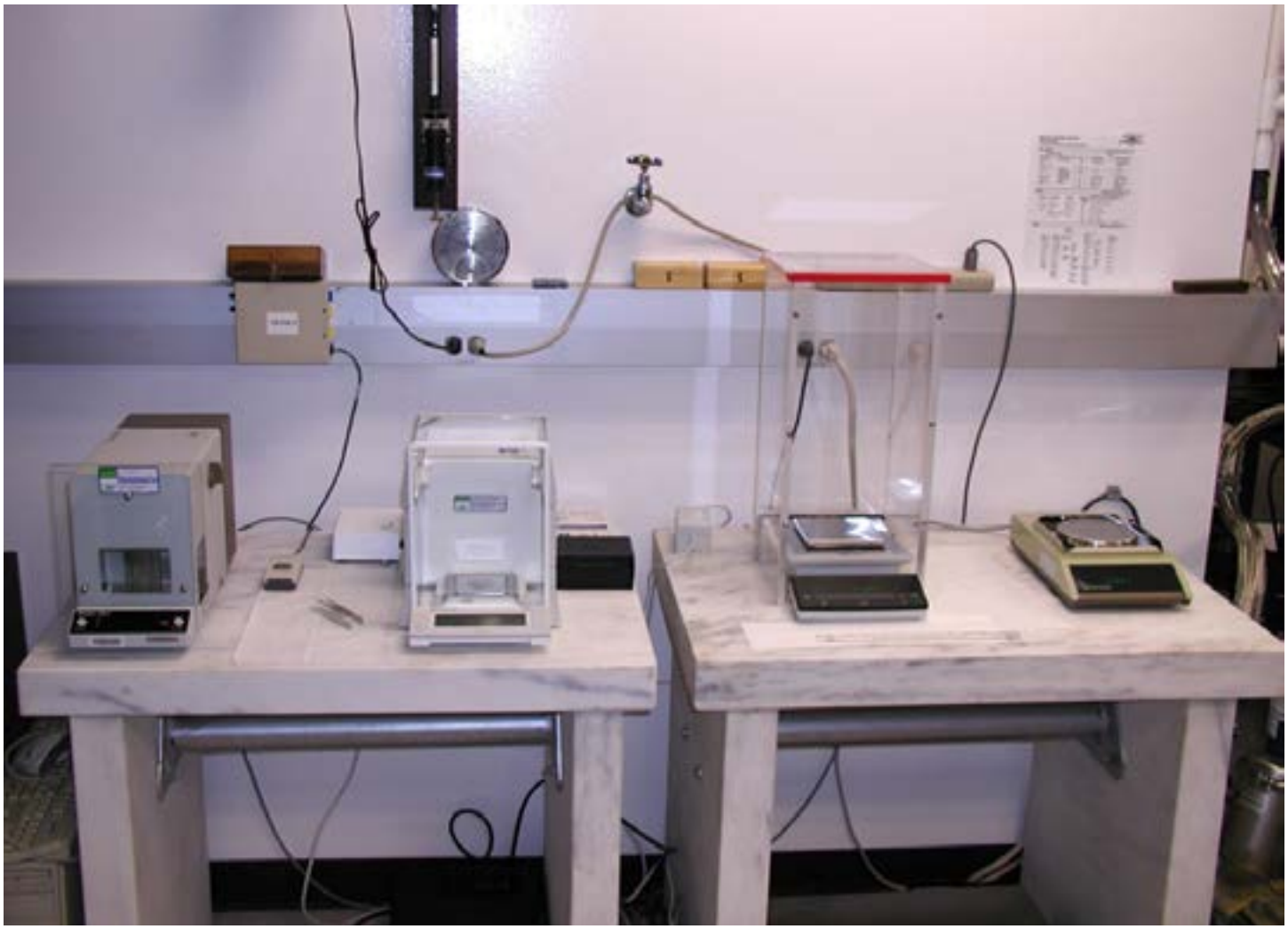
Project: Preparing whole air gas standards for the scientific community

CIESRDS contributors: Andrew Crotwell, Stephen Devogel

Relevance to NOAA: Whole air gas standards prepared by CIESRDS scientists are critical for ensuring accurate measurements of atmospheric componentsin NOAA laboratories and the broader scientific community.

CIESRDS scientists in the NOAA Global Monitoring Laboratory Central Calibration Laboratory (CCL) prepare and calibrate whole-air gas standards for end users in the scientific community, including NOAA's Air Resources Laboratory, Pacific Marine Environmental Laboratory, and the National Institute of Standards and Technology. Whole air gas standards are precisely defined mixtures of gases used for calibrating analytical instruments. These standards are critical for ensuring accurate measurements of atmospheric components.

The CCL provides high-precision reference gas mixtures, carries out primary scale validations, and supports global networks in achieving measurement consistency and accuracy. Since 2019, CCL has updated the carbon dioxide calibration scale while working with national and international partners to propagate it across atmospheric laboratories, improving global measurement consistency. Over the next five years, the CCL will update the carbon dioxide manometer system with new hardware and software to support.



Balances used in the preparation of gravimetric standards.
Credit: NOAA GML Central Calibration Laboratory

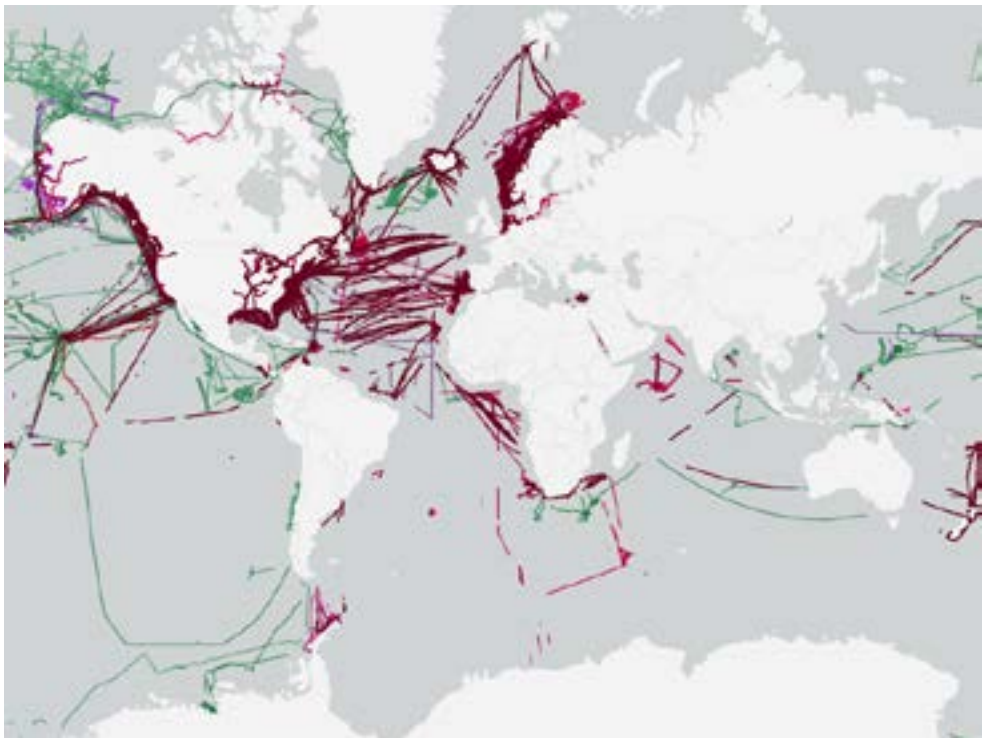
Project: Marine geophysical data archival for improved oceanic and coastal seafloor mapping

CIESRDS contributors: Daniel Alemayehu, Charles Anderson, Atticus Baker, Lila Brodsky, Payton Cain, Clint Campbell, John Cartwright, Peemin Chen, Vidhyadhari Gondle, Tobey Kegley, Rudy Klucik, Kevin Lally, Julia McVeigh, Teodora Mitroi, Jessica Nation, Rachel Peterson, Caitlin Ruby, Jordan Schweizer, Lee Shoemaker, Chris Slater, Max Smith, Jesse Varner, Georgie Zelenak

Relevance to NOAA: The Multibeam Bathymetry Archive provides NOAA and the scientific community an archive for mission-critical bathymetric sonar data. Crowdsourced bathymetry provides NOAA with an archive for bathymetric observations and measurements from participants in citizen science and crowdsourced programs. The Gazetteer is a digital gazetteer of seafloor names and features.

NOAA National Centers for Environmental Information (NCEI) Ocean and Coastal Mapping Archives hold millions of nautical miles of single-beam and multibeam depth data from more than 10,000 cruises spanning more than 100 years. Data are contributed by private industry, governments, academia, research institutions, and crowdsourcing efforts. These data feed comprehensive bathymetric charting efforts and support regional, national, and global mapping.

Since 2022, a new multibeam data ingest pipeline developed at CIESRDS more than doubled data ingest rates compared to the previous four years, and the crowdsourced bathymetry initiative saw a 61 percent increase in submissions, with eight new contributors including Carnival Cruise Lines. NOAA's Office of Marine and Aviation Operations Data Rescue Project, spearheaded by CIESRDS, resulted in more than 80 terabytes of at-risk marine geophysical data archived at NCEI. CIESRDS scientists also led data access and stewardship capacity-building workshops at national and international seafloor mapping meetings. Over the next five years, the researchers will modernize archive pipelines to eliminate backlogs and work across NOAA cloud infrastructure while incorporating new data. They will establish NOAA ocean imagery guidelines covering AI-ready data and annotation standards, strengthen global capacity development through expanded outreach to promote international data exchange and technical collaboration, and improve sharing interface for data managers and contributors to summarize the status of the crowdsource bathymetry archive.



15.4 TB of multibeam bathymetry (green and purple) and 985 million points of crowdsourced bathymetry (maroon and pink) data have been published to the NCEI Bathymetry Archive since September 2022.
Credit: NOAA NCEI

Project: Stewarding ocean acoustics data for the scientific community

CIESRDS contributors: Charles Anderson, Emilie Barbattini, Payton Cain, Quincy Cantu, Gabrielle Dorsey, Julia Kirk, Rudy Klucik, Elizabeth Jimenez, David La, Paglia Clinton Lohr, Veronica Martinez, Rory O'Flynn, Jesse Varner, Carrie Wall Bell

Relevance to NOAA: The ocean acoustics data program provides NOAA and the scientific community the ability to archive their NOAA mission-critical passive acoustic and water column sonar data supporting NOAA Fisheries initiatives.

CIESRDS scientists in NOAA's National Center for Environmental Information (NCEI) Ocean Acoustic Archives steward water column sonar and passive acoustic data that support fisheries stock assessments and endangered species monitoring.

Since 2022, the researchers have grown ocean acoustic archives by about 700 terabytes. Since June 2023, free cloud-based access resulted in data downloads totaling 1.85 petabytes of sonar and 1.59 petabytes of passive acoustic data. The team developed a new workflow to transfer metadata and data from the NOAA cloud directly into archive pipelines. They also developed a method to convert complex sonar files into analysis-ready, cloud-optimized format powering EchoFish, a web-hosted platform for large-scale sonar visualization, and AI and machine learning analyses to extract clusters from fish schools. Over the next five years, the team plans to archive pipelines to eliminate backlogs, work across NOAA cloud infrastructure to archive over one petabyte of data, and incorporate new sensors and partners. The team will also complete machine learning analyses on sonar data, working in collaboration with national scale NOAA Fisheries initiatives.

Growth of the Ocean Acoustic Archives from 2013 to 2025.
Credit: NOAA NCEI

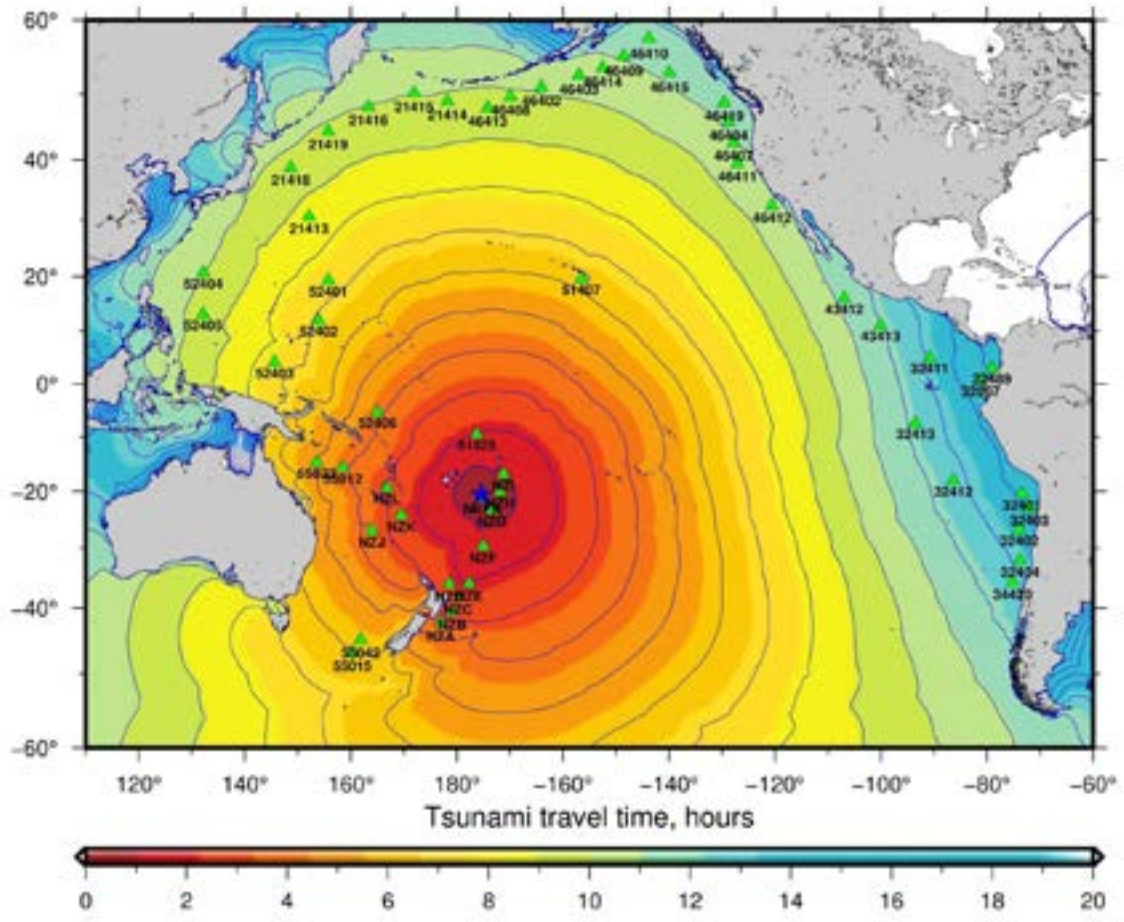
Project: Enhancing coastal data services, integration, and modeling for natural hazard preparation

CIESRDS contributors: Kelly Carignan, Elliot Lim, Lindsey Wright, George Mungov, Aaron Sweeney, Matt Love, Chris Amante, Michael MacFerrin, Jesse Varner

Relevance to NOAA: These products and services are the authoritative resource for data and applications related to coastal hazards (e.g., historical tsunami databases, coastal tide gauge data, deep ocean data) and products generated to help NOAA plan, prepare for, and better understand ocean and coastal processes and their impact on the environment, economies, and societies.

This project develops new data processing algorithms and products for more accurate assessments of coastal hazards, vulnerability, and community risk. CIESRDS researchers develop seamless, high-resolution, integrated bathymetric-topographic digital elevation models to improve the accuracy of coastal inundation modeling; develop and expand historical hazard-event databases, including tsunami deposit databases, raw and processed coastal tide gauge databases, and raw and processed Deep-ocean Assessment and Reporting of Tsunami (DART) buoy databases that improve understanding of past events and future risk; and develop enhanced processing algorithms that will refine tsunami detection in coastal and open-ocean areas, thus improving real-time tsunami forecasts.

These products support coastal resilience and strengthen national and international partnerships to mitigate natural hazards. Over the past five years, the team has produced an Authoritative Event Report for the 2022 Hunga Tonga eruption event; archived high-resolution water level data from NOAA Center for Operational Oceanographic Products and Services and National Tsunami Warning Center tide gauge stations along with DART data; and produced new high-resolution digital elevation models for communities spanning Alaska, the Pacific Northwest, Central California, and the Northern Mariana Islands.



DART stations (green triangles) and theoretical tsunami (long wave) travel time (TTT) map. The contour intervals for the TTT is 1 hour. Blue star represents the location of Hunga Tonga - Hunga Ha'apai volcano.
Credit: Gusman, A.R. and Roger, J., GNS Science

Project: Determining the outer limits of the U.S. Extended Continental Shelf

CIESRDS contributors: Finn Dahl, Barry Eakins, Erin Levre, Elliot Lim, Rick Saltus, Jesse Varner, Chris Slater

Relevance to NOAA: This project defines the limits of U.S. sovereignty and identifies areas of the seafloor the United States now has the rights to conserve, explore, and manage. This work directly serves NOAA's mission to conserve and manage coastal and marine ecosystems and resources.

CIESRDS researchers on this project supported the U.S. Extended Continental Shelf (ECS) Project, led by the Department of State. The project's goal was to establish the full extent of the United States extended continental shelf area: the extension of a country's land territory extending beyond 200 nautical miles from its coastlines.

Over the course of the project, NOAA mapped more than three million square kilometers of seafloor in U.S. coastal areas. With their expertise in marine geophysics, data management, GIS, and cartography, CIESRDS researchers on this project led the effort to analyze the data collected. The monumental task involved evaluating all three million square kilometers of newly mapped seafloor, interpreting the geologic features in certain key areas, and managing and archiving the gigantic amount of data produced.

As a result of this effort, the United States released the geographic coordinates defining the outer limits of its ECS in December 2023, giving the United States sovereignty over a million square kilometers of additional seafloor. This landmark release marked over 20 years of interagency collaboration. Over the next five years, CIESRDS experts will provide technical and analytical support for U.S. maritime boundary negotiations while preserving ECS-related data by migrating legacy files into standardized archival formats.

Map of the U.S. Extended Continental Shelf regions as defined by the ECS project.
Credit: U.S. Department of State

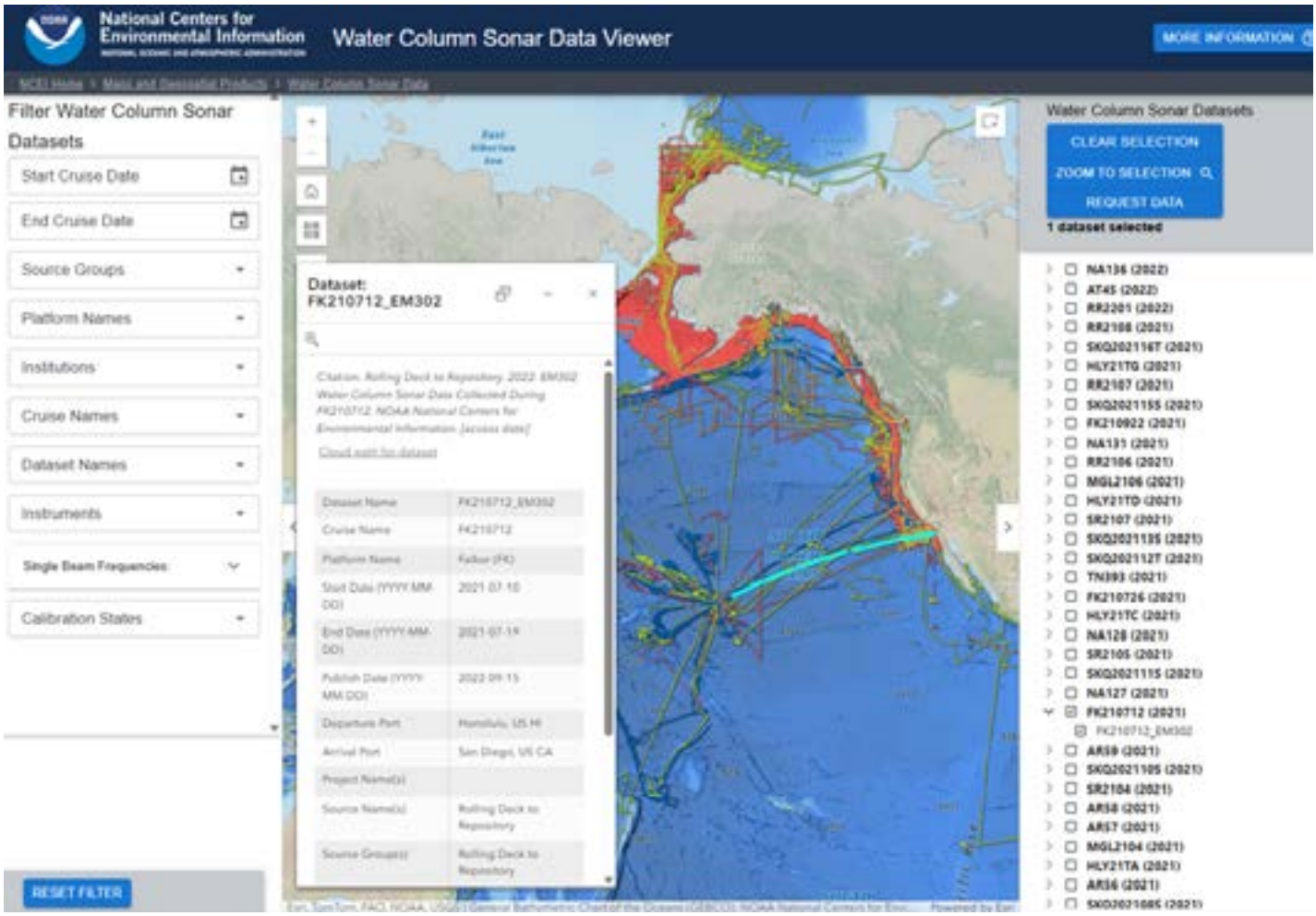
Project: Developing map viewers and other web tools for visualizing NOAA mission-critical data

CIESRDS contributors: Matt Bochain, Payton Cain, Peemin Chen, Rudy Klucik, Chris Slater, Jesse Varner, Clint Campbell, Quincy Cantu, Clinton Lohr, Vidhyadhari Gondle, Rachel Peterson, Max Smith, Finn Dahl

Relevance to NOAA: This project enhances public access to NOAA mission-critical data through map viewers that enable discovery, access, and visualization of archived datasets.

This project team develops map viewers and web tools for visualizing NOAA data. Over the past five years, the team has modernized nine interactive map viewers for NOAA data and migrated them to the NOAA GeoPlatform, improving performance, usability, and long-term maintenance of these sites. The researchers also built a new web service that tracks the real-time location of NOAA's Office of Ocean Exploration and Research vessel along with its remotely operated vehicle.

They also developed a workflow that cost-effectively applies quality control for NOAA's World Ocean Database. The team modernized the GEBCO Gazetteer, the authoritative global registry of undersea feature names. Over the next five years, they plan to support NOAA's National Center for Environmental Information's (NCEI) cloud migration of data to improve scalability and long-term stewardship. They will also launch the cloud-based Argo Global Data Assembly Center to strengthen global ocean observing data interoperability.



Modernized NCEI Water Column Sonar Data Viewer.
Credit: NOAA NCEI

Project: Monitoring Antarctic stratospheric ozone recovery

CIESRDS contributors: Irina Petropavlovskikh, Glen McConville, Chance Sterling

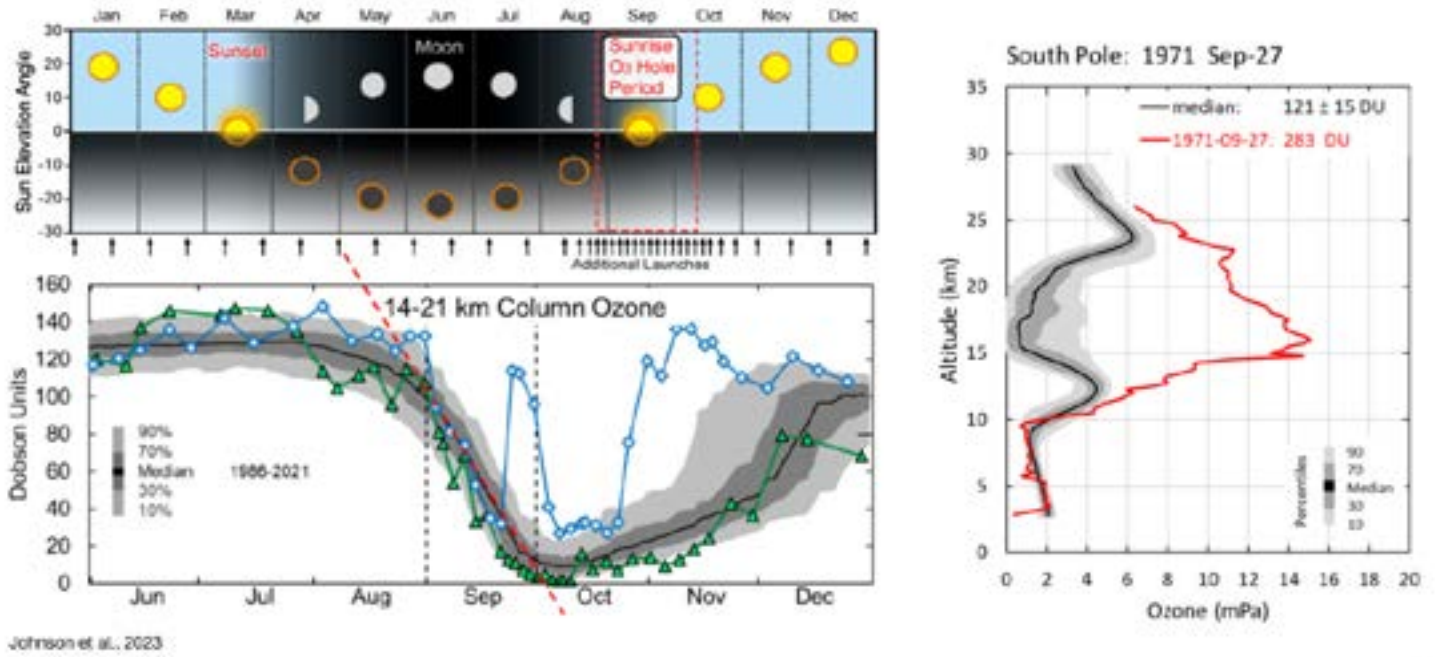
Relevance to NOAA: Monitoring recovery of the Antarctic ozone layer, which blocks harmful UV for people and ecosystems. The uninterrupted 40-year South Pole ozonesonde record and future balloon-borne measurements provide unique and vital data for ozone hole analyses.

Monitoring the recovery of the Antarctic ozone layer is a congressionally mandated responsibility, and NOAA's Global Monitoring Laboratory plays a central role in fulfilling it. Each year during the austral spring, balloon-borne and ground-based instruments at South Pole Station track the onset, evolution, and severity of stratospheric ozone destruction driven by the legacy of chlorofluorocarbons (CFCs) and other ozone-depleting substances. While satellites provide valuable global context, their coverage is limited directly over the South Pole—precisely where the ozone hole is centered—making in situ observations indispensable. Dobson spectrophotometer measurements offer long-term total column ozone records, but they are unavailable during the austral fall and, critically, during the spring period of rapid ozone loss. To fill this gap, NOAA has maintained a continuous record of balloon-borne ozonesonde launches from 1986 to 2021, providing high-vertical-resolution profiles of ozone and temperature from the surface to roughly 30–35 km. Launch frequency increases in late winter to capture the onset of chemical ozone destruction in September.

This 36-year ozonesonde record shows clear signs of long-term ozone hole improvement. Metrics such as annual minimum total column ozone, minimum partial column ozone in the 14 to 21 kilometer layer, and September ozone loss rates have all become less severe since around 2001, consistent with expectations from the Montreal Protocol and its amendments.

Ensuring the accuracy of this long-term record requires rigorous validation. Ongoing comparisons between ozonesonde-derived total column ozone and measurements from the South Pole Dobson spectrophotometer confirm a small, well-characterized bias: ozonesondes read approximately 2 ± 3% higher than the Dobson instrument following a comprehensive homogenization of the dataset completed in 2018. This consistency strengthens confidence in the long-term trends and year-to-year variability derived from the ozonesonde record. To further disentangle the chemical and dynamical drivers of low-ozone events, some balloon payloads now include additional sensors for aerosol and water vapor—two factors that strongly influence ozone loss chemistry and stratospheric radiative balance.

Together, these sustained observations form the backbone of the nation's effort to track Antarctic ozone recovery. They provide the high-quality, long-term data needed to evaluate the effectiveness of international policy, understand the evolving behavior of the polar stratosphere in a warming climate, and ensure continued protection from harmful ultraviolet radiation for people and ecosystems.



Stratospheric zone concentration changes throughout the year, relative to 1971, prior to the formation of the Antarctic ozone hole.
Credit: Bryan Johnson/NOAA GML

Project: Quantifying global stratospheric ozone trends

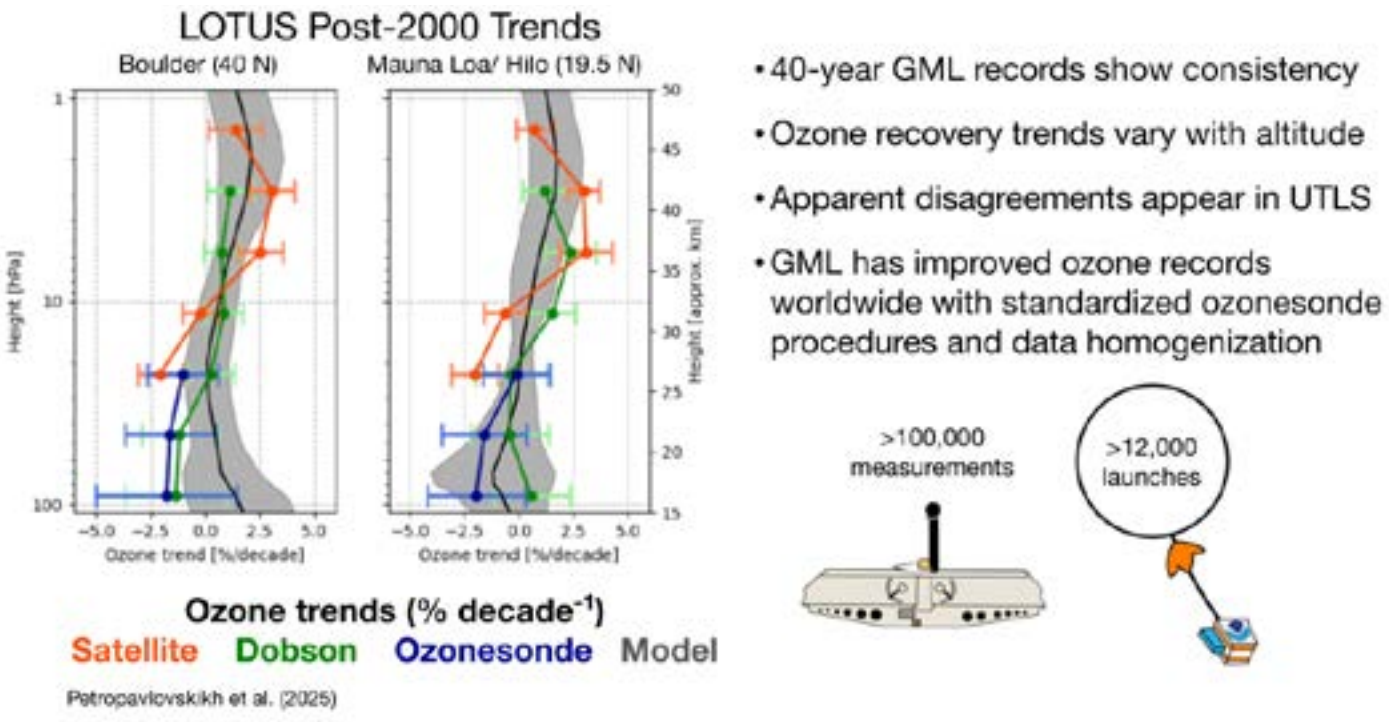
CIESRDS contributors: Irina Petropavlovskikh, Peter Effertz, Glen McConville

Relevance to NOAA: This is the first project in the United States to install trace gas measurements on a domestic carrier and will allow NOAA to collect atmospheric composition measurementswithout using NOAA aircraft..

CIESRDS scientists analyze more than 40 years of NOAA GML ozone profile records, a task that is essential for ensuring the consistency, stability, and scientific value of one of the longest continuous stratospheric ozone datasets in the world. The long-term record, derived from four NOAA Dobson spectrophotometers, was recently reprocessed following updates to instrument calibration procedures. This effort also included the development of a new quality-control tool within the Dobson automation software (WinDobson), enabling more rigorous screening and improved reliability of the retrieved ozone profiles. Because the record is composed of multiple instruments with different optical characteristics, instrument-specific stray light effects can introduce step changes and biases over time. Evaluating and correcting these discontinuities is central to maintaining a homogeneous, climate-quality dataset.

A key component of this work is the identification and correction of instrumental step changes in the record. The Modern-Era Retrospective analysis for Research and Applications version 2 (MERRA-2) Global Modeling Initiative (M2GMI) and the NASA Global Modeling Initiative chemistry transport model (GMI CTM) were used to evaluate the timing and magnitude of these discontinuities by matching model output to station location and observation dates. This approach provides an independent reference for diagnosing calibration-related artifacts and for guiding the homogenization of the long-term record. The resulting method corrects biases and discontinuities arising from Dobson calibration updates, repairs, or optical realignments, producing a more stable and internally consistent ozone profile dataset.

Homogenization of ground-based ozone records is critical for quantifying long-term stratospheric ozone trends and for understanding how ozone is responding to declining ozone-depleting substances and a changing climate. By improving the consistency of the record and strengthening agreement with satellite and model datasets, this work enhances confidence in trend assessments and helps clarify the sources of discrepancies across observing systems.



Agreement between models, satellites, sondes and Dobson observations at two NOAA GML measurement sites: Boulder, Colorado and Mauna Loa, Hawaii. UTLS refers to the upper troposphere and lower stratosphere. LOTUS stands for Long-term Ozone Trends and Uncertainties in the Stratosphere.

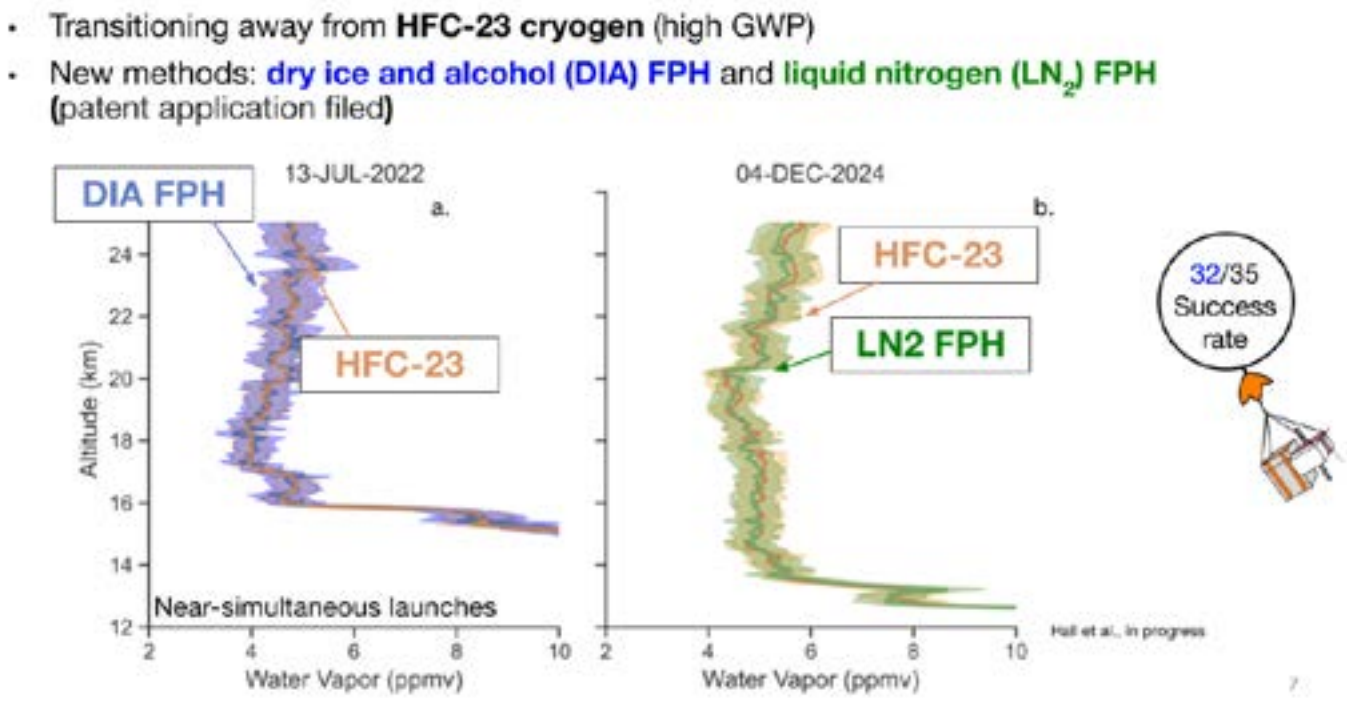
Credit: Irina Petropavlovskikh/CIESRDS

Project: Developing new frost point hygrometer technology

CIESRDS contributors: Emrys Hall, Dale Hurst, Alex Fritz, Elizabeth Asher

Relevance to NOAA: This project helps NOAA comply with the Kigali Amendment of the Montreal Protocol by developing atmospheric observing instruments that use alternative cryogens instead of the potent greenhouse gas HFC-23.

Frost point hygrometers collect profiles of atmospheric water vapor. In compliance with the Kigali Amendment of the Montreal Protocol, the researcherst developed balloon-borne frost point hygrometer instruments that use dry ice and alcohol or liquid nitrogen as the cryogen instead of HFC-23, a powerful greenhouse gas. Since September 2022, the team members filed a patent and have nearly completed the transition to alternative cryogen FPH instruments. Over the next five years, researchers will complete the transition away from HFC-23 entirely and transition this instrument from research to operations.



This graph shows data collected by HFC-23 frost point instruments and alternative cryogen frost point instruments, showing the alternative cryogen instruments perform just as well as traditional HFC-23 instruments. Credit: NOAA GML

Project: Modernizing the Science on a Sphere® software ecosystem

CIESRDS contributors: Adrian Chase, Alex Kirst, Beth Russell Wehe, Hilary Peddicord, Sung-Chu Liao, Shilpi Gupta

Relevance to NOAA: Maintaining and upgrading software ensures long-term sustainability of Science on a Sphere® and provides user-focused improvements. Distributing SOSx as a free app expands our educational reach to teachers and the general public.

NOAA's Science on a Sphere® (SOS) software has been operational since 2004, and to keep up with changing technology and innovation, this team continues to modernize and enhance the SOS and SOS Explorer (SOSx) platforms. SOS is a room-sized, global display system that projects visualizations of planetary data onto a six-foot-diameter sphere. Since 2022, the team has migrated legacy on-premises servers and data to the cloud while delivering 21 releases with updates and new features. They also released SOSx as a free download via a professional-grade Windows installer. Looking ahead, the team plans to rewrite SOSx software and the SOS kiosk with AI integration. They will modernize the SOS data catalog, add agentic AI for presentation assistance, and explore LED spheres.

A docent presents Science On a Sphere® to visitors.
Credit: Will Von Dauster/NOAA GSL

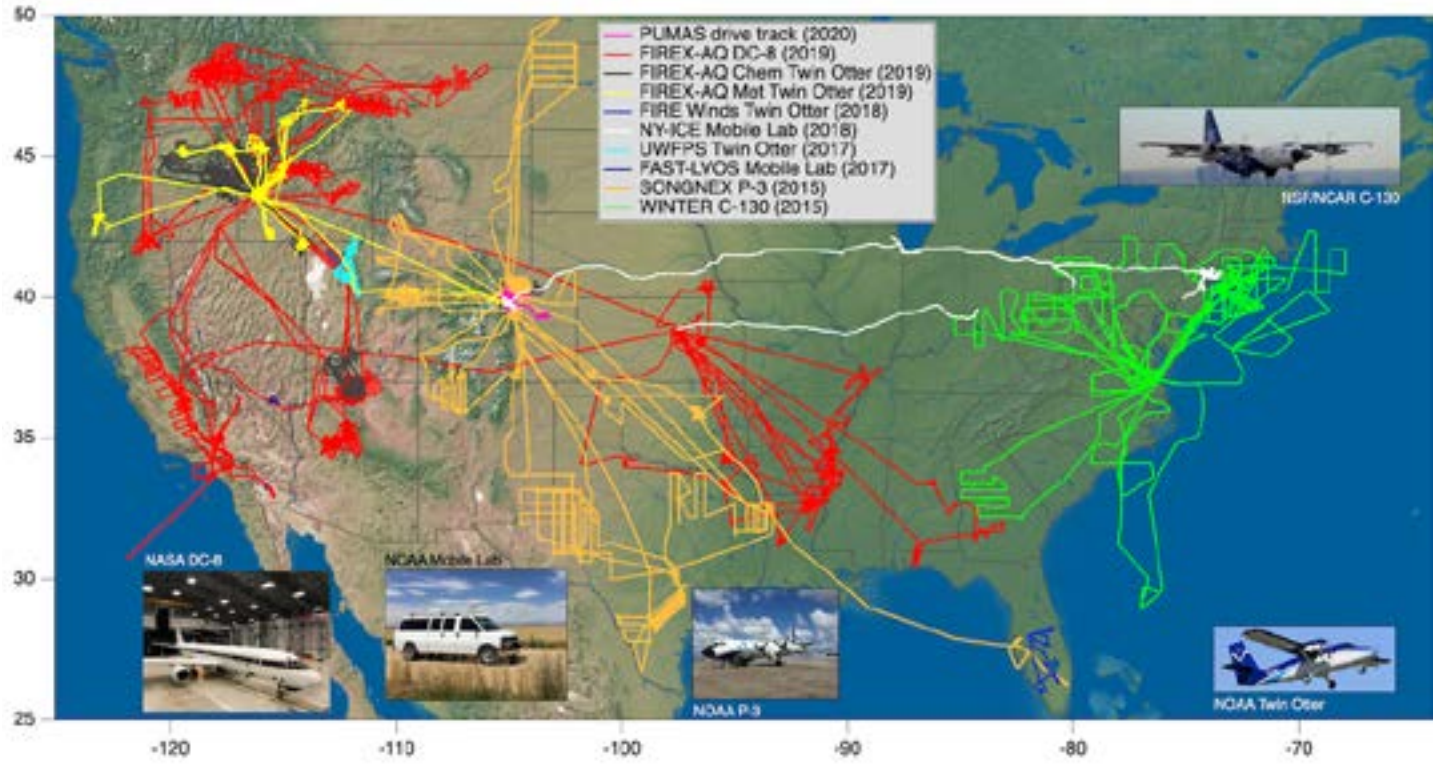
Project: Maintaining Chemical Sciences Laboratory (CSL) field campaign websites

CIESRDS contributors: Cathy Bergorf Rasco

Relevance to NOAA: This project supports NOAA scientific priorities by publishing research from 'beginning to end'

Field campaigns are an essential part of the CSL science portfolio; the size and scope of lab's field campaigns sets CSL apart from other labs. Maintaining CSL field campaign websites allows NOAA, partners, and the public to view all past and planned future CSL field campaigns, giving them a clear picture of the lab's research activities over time and NOAA's research priorities in the field of atmospheric chemsitry and composition. The sites also allow users to understand the needs of U.S. cities, states, and communities that ask CSL to collect crucial air quality data for them.

Over the past five years, this project has used field campaign websites to house data, findings, and publications. Looking ahead, the websites will showcase CSL's engineering needs for instrument deployment for field campaigns. The project will also provide successful IT user support for CSL staff while developing a web presence, maintain the publication internal review and notification process, produce quarterly publication reports, and manage submissions to the NOAA Central Library Internal Repository.



A map of where CSL field campaigns collected data in the United States between 2015 and 2020. During this period, CSL led and participated in 7 aircraft and 3 mobile laboratory field campaigns throughout the United States, addressing research topics covering oil and gas emissions, wintertime air quality, urban air quality, and fire emissions.

Credit: NOAA CSL

Project: Stewarding cryospheric data products

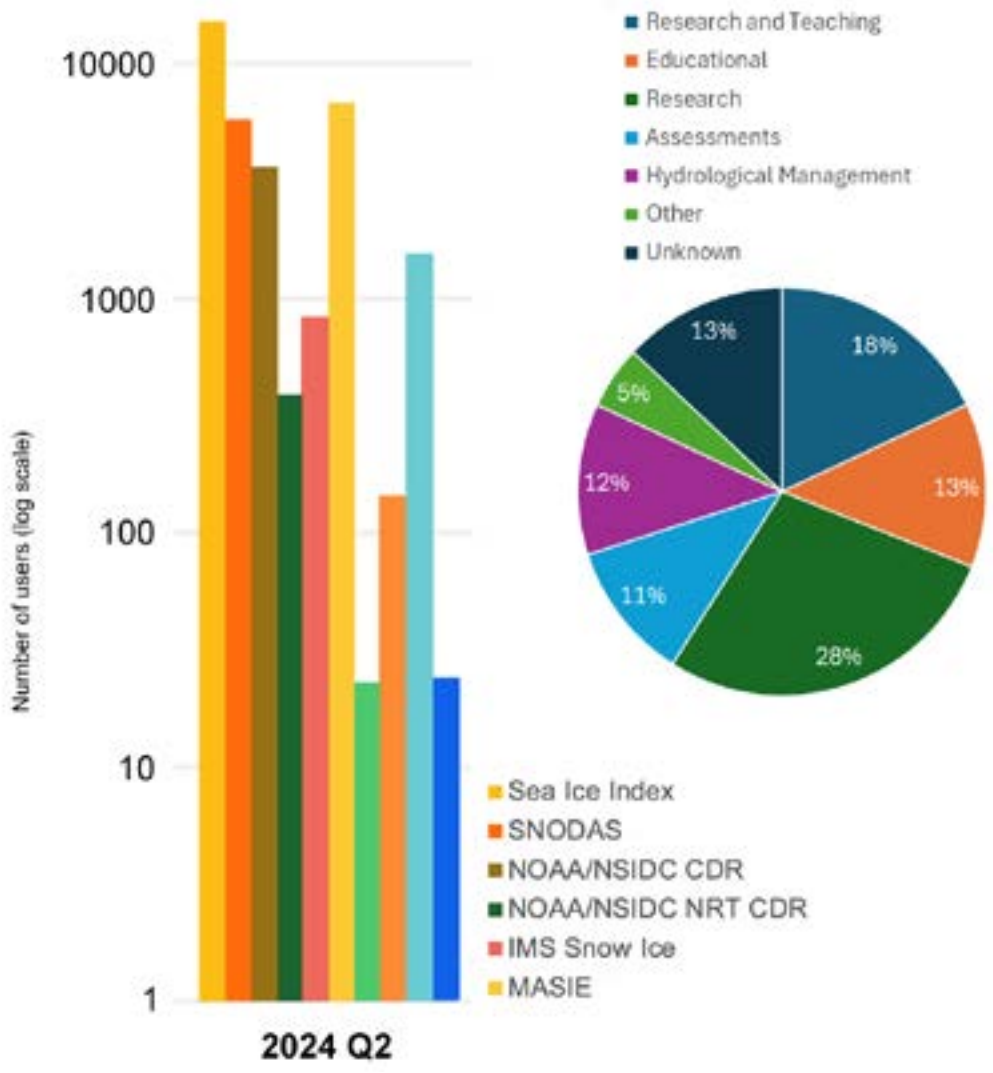
CIESRDS contributors: Ann Windnagel, Florence Fetterer, and Danica Cantarero

Relevance to NOAA: This program supports research that improves weather and ice forecasting and increases accuracy of climate models. The Sea Ice Index, Glacier Photograph Collection, and other user-friendly data increase public awareness.

The NOAA program at the National Snow and Ice Data Center (NOAA@NSIDC) offers free and open-access data about Earth's fast-changing frozen regions. The diverse data include current and historical sea ice conditions, decades-long records of snow extent, historic glacier photographs, atlases assembled through international collaborations, and even declassified Cold War submarine observations of the Arctic. NOAA@NSIDC aims to preserve data over the long term to support current and future research. Data products serve scientists engaged in research, decision-makers planning activities affected by snow and ice, and members of the general public curious about the cryosphere.

The NOAA@NSIDC team advances understanding of the cryosphere by making data useful to a broad spectrum of users. The team does this by documenting data thoroughly, and often by reformatting data into user-friendly formats that support access and sharing, and creation of new data products.

The NOAA@NSIDC collection of over 100 data sets includes rescued data not available elsewhere. Two full time employees manage the data each year. Over the next five years, the team would like to secure funding to maintain the collection, address gaps and quality problems in certain data sets, and improve the flagship Sea Ice Index and sea ice climate data record.



Number of users downloading selected datasets and research sectors of users for Quarter 2 of 2024.
Credit: NOAA@NSIDC

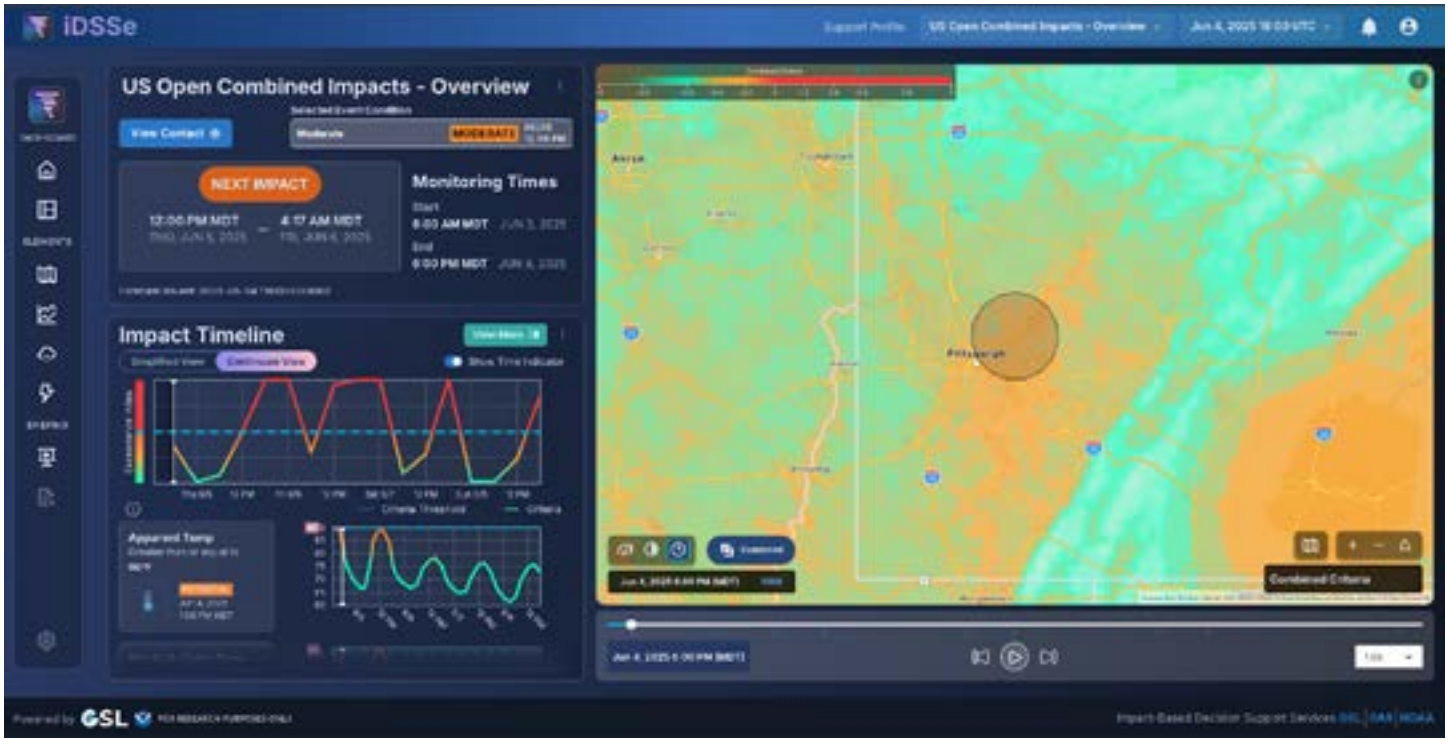
Project: Advancing the future of weather-driven decision support services

CIESRDS contributors: Michael Rabellino

Relevance to NOAA: This project directly supports implementing the National Weather Service's 2023-2033 Strategic Plan to build expertise and tools to increase our capacity to understand, interpret, and communicate risk-based/probabilistic information.

The Impact-Based Decision Support Services (IDSS) Engine is a web-based platform that helps meteorologists deliver tailored, impact-focused weather guidance to decision-makers such as emergency managers, event planners, and transportation officials. The IDSS Engine transforms traditional forecasts into actionable insights by visualizing when, where, and how weather conditions may meet user-defined impact thresholds and displaying their likelihood, duration, and intensity. This personalized approach makes weather information more relevant and effective for real-time decision support in weather-sensitive operations.

Since 2022, the IDSS Engine has been tested at NOAA National Weather Service (NWS) Forecast Offices nationwide in real-world scenarios, including the 2025 U.S. Open. Its datasets now include deterministic and probabilistic forecast information on 17 key weather conditions. The project is advancing toward operational use as a planned Research to Operations (R2O) initiative as part of the NWS's Meteorological Development Laboratory's NWS Connect system at the end of fiscal year 2026. In addition to transitioning to operations, plans include additional forecast datasets and observational and real-time data to enhance analysis and verification capabilities. The project also aims to integrate with Hazard Services for Watches, Warnings, and Advisory information and develop a self-service portal where partners can asynchronously view forecaster-updated, real-time graphics.



The IDSS Engine was used during the U.S. Open to determine whether thunderstorms and high winds would create unsafe conditions for players and attendees.
Credit: NOAA GSL

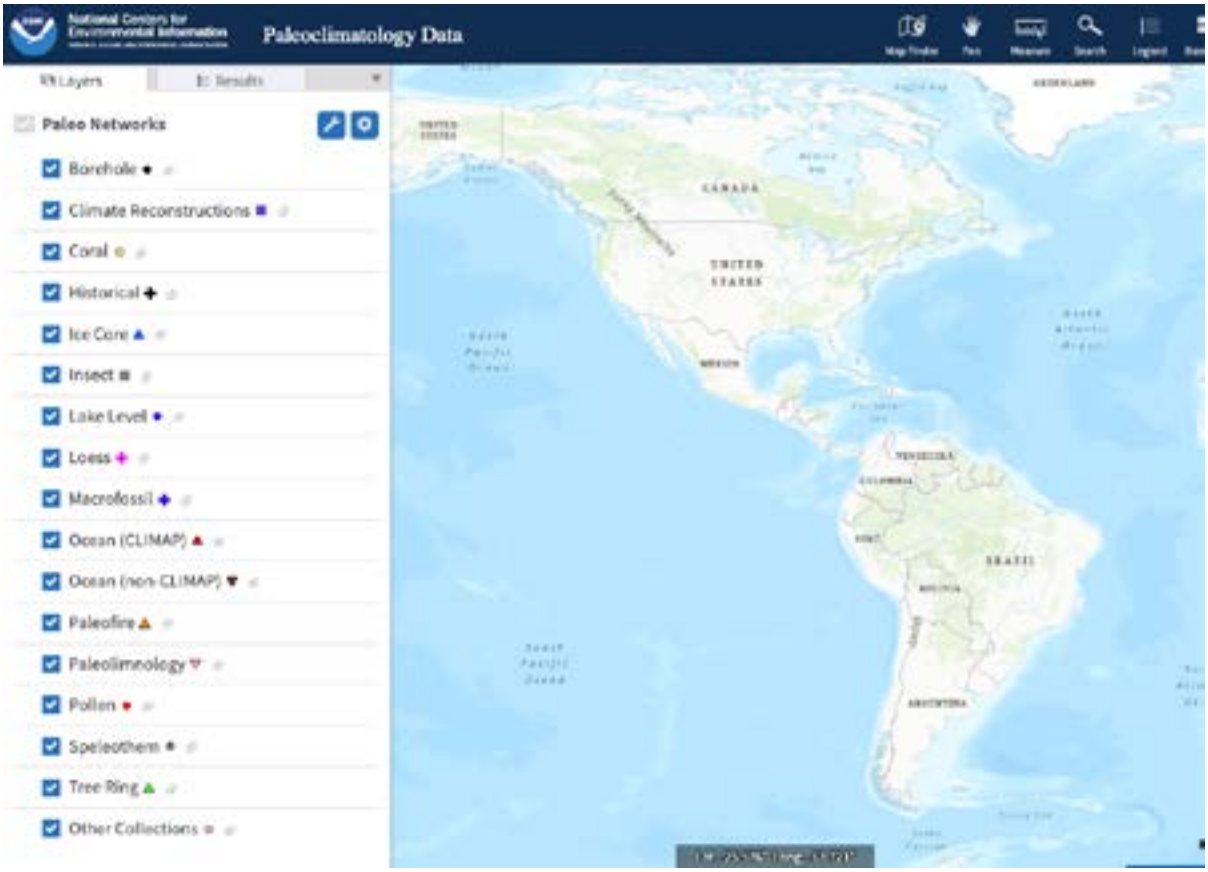
Project: Maintaining the world data service for paleoclimatology

CIESRDS contributors: Christopher Guiterman, Edward Gille, Calie Payne

Relevance to NOAA: This project stewards and preserves the data necessary to understand and model environmental variability prior to instrumental measurements (before 1850). As the only source of this long-term perspective, this information is essential for improving predictions of extreme events and natural variability in weather and climate and putting current events into a historical context.

The project aims to provide reliable, timely, and functional access to paleoenvironmental data developed and contributed by the global research community, while enhancing user experience in discovery and exploration of paleoenvironmental data through product and software development. Researchers maintain field-specific and international standards of data quality and interoperability and are a recognized and certified source for trusted information.

Since 2022, the project has ingested and disseminated 2,290 scientific datasets contributed by global researchers. The program receives on average more than 8,700 data requests per month. The data has empowered more than a dozen high-impact research papers per year appearing in top-tier journals, and the team published a paper on recent dataset improvements. Over the next five years, the program will continue its global recognition as a trusted repository of paleoenvironmental data. The team members will implement a cloud migration, develop new search and explore tools in response to user needs, and develop and update products derived from contributed datasets (e.g., living-blended drought atlas for the conterminous United States).



A screenshot of the NCEI user interface for paleoclimatology data.
Credit: NOAA NCEI

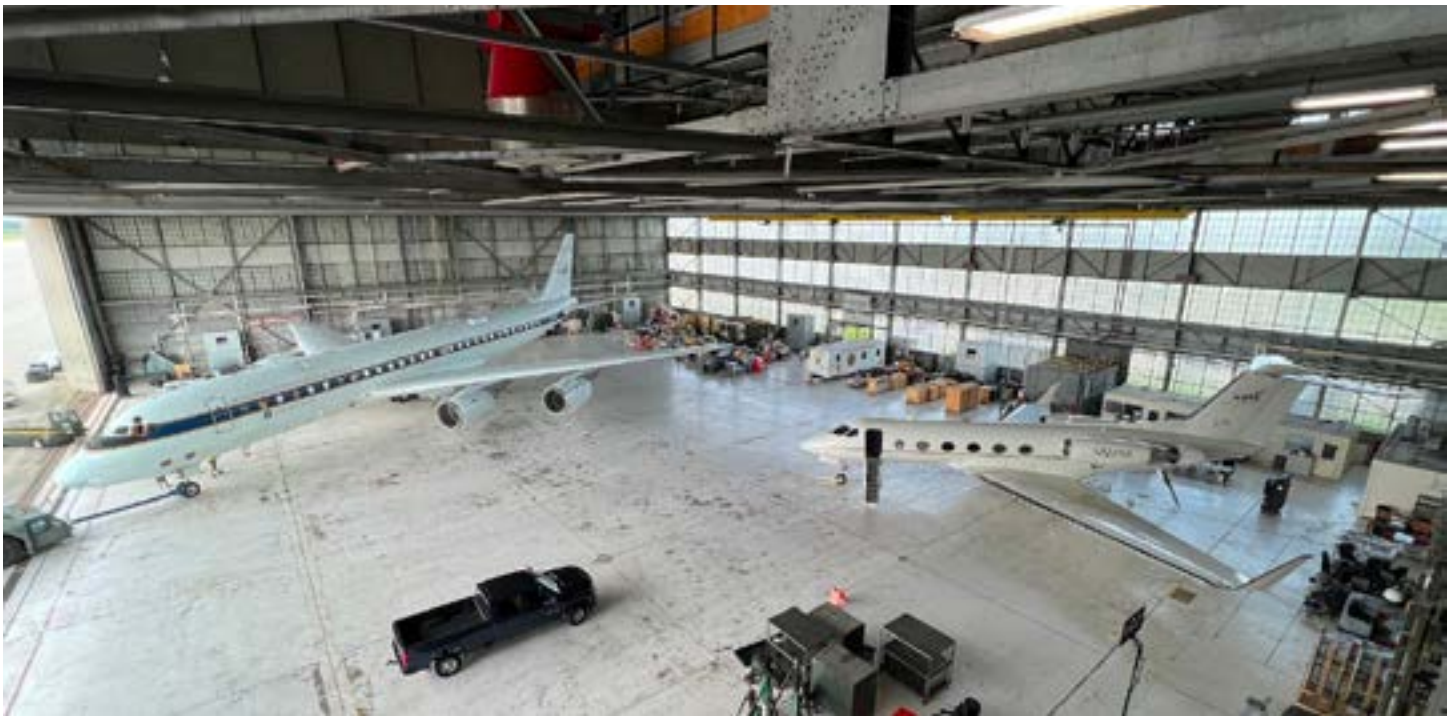
Project: Studying atmospheric emissions and chemistry over U.S. megacities and marine areas

CIESRDS contributors: Colin Gurganus, Eleanor Waxman, Samantha Delone, Georgia Michailoudi

Relevance to NOAA: This project strengthens NOAA's mission by improving the accuracy of satellite-derived air quality products. Enhanced data quality supports better forecasting, emissions tracking, and policy decisions, helping communities reduce exposure to harmful pollutants and improve public health and environmental management across North America.

In 2023, CIESRDS scientists participated in NOAA's Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas (AEROMMA) field campaign, where they deployed four instrument payloads aboard NASA's DC-8 aircraft to investigate key atmospheric emission processes. The mission focused on characterizing the marine sulfur cycle, including measurements of carbonyl sulfide and sulfur dioxide, and quantifying nitrogen emissions from urban and coastal regions. These observations supported validation of the new TEMPO satellite and improved understanding of air quality, atmospheric chemistry, and land-ocean-atmosphere interactions across diverse environments.

Since September 2022, the team has archived four major datasets, advancing observational records of atmospheric composition. The effort has contributed to four co-authored papers under review and two invited talks. A key outcome is the successful validation of TEMPO satellite nitrogen dioxide data over North American megacities, with a manuscript currently in preparation. Over the next five years, the project will focus on continued data analysis, expanded model and remote-sensing validation, and submission of additional publications. Special emphasis will be placed on detailed investigation of the marine sulfur cycle and its role in sulfate aerosol formation, improving understanding of aerosol–cloud interactions and climate-relevant marine processes.



The NASA DC-8 and G-III aircraft in a hangar at Wright-Patterson Air Force Base in Dayton, Ohio. The DC-8 is the world's largest flying chemistry laboratory. CIESRDS and NOAA scientists collected measurements from both aircraft during the 2023 AEROMMA field campaign.

Credit: Jhony Zavaleta/NASA

Project: Leading congressionally mandated national soil moisture efforts

CIESRDS contributors: Elise Osenga, Molly Woloszyn, Jason Gerlich

Relevance to NOAA: This effort supports the National Integrated Drought Information System (NIDIS) Public Law stating that NOAA shall develop a strategy for a national coordinated soil moisture monitoring network.

This project leads the implementation of the National Coordinated Soil Moisture Monitoring Network (NCSMMN), a multi-institutional initiative to integrate soil moisture data from across the country while capitalizing on its transformative potential across sectors of the economy. The project supports soil moisture network expansion, improves forecasts, develops maps and tools, and leads a $1 million data value study for the Upper Missouri Basin.

This project has resulted in two national workshops, a national strategy, two technical memos, and coordination and support of over 100 active community partners, 33 state partner data networks, and a network of over 935 of people. Over the next five years, this effort will continue to implement the NCSMMN strategy. This effort includes a report due in 2027 to Congress as part of the Upper Missouri River Basin Soil Moisture and Plains Snow Data Value Study.

Conceptual diagram for the National Coordinated Soil Moisture Monitoring Network.
Credit: NIDIS/drought.gov

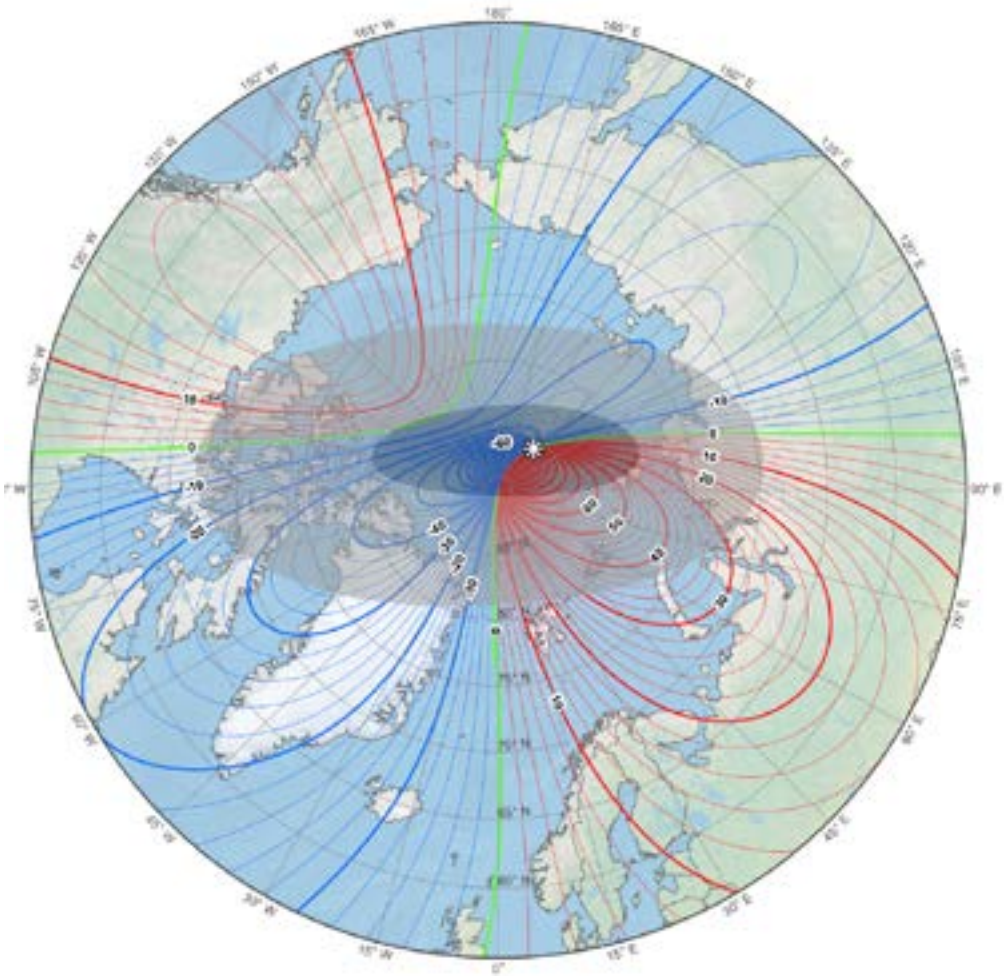
Project: Developing the World Magnetic Model

CIESRDS contributors: Patrick Alken, Nir Boneh, Sam Califf, Arnaud Chulliat, Collin Kadlecek, Liam Kilcommons, Wilson Moyer, Manoj Nair, Jordan Schweizer, Jesse Varner, Lily Young

Relevance to NOAA: The World Magnetic Model, with about 13,000 downloads and 120 million calculator hits since September 2022, is NOAA's widely used geomagnetic reference model. It supports U.S. defense operations, civil aviation, satellite attitude control, consumer electronics, and international organizations, including the North Atlantic Treaty Organization.

The World Magnetic Model (WMM) is the U.S. standard geomagnetic model for navigation and orientation. The tool is jointly produced by the National Geospatial-Intelligence Agency (NGA) and the U.K.'s Defence Geographic Centre, and is co-developed by NCEI and the British Geological Survey. This CIESRDS team develops the model and its data products, maintains supporting software and online calculators, researches the use of commercial-satellite magnetometer data, and supports the NGA-sponsored MagQuest challenge to identify post-swarm satellite data sources.

Since 2022, the team has released the World Magnetic Model 2025 (WMM2025) and a new, higher-resolution version (WMMHR2025) with associated software and a technical report. The researchers published three annual "State of the Geomagnetic Field" reports assessing WMM performance and notable changes in Earth's magnetic field, including pole drifts and the South Atlantic Anomaly. They demonstrated the Iridium satellite constellation as a potential backup data source and supported the MagQuest challenge through site visits, documentation, and project reviews. Over the next five years, the team will evaluate data from three MagQuest Cubesats, monitor the performance of WMM2025 and WMMHR2025 and changes in Earth's magnetic field, develop and release WMM2030 and WMMHR2030, and advance research to improve secular variation forecasts.



The World Magnetic Model 2025 (WMM2025) provides more precise navigational data for all military and civilian planes, ships, submarines, and GPS units. Red contours are positive (east); blue are negative (west); and green are zero (agonic) line.
Credit: NOAA NCEI

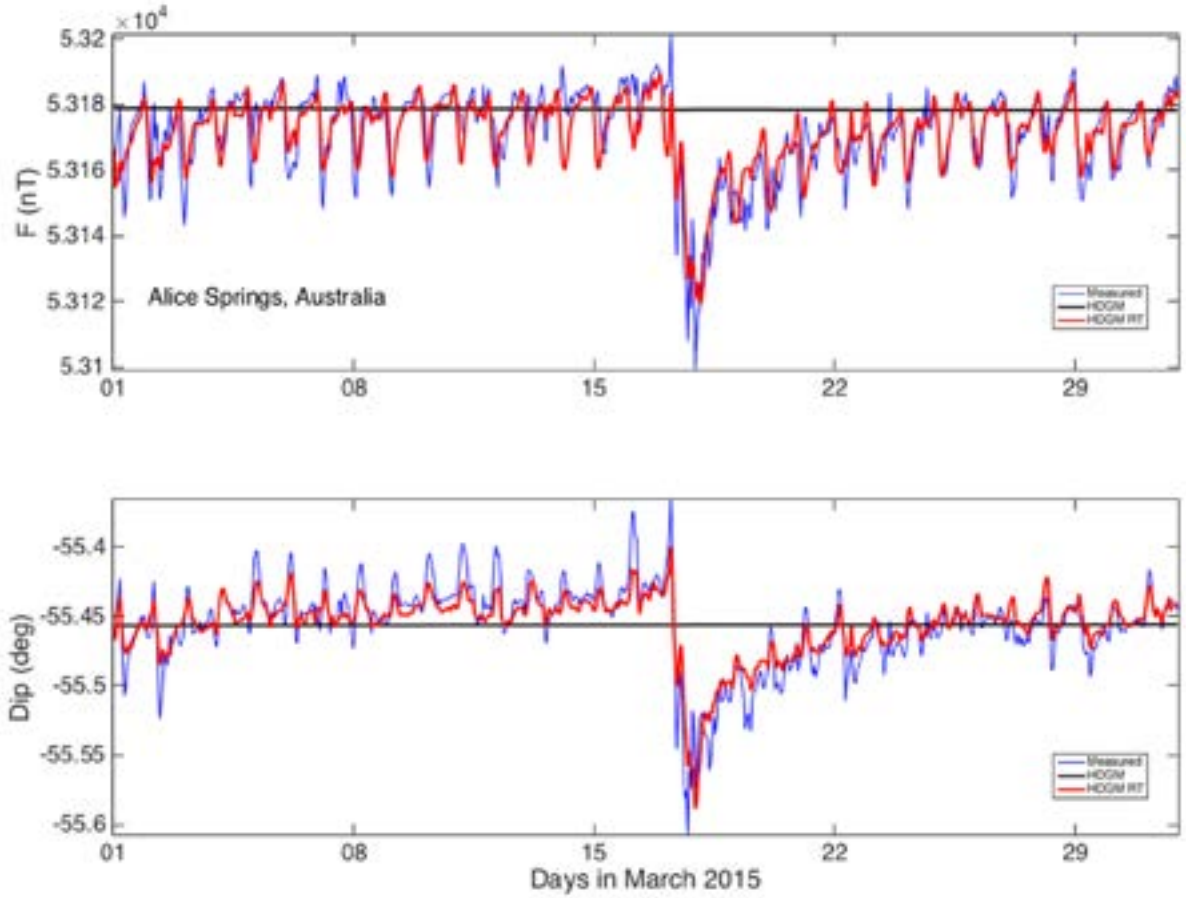
Project: Developing the High-Definition Geomagnetic Model to support directional drilling applications

CIESRDS contributors: Patrick Alken, Nir Boneh, Sam Califf, Arnaud Chulliat, Collin Kadlecek, Liam Kilcommons, Manoj Nair, Rick Saltus, Lily Young

Relevance to NOAA: The High-Definition Geomagnetic Model (HDGM/HDGM-RT) is used by major oilfield services companies to support safe, efficient directional drilling, to enhance national energy security. The team disseminates critical geomagnetic information to engineers and field practitioners through industry collaborations and presentations.

The High-Definition Geomagnetic Model (HDGM) integrates research-grade core, crustal, and external Earth magnetic field models into user-friendly software for directional drilling in oil, gas, and geothermal applications. The satellite-based core field is updated annually. The high-resolution crustal field combines global anomaly grids and satellite models. External fields are modeled globally under all geomagnetic conditions, with a real-time option providing one-hour forecasts of large-scale magnetospheric disturbances.

Since 2022, the team has released four High-Definition Geomagnetic Model (HDGM) and HDGM-RT (real-time add-on) versions. Crustal field resolution increased and the project improved the underlying magnetic anomaly grid. New external field models capture diurnal variations and near-Earth magnetospheric fields. A disturbance forecast methodology developed as part of the MagNet competition was successfully transitioned into operational HDGM-RT. Over the next five years, this team will continue developing and releasing annual HDGM/HDGM-RT updates, and advance crustal field modeling to increase spatial resolution and accuracy, while improving and researching external field models to enhance HDGM-RT reliability during periods of active geomagnetic conditions.



Comparison of HDGM-RT predictions of total field (F) and magnetic inclination (Dip) with observations from the Alice Springs magnetic observatory, Australia, in March 2015.
Credit: NOAA NCEI

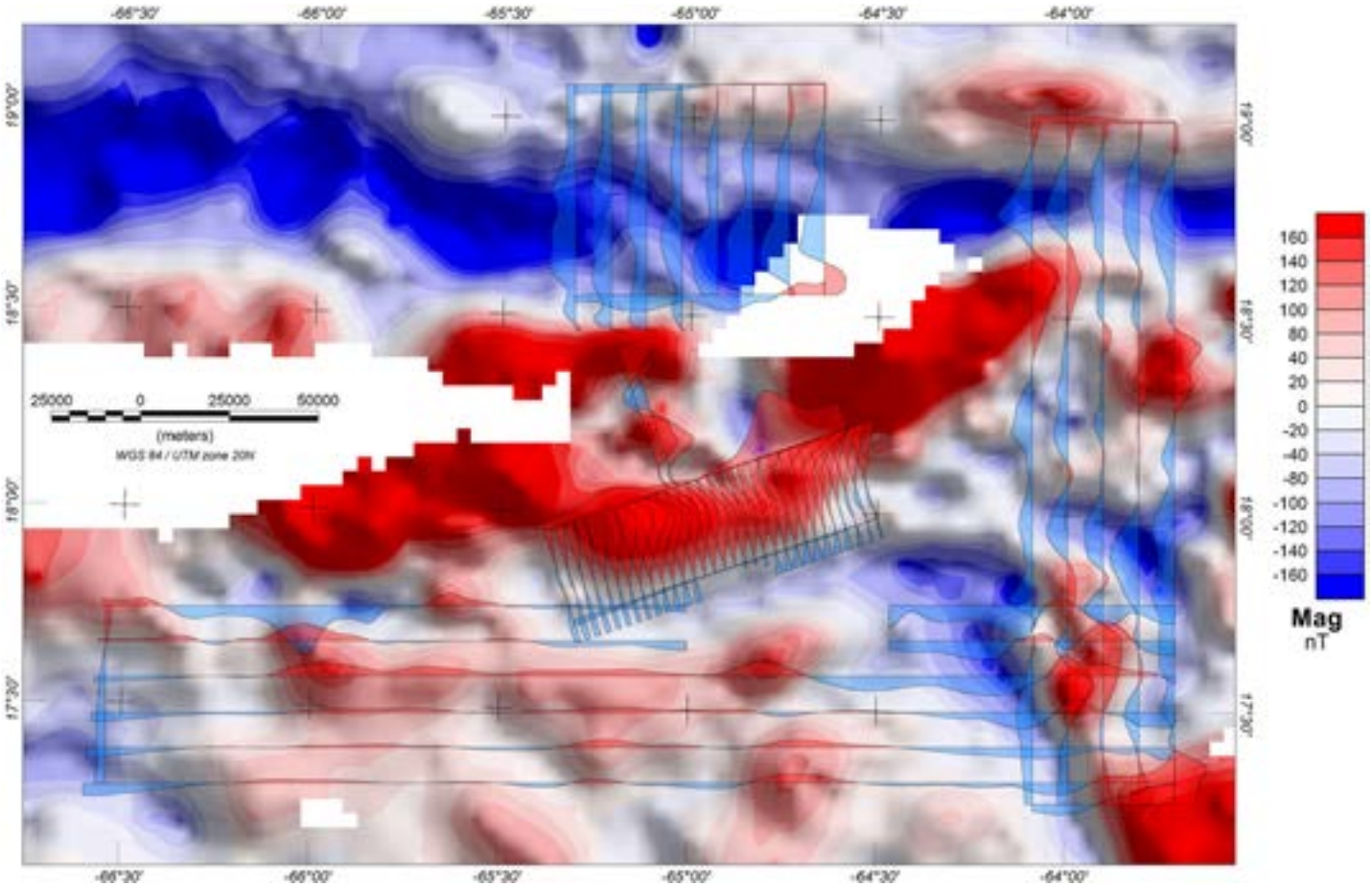
Project: Enabling magnetic navigation (MagNav) through high-resolution magnetic mapping

CIESRDS contributors: Annette Balmes, Nir Boneh, Arnaud Chulliat, Collin Kadlecek, Liam Kilcommons, Manoj Nair, Rick Saltus, Jordan Schweizer, Lily Young

Relevance to NOAA: Magnetic Navigation (MagNav) improves navigation in areas where GPS is unavailable or degraded by providing a GPS-independent positioning solution, thus supporting national security.

Magnetic Navigation (MagNav) is an alternative positioning and navigation technology that operates without GPS by detecting and matching magnetic map patterns using accurate magnetic maps and models derived from space-based and survey data. This team develops dedicated maps, data products (including uncertainty estimates), and software to support MagNav applications for U.S. government agencies. It also explores the use of Very Low-Earth Orbit (VLEO) satellite data for high-resolution crustal field modeling to enhance MagNav performance.

Since 2022, researchers developed and tested a novel method to estimate uncertainties in magnetic anomaly maps derived from marine trackline data by using a dedicated aeromagnetic survey dataset. They then applied this method to produce magnetic maps and uncertainty analyses for multiple regions of interest to U.S. government agencies, developed software to correct magnetic maps, and created a simulation tool to support the assessment of VLEO satellite mission scenarios. Over the next five years, this team will research ways to enhance magnetic maps for Magnetic Navigation in collaboration with MagNav researchers and practitioners in other government agencies. It will also continue investigating the use of VLEO satellite data in geomagnetic field modeling.



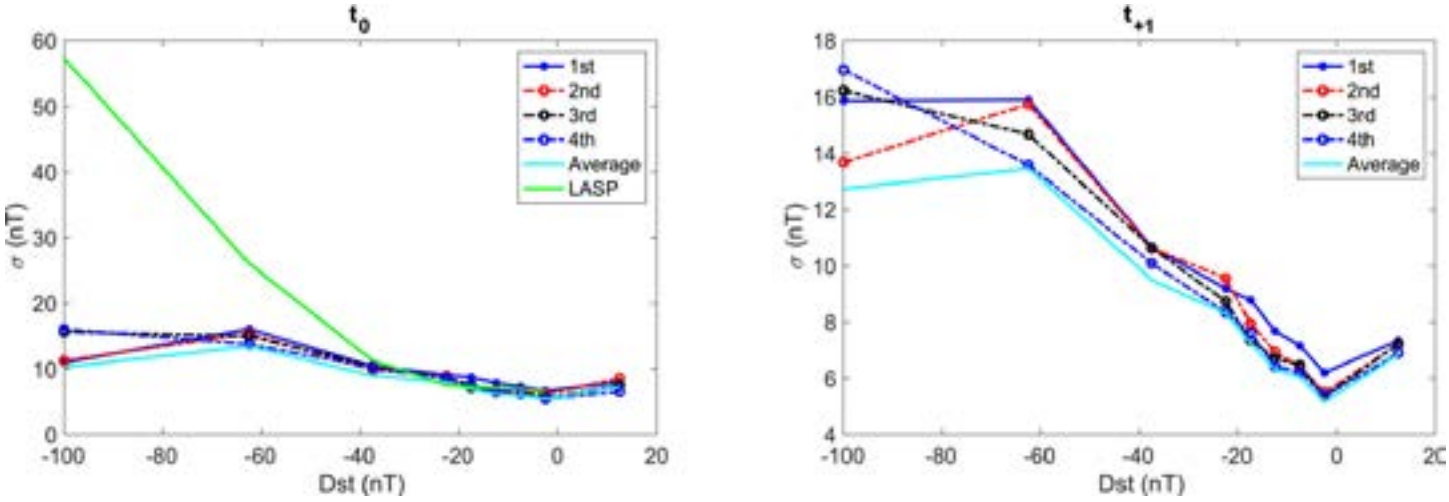
Map comparing the gridded marine trackline magnetic anomalies overlain by the Sander Geophysics Ltd. Caribbean Alternative Navigation Reference Experiment aeromagnetic profiles.
Credit: Saltus et al. 2023, *Earth and Space Science*

Project: Exploring artificial intelligence and machine learning applications in geomagnetism

CIESRDS contributors: Arnaud Chulliat, Manoj Nair, Rick Saltus, Lily Young

Relevance to NOAA: This project supports NOAA's adoption of artificial intelligence and machine learning (AI/ML), one of six key Science and Technology Focus Areas advancing the agency's mission. It also benefits society by improving the accuracy and usefulness of NOAA's geomagnetic products for government, industry, and the general public.

This project applies artificial intelligence and machine learning (AI/ML) to advance geomagnetic capabilities relevant to NOAA's mission. This team's efforts include near-term forecasting of geomagnetic indices and external magnetic fields, prediction of magnetic anomaly maps, and the use of large language models to deliver accurate, real-time geomagnetic calculations and visualizations. Since 2022, the researchers led the MagNet challenge, a global competition to develop new models predicting the disturbance storm-time index from solar wind data. The winning solution, an ensemble of the top machine learning models, is accurate and operationally viable for NOAA forecasting. The team also developed ChatGeo-Magi, an AI-powered assistant delivering interactive, real-time geomagnetic calculations and visualizations using Retrieval Augmented Generation and NOAA data. Over the next five years, this team will advance research on artificial intelligence and machine learning in geomagnetism, focusing on applications directly relevant to the team's mission, including predicting magnetic anomaly maps in regions with sparse trackline coverage and forecasting geomagnetic secular variation.



Root mean square error score (vertical axis) for the top four MagNet competition models versus Disturbance Storm-Time (Dst) (horizontal axis). Traces: first place (solid blue), second (red), third (black), fourth (dashed blue), and ensemble mean (light blue). Left: prediction at t0; right: prediction at t+1.
Credit: Nair et al. 2023, *Space Weather*

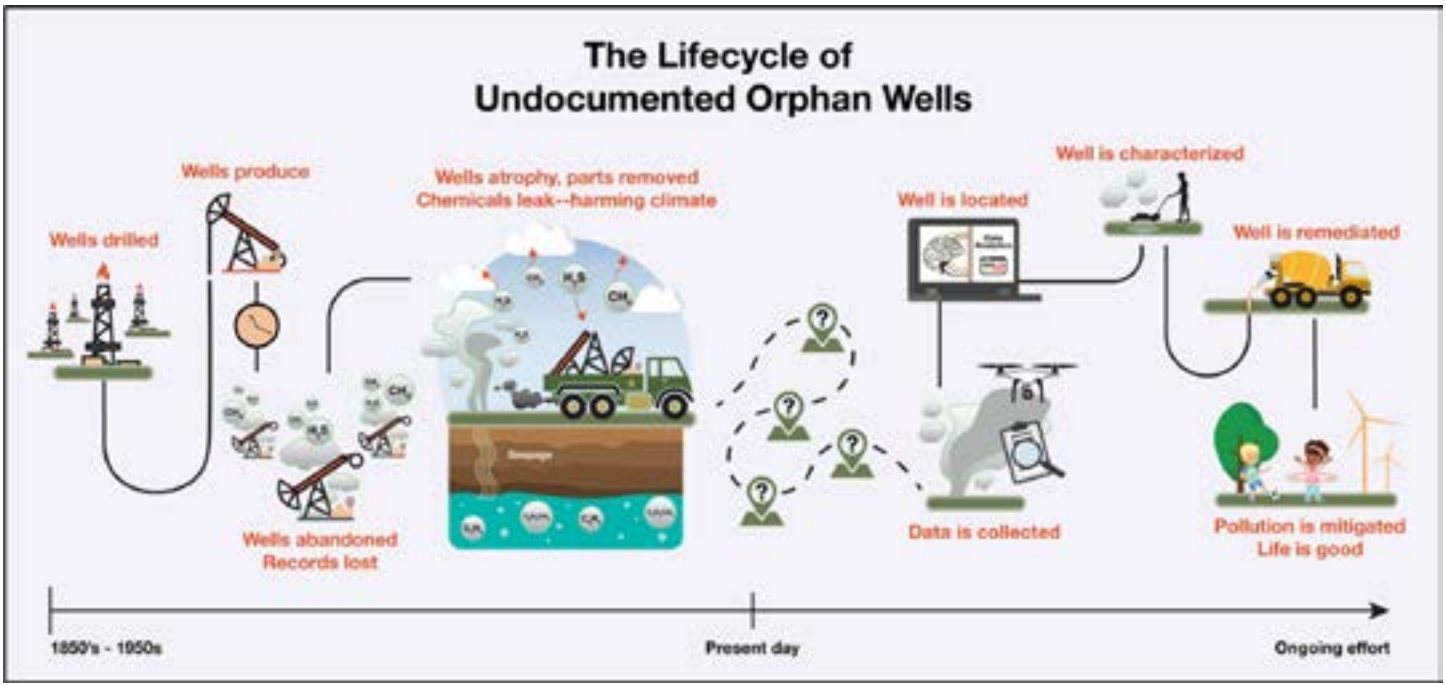
Project: Mapping orphan wells with MagMapper

CIESRDS contributors: Nir Boneh, Manoj Nair, Rick Saltus, Jordan Schweizer, Jesse Varner

Relevance to NOAA: MagMapper engages the public to help identify and map orphan wells, generating cost-effective data that supports government remediation efforts. This approach improves prioritization of cleanup, reduces environmental impacts, and enhances understanding of abandoned wells across communities.

The MagMapper project leverages smartphone magnetometers and a crowdsourcing app to locate undocumented orphan wells. Orphan wells are abandoned oil and gas wells with no responsible owner, posing significant environmental risks by leaking methane, oil, and toxic chemicals that contaminate air, soil, and groundwater. With MagMapper, citizen scientists can collect magnetic anomalies, GPS coordinates, and photos of potential well sites to detect steel casing signals and enable expert verification. By combining public participation with low-cost sensing, the project improves orphan well mapping at scale, supporting environmental monitoring and prioritization of mitigation efforts.

Since its start in 2024, the team has developed and field-tested a beta version of the MagMapper smartphone app. Early field trials have demonstrated the feasibility of crowdsourcing well-location data. Over the next five years, the researchers will finalize and field test the MagMapper app, enhancing features that support public participation to detect and characterize orphan wells while ensuring data reliability for effective mapping and prioritizing remediation.



An undocumented orphan well begins its life as an energy-producing resource but gradually atrophies, becoming an environmental problem that is difficult to address. MagMapper helps locate and characterize these wells.
Credit: O'Malley et al. 2024, *Environmental Science and Technology*

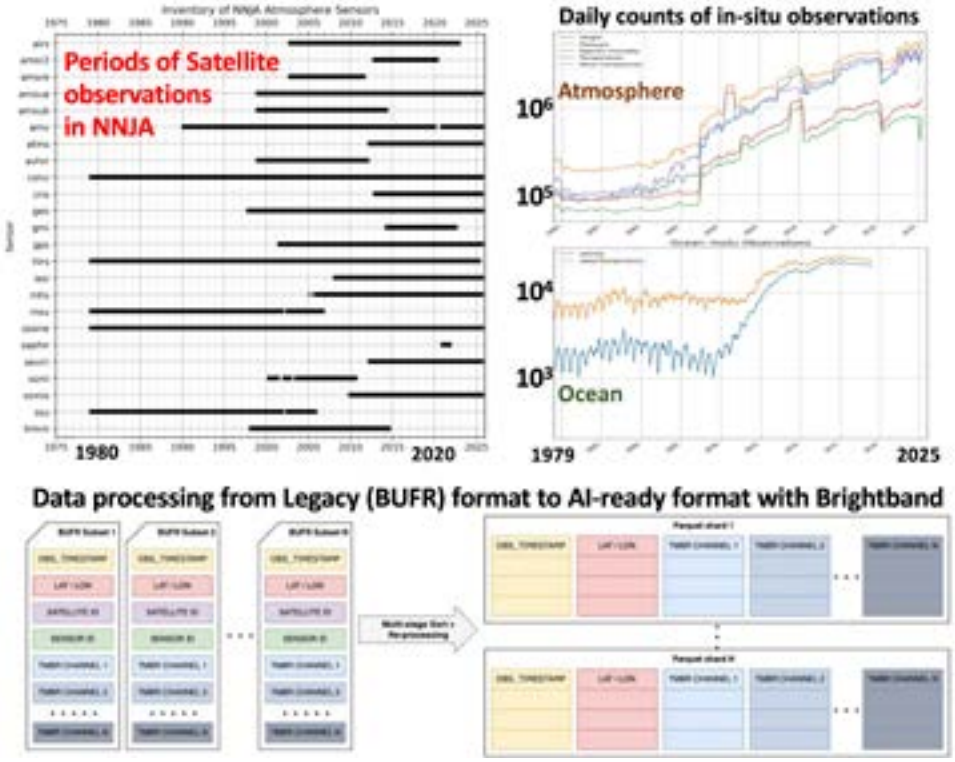
Project: Developing the NOAA-NASA Joint Archive (NNJA) observation dataset for reanalysis and artificial intelligence applications

CIESRDS contributors: Jessica Knezha, Adam Schneider, Sherrie Fredrick, Joao de Souza, Gilbert P. Compo, Henry Winterbottom

Relevance to NOAA: The NNJA dataset provides co-located, consistent satellite-based and in situ observations for next-generation NOAA and NASA reanalysis products. Its cloud-based storage and multiple formats make public access convenient for reanalysis and AI applications. Improving NOAA predictions depends on reanalysis data for initializing and testing models across decades of forecast cases.

Spanning 1979 to present, this project has created a first-of-its-kind, curated, quality-controlled observation dataset of atmospheric, oceanic, ice, and land weather observations. This NOAA-NASA joint observational archive draws from more than 40 satellite missions, the satellite data reprocessing of international centers, and the worldwide weather data collection of national centers. The main dataset and an AI-focused version are used for reanalysis and for training AI forecasting models. It is updated in near real-time.

Since 2022, this improved archive of ocean, land, ice, and atmospheric observations has generated two cloud-based datasets. One of these is ready for AI applications, while the other is ready for data assimilation and reanalysis using NOAA's and NASA's existing numerical weather prediction and earth system model systems. NNJA is operationally maintained with continuous updates. The team inspired a global meeting on improving observation, sharing with two websites and four meeting presentations. Over the next five years, the researchers will continue to add observations for reanalysis, including ocean, snow, and atmosphere data while converting additional observations to AI-ready formats. They will improve ease-of-access for AI model development and enhance the software infrastructure for reduced maintenance and will continue representing a model of data sharing internationally.



The NOAA-NASA Joint Archive (NNJA) provides comprehensive observational data for reanalysis and artificial intelligence applications. (top left) The periods of time when observations from atmospheric sensors mounted to a satellite or series of satellites are present in the NOAA-NASA Joint Archive. (top right) The number of daily observations by variable for directly observed atmospheric and oceanic measurements contained in the NOAA NASA Joint Archive on a logarithmic scale. (bottom) Illustration of the transformation process implemented with Brightband to convert legacy World Meteorological Organization BUFR (Binary Universal Form for the Representation of meteorological data) format into AI-ready Apache Parquet format, enabling efficient access for machine learning applications.
Credit: Jessica Knezha/CIESRDS and Brightband

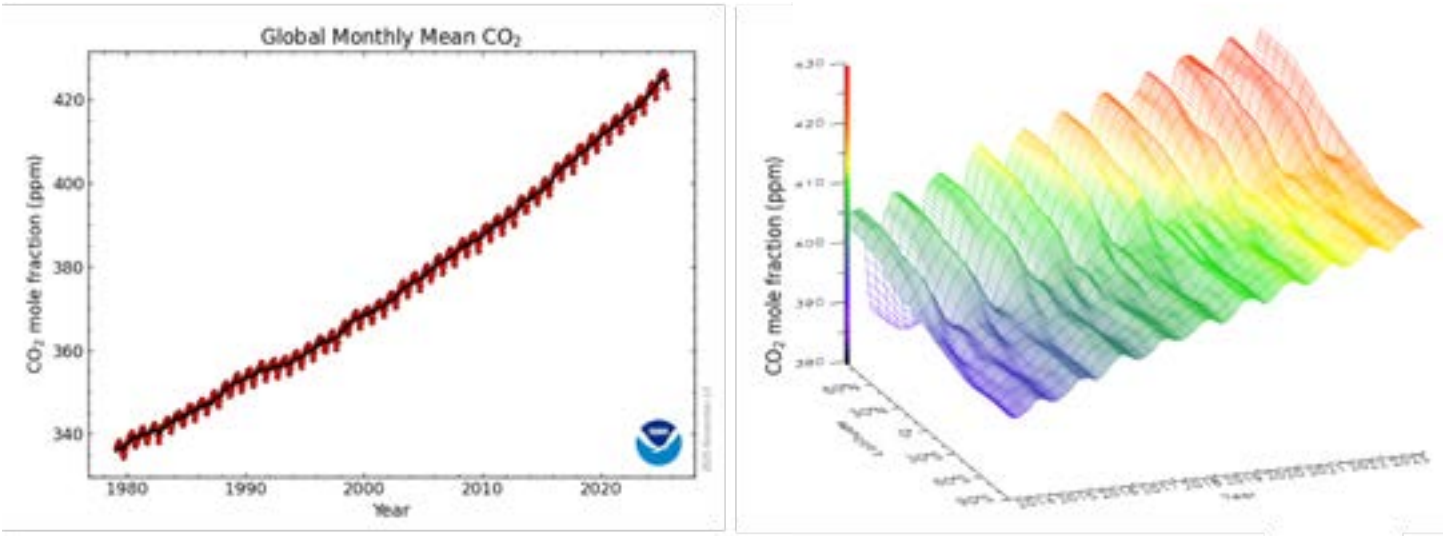
Project: Monitoring and reporting greenhouse gas trends in Earth's atmosphere

CIESRDS contributors: Xin Lan, Gabriell Petron, John Mund, Kenneth Schuldt

Relevance to NOAA: This project monitors and reports global greenhouse gas trends. It is in line with NOAA Research's science priorities to observe atmospheric composition changes in support of public health and economics. It benefits global society by tracking global efforts on mitigating carbon emissions, and provides fundamental data for research to understand greenhouse gas impacts on the global energy balance that drives extreme weather events, helping improve predictions of future weather and climate.

This team provides real-time monitoring of global greenhouse gas levels and dissemination of that information to the public. Monitoring includes real-time calculations of carbon dioxide trends observed at NOAA's Mauna Loa Observatory in Hawaii and an annual publication of trends in global carbon dioxide, methane, nitrous oxide, and sulfur hexafluoride levels in the atmosphere. Trends derived from Mauna Loa observations are communicated with the public and scientific community on NOAA's Global Monitoring Laboratory website, which is viewed about 100,000 times a month. The site sees about 800,000 downloads each year. The team also contributes to the calculation of greenhouse gas radiative forcing as inputs for NOAA Global Monitoring Laboratory's Annual Greenhouse Gas Index (AGGI) product.

Over the next five years, the team will strengthen current capacity on near-real-time reporting of atmospheric greenhouse gas trends with improved accuracy and stability in calculation. The project will also improve communication on the trend results, and contribute to research efforts on improved ecosystem processes related to carbon emissions and sinks.



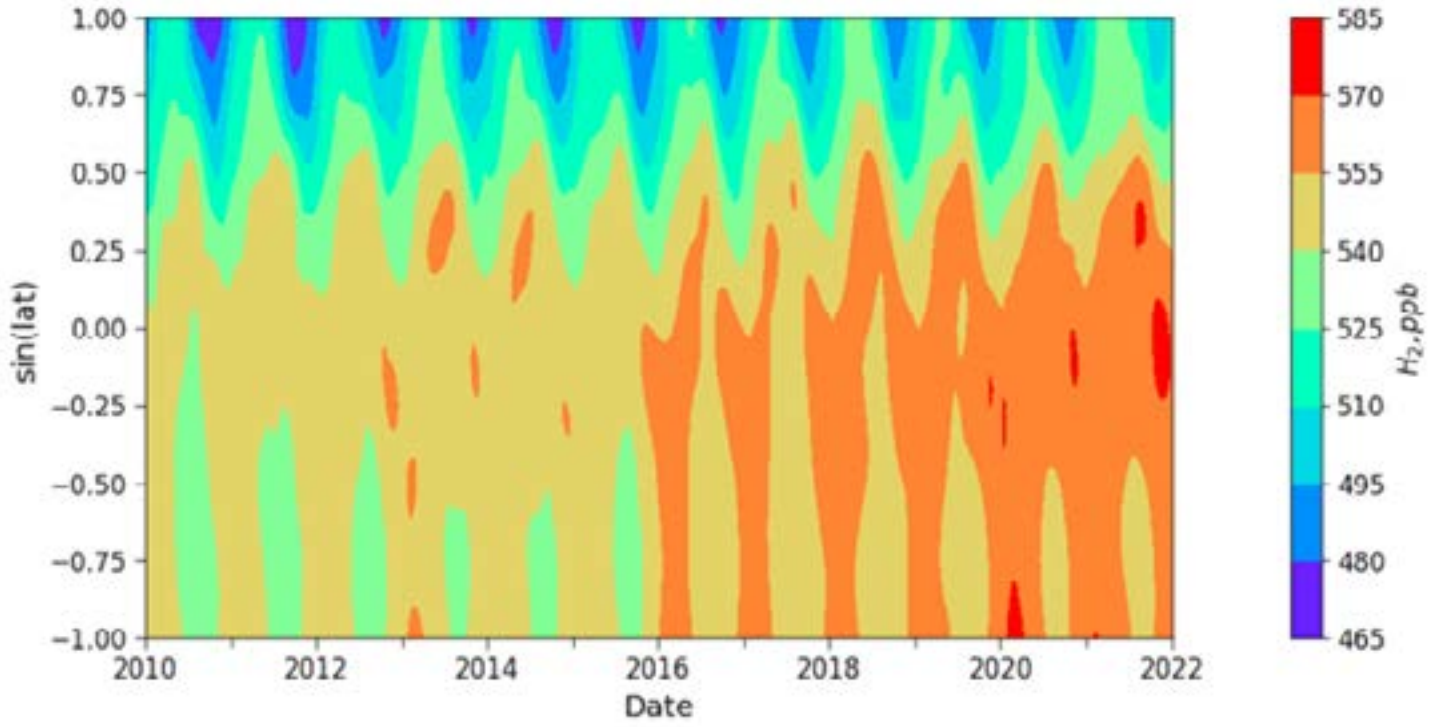
Graph showing a steady rise in global monthly mean CO2 levels from 1980 to 2020, with a 3D colored chart on the right illustrating seasonal fluctuations.
Credit: Xin Lan/CIESRDS and NOAA GML

Project: Processing atmospheric hydrogen data

CIESRDS contributors: Gabrielle Petron, Andrew Crotwell, Thomas Mefford, John Mund, Molly Crotwell, Monica Madronich, Eric Moglia, Sonja Wolter

Relevance to NOAA: This project provides a hydrogen data update with improved quality, as a fundamental step to track changes in atmospheric hydrogen levels, since green hydrogen has been proposed as a renewable energy source. This is in line with NOAA's science priority to observe atmospheric composition changes in support of the economy.

This project reprocesses atmospheric hydrogen data. Since September 2022, the team has finished processing hydrogen measurements from 2010 to present and published an updated dataset. This work contributed to research on the global and regional hydrogen budget. Over the next five years, the team plans to sustain hydrogen measurements and high-quality data publication while contributing to hydrogen research efforts and stakeholder communications.



Atmospheric background hydrogen distributions based on measurements from the NOAA Global Greenhouse Gas Reference Network. Credit: Gabrielle Petron/CIESRDS and NOAA GML

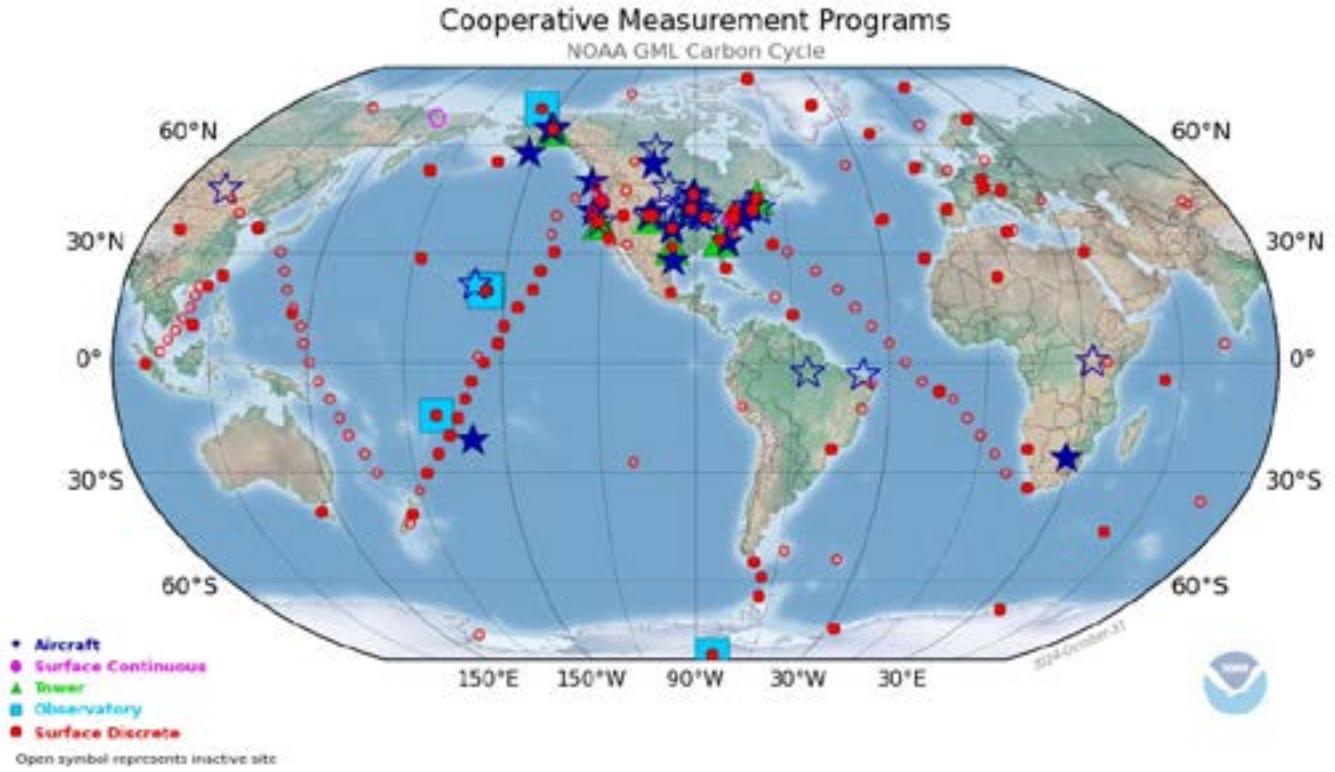
Project: Sustaining greenhouse gas measurements and data publications

CIESRDS contributors: Xin Lan, Gabrielle Petron, Kate Baugh, Andrew Crotwell, Molly Crotwell, Stephen DeVogel, Monica Madronich, Joshua Mauss, Thomas Mefford, Eric Moglia, John Mund, Aerin Searle, Sonja Wolter, Emily Kaiser, Jonathan Kofler, Janelle Hakala, Philip Handley, Andrew Clarke, Julianne Fernandez, Matthew Martinsen

Relevance to NOAA: This project directly addresses NOAA research's priority to collect atmospheric composition observations in support of public health and the economy. Greenhouse gas measurements from this project lead the world in global measurements that enable accurate forecasting and preparedness against environmental threats. CIESRDS researchers make significant contributions to global greenhouse gas measurements and science, including by serving in advisory roles to the World Meteorological Organization and International Bureau of Weights and Measures.

This project sustains measurements of greenhouse gases in Earth's atmosphere. Since 2022, the team has maintained measurement scales of carbon dioxide, methane, nitrous oxide, and sulfur hexafluoride while improving the carbon monoxide measurement scale. These scales, designated by the World Meteorological Organization, are used to anchor and connect worldwide measurements. Additionally, the team has updated in situ continuous measurement systems with state-of-the-art instrumentation, communication, and data management codes at NOAA baseline observatories.

Since 2022, the team has published high-quality measurement data yearly along with raw instrument data, calibration data, and data processing code for improved transparency. The data website is popular, receiving more than 300,000 downloads per year on the World Meteorological Organization's World Data Center for Greenhouse Gases. Over the next five years, the team plans to sustain current measurement networks and strengthen collaborations worldwide; continue improvements on data transparency and archiving; finish upgrading carbon monoxide measurement scales and data reprocessing; and continue monitoring atmospheric greenhouse gas abundances with improved instrumentation and measurement capacity for improved monitoring from key climate-sensitive regions.



NOAA Global Greenhouse Gas Reference Network sites.
Credit: NOAA GML

Project: Examining trends in surface radiation to understand changes in the atmosphere

CIESRDS contributors: Gary Hodges, Ben Sheffer, Christian Herrera, Logan Soldo, Laura Riihimaki

Relevance to NOAA: Long-term weather forecasts can improve if internal variability is simulated well by models. The correlation between cloudiness and patterns implies there may be potential for decadal or seasonal-to-subseasonal forecasts of solar radiation, which are useful for agriculture, energy, and other sectors.

Long-term measurements of surface irradiance at 14 sites in the continental United States and four sites in remote polar and tropical locations provide valuable information about how clouds, aerosols, and surface properties are changing over time. Solar transmission data collected at Mauna Loa, Hawaii, show changes due to stratospheric and upper-tropospheric aerosol loading from volcanoes and wildfires. Solar irradiance in the continental United States reveals trends related to cloudiness. These patterns relate to changes in sea surface temperatures (SSTs) and corresponding geopotential height anomalies, suggesting cloudiness is caused by widespread pressure anomalies set up by sea surface temperatures.

Since 2022, this team has produced one paper along with multiple presentations on high-quality, multi-decadal datasets at 14 stations around the United States. Next steps include continuing to collect high quality irradiance measurements around the continental United States and at NOAA GML observatories to extend trends and interpretation, expanding analysis to examine correlations between SST changes and solar irradiance at shorter time scales, and examining polar irradiance trends for shifts due to melting ice.

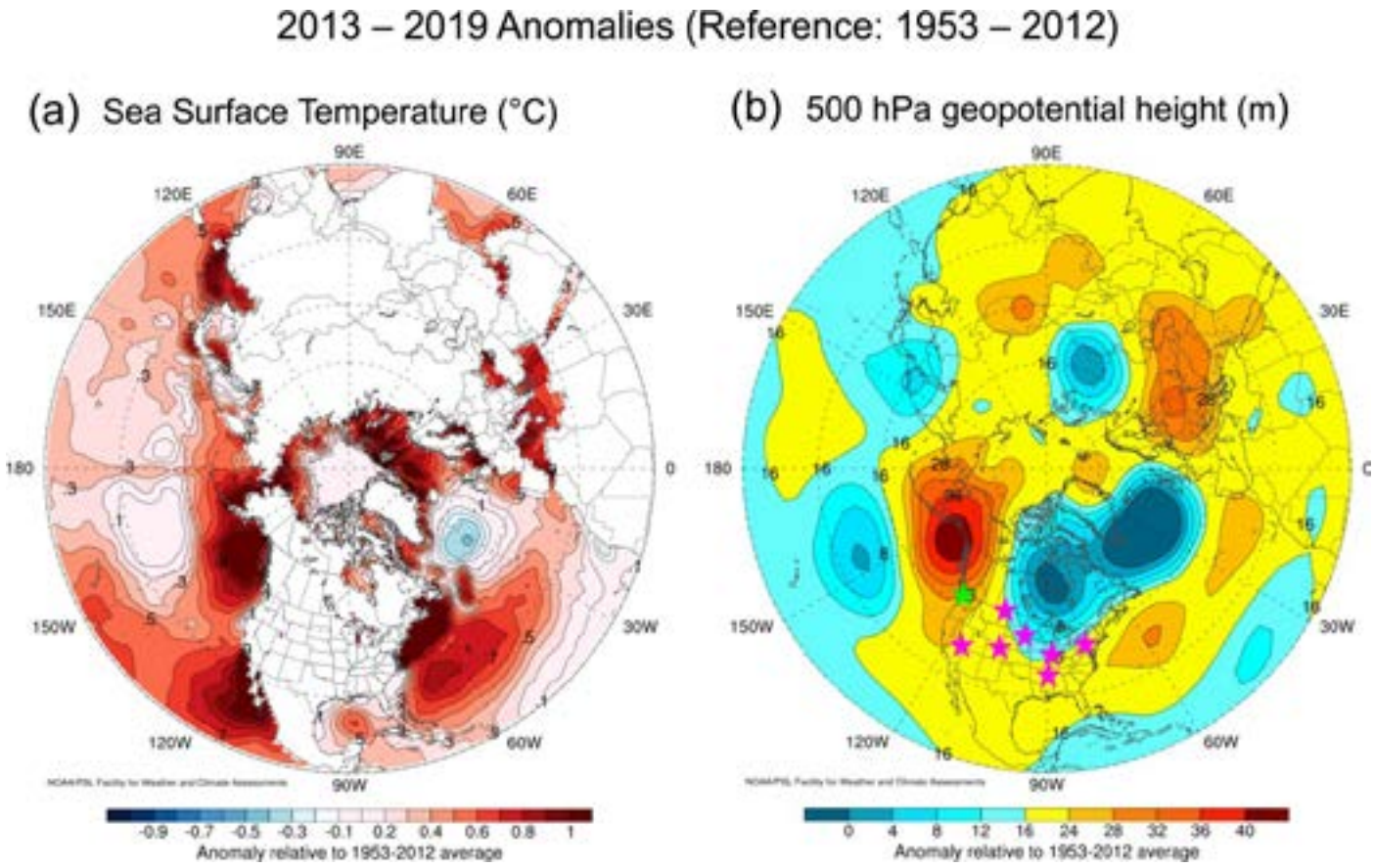


Image shows anomalies of Sea Surface Temperature (left) related to 500 hPa geopotential height (right) and corresponding directions of surface solar irradiance trends in the stars (right). The green star in Seattle shows the increasing trend between 2013-2019 that corresponds with an overall high-pressure anomaly related to very high sea surface temperatures in the Pacific. The decreasing trend in surface solar irradiance around the rest of the continental United States relates to low pressure and cooler sea surface temperatures in the northern Atlantic.

Credit: Augustine, J. A., & A. Capotondi 2022, *Journal of Geophysical Research: Atmospheres*

Project: Using in situ aerosol optical properties to understand cloud condensation nuclei concentrations

CIESRDS contributors: Elisabeth (Betsy) Andrews; Inez Zabala, Juan Andres Casquero-Vera

Relevance to NOAA: Clouds are the most uncertain component of climate forcing and likely play a major role in the diversity of radiative forcing predicted by earth system models. This project examines relationships between aerosol optical properties to understand cloud condensation nuclei to better constrain understanding of these key drivers of climate.

The NOAA Federated Aerosol Network (NFAN) makes measurements of aerosol optical properties (AOPs) across the globe. These AOP measurements are often collocated with other measurements. By combining AOP and cloud condensation nuclei (CCN) concentrations, scientists can learn more about what types of particles can act as cloud condensation nuclei. Since September 2022, the team has produced six papers (four published and two submitted) relating CCN and aerosol properties. In addition to paper publication, team members have mentored four students. Over the next five years, team members will continue to make collocated CCN and AOP measurements and use machine learning tools to determine how well AOPs can be used to predict CCN concentrations and explore how new particle formation impacts CCN concentrations.

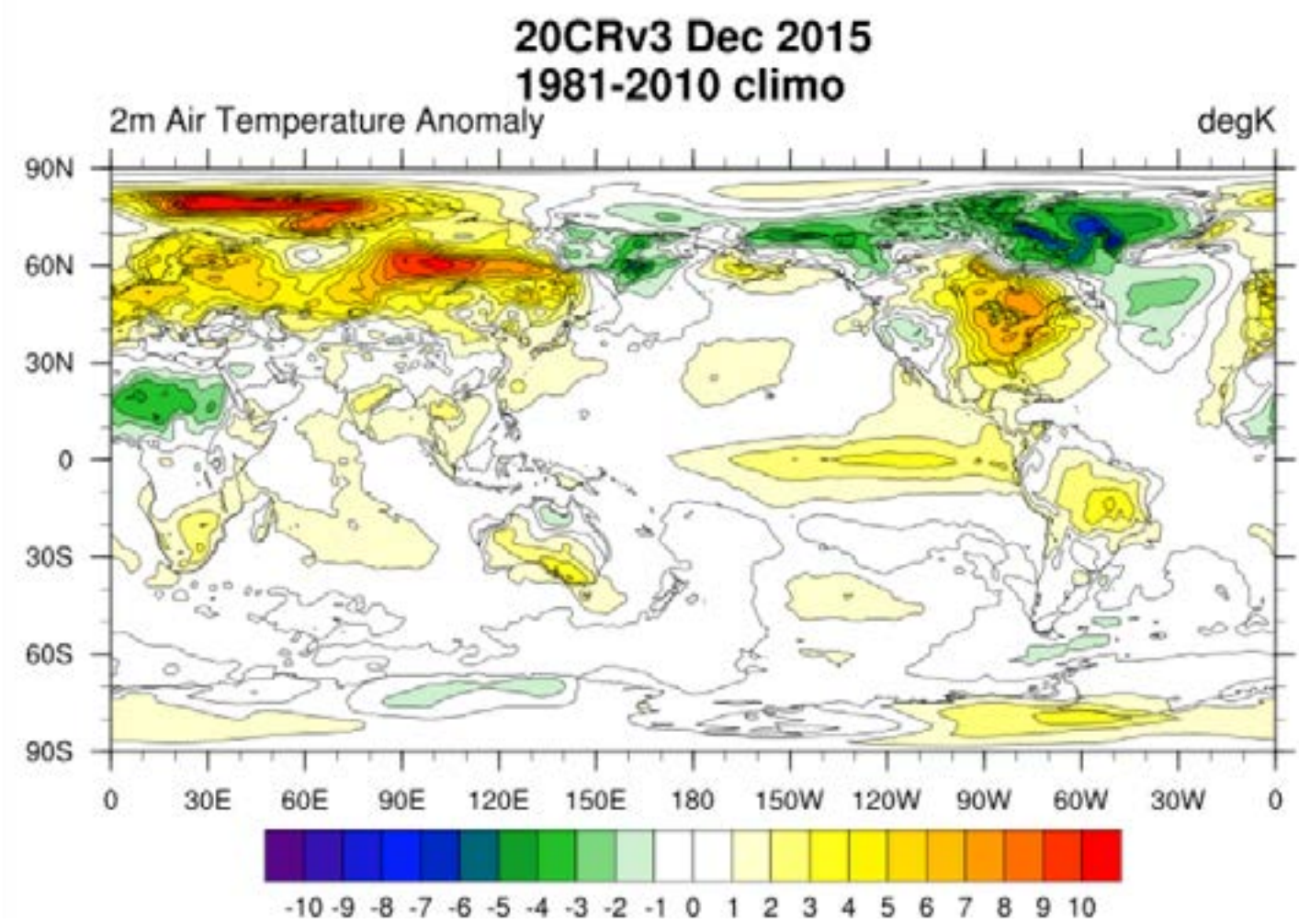
A CIESRDS researcher climbs a tower at Summit, Greenland, to install and align an anemometer as part of the NOAA Federated Aerosol Network (NFAN).
Credit: Caleigh Warner

Project: Maintaining Physical Sciences Laboratory dataset collections

CIESRDS contributors: Cathy Smith, Don Murray, Don Hooper

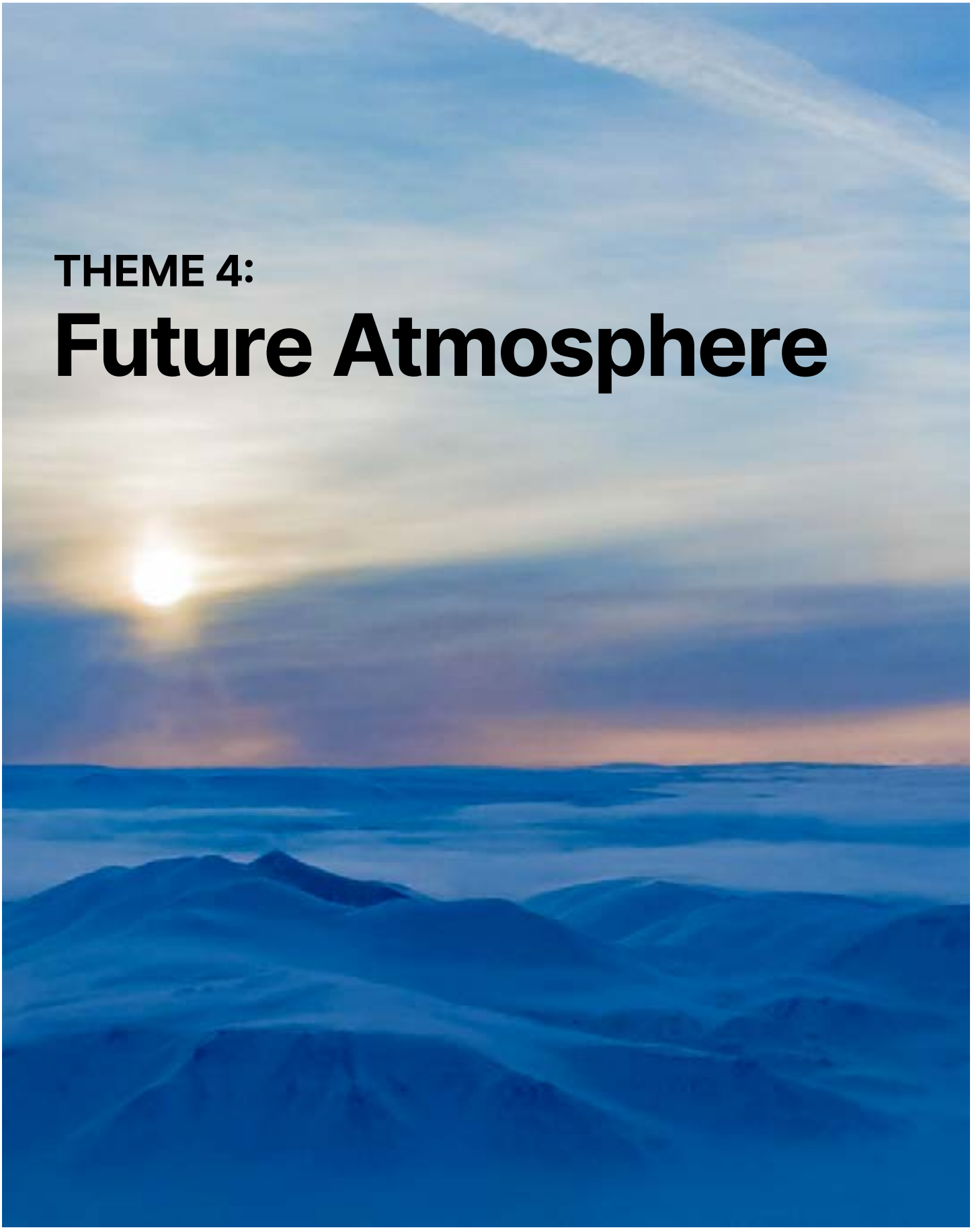
Relevance to NOAA: The datasets hosted at NOAA's Physical Sciences Laboratory are key to the lab's research and underscore efforts to understand and predict understanding and predicting changes in climate, weather, ocean, and coasts. The datasets are shared so others can use this information in their research.

The Physical Sciences Laboratory (PSL) dataset collection is a mixture of PSL-created data and outside datasets used in PSL's research. Research ranges from the study of small-scale weather processes to large-scale, decadal climate projections. Over the next five years, the team will collect, document, and make available more useful datasets including reanalysis, analysis, time-series, forecast, and observational data for use in PSL' s research. The researchers will store more data in self documenting and AI-ready formats.



NOAA-CIRES-DOE 20th Century Reanalysis V3 contains objectively-analyzed 4-dimensional weather maps and their uncertainty from the early 19th century to the 21st century. (20CR Project).

Credit: NOAA PSL



THEME 4:

Future Atmosphere

During the Atmospheric Tomography mission, scientists logged four complete global circuits from the Arctic to the Antarctic over the remote oceans, including over the Canadian Arctic, while instruments continuously sampled the atmosphere for various pollutants.
Photo: Sam Hall/NCAR

FUTURE ATMOSPHERE

Understanding the composition of Earth's atmosphere and how it changes over time is crucial for managing weather, air quality, climate change impacts, and stratospheric ozone depletion. CIESRDS research aims to better understand Earth's future atmosphere by studying atmospheric chemistry, emissions of aerosols and greenhouse gases, and Earth's radiation budget and climate intervention strategies.

This work involves atmospheric monitoring, laboratory experiments, designing custom instruments for sampling the atmosphere, collecting observations through field campaigns, developing and improving atmospheric models, and integrating models with observations.

A key focus of CIESRDS work on this theme has been collecting first-of-their-kind measurements of Earth's atmosphere to inform air quality policies and pollution reduction strategies. In 2023, CIESRDS scientists participated in NOAA's AEROMMA and CUPIDS field campaigns, collecting atmospheric observations over major U.S. cities from various aircraft. Their research illuminates how anthropogenic and marine emissions alter atmospheric composition and impact air quality and climate over North America.

CIESRDS scientists also partnered with federal colleagues to study air quality in Las Vegas, Nevada, and found cooking emissions can account for nearly a quarter of human-made volatile organic compounds in cities.

CIESRDS scientists led the 2022 California Fire Dynamics Experiment, the first field campaign to capture coordinated wildfire observations in real time. Their work shows it is possible to collect measurements of fire and smoke chemistry, weather conditions, and smoke plume dynamics in real time around an active wildfire. The findings will improve smoke forecasts, support safer firefighting operations, and inform wildfire mitigation strategies.

They also developed a new air pollutant emissions inventory that helped inform air quality modeling by Nevada's Clark County Department of Environmental Quality for their ozone implementation plan, increasing confidence in pursuing the right pollution control strategies. CIESRDS scientists also co-led a publication showing how the 2023 Canadian wildfires produced record-breaking air pollution levels across the Upper Midwest.

Finally, CIESRDS scientists use high-altitude aircraft to study the transport, chemistry, physics, and radiative properties of aerosols in the upper troposphere and lower stratosphere to better understand Earth's radiation budget.

Project: Developing a dataset of composition-informed aerosol size distributions and validated optical properties

CIESRDS contributors: Ming Lyu, Adam Ahern, Samuel Taylor, and Han Huynh

Relevance to NOAA: Particles are important to the global radiative balance and their effect on human health. Sources and processes also change as human activity and the planet evolves. Satellite-borne sensors provide the best spatial and temporal coverage, but need in situ measurements to retrieve aerosol properties from space.

Aerosols in the troposphere have a harmful effect on the health of humans, many of whom live in or around cities. As part of the AEROMMA campaign, we measured the size and composition of aerosol properties that affect human health, as well as optical properties that affect the ability of satellites to measure the particles from space. These measurements will be combined into a data product that will validate aerosol products from a new satellite, TEMPO. The researchers completed measurements in the summer of 2023, and published data from two sets of instruments.

The three-year project funded by the NOAA Climate Program Office is on track, having hit the analysis milestones for years one and two. In the next year, researchers will publish a dataset that provides detailed information about the particle microphysical, chemical, and optical properties. They will publish the dataset in a format that will make it useful to both global modelers and developers of satellite retrieval algorithms.

View from the NASA DC-8, sampling particles above New York City during the AEROMMA campaign.
Credit: Rafael Mendez Pena/Bay Area Environmental Research Institute

Project: Measuring aerosol optical properties to inform satellite retrievals and global model assumptions

CIESRDS contributors: Cecile Carlson, Adam Ahern, Samuel Taylor, Tegan Brown, Dan Law, and Han Huynh

Relevance to NOAA: This project provides in situ measurements of aerosol optical properties that can improve satellite measurements of Earth's surface radiation budget.

This project team investigates the optical properties of aerosols to better understand how they reflect energy into space. This energy determines how aerosols affect the global radiation budget and how satellites can infer aerosol properties. CIESRDS researchers on this project have measured these optical properties using a custom-built instrument and a particle size distribution instrument, and compared these measurements with results from a satellite retrieval algorithm. They published recommended values of the real refractive index for use in satellite retrievals of wildfire smoke aerosol properties based on measurements from the 2025 Fire Influence on Regional to Global Environments and Air Quality (FIREX-AQ) campaign.

The researchers also participated in NASA's Plankton, Aerosol, Cloud, ocean Ecosystem Postlaunch Airborne eXperiment (PACE-PAX) campaign in August and September 2024 and published the resulting dataset. The team works with NASA researchers to include the measurements of optical properties from PACE-PAX in analysis algorithmsfor various instruments on the PACE satellite. Over the next five years, they plan to expand their analysis of wildfire smoke optical properties to include more data measured during the 2023 AEROMMA campaign and other PACE-PAX deployments.

Wildfires outside of Los Angeles, as seen from high-altitude aircraft during the PACE-PAX field campaign.
Credit: NASA Armstrong Flight Research Center

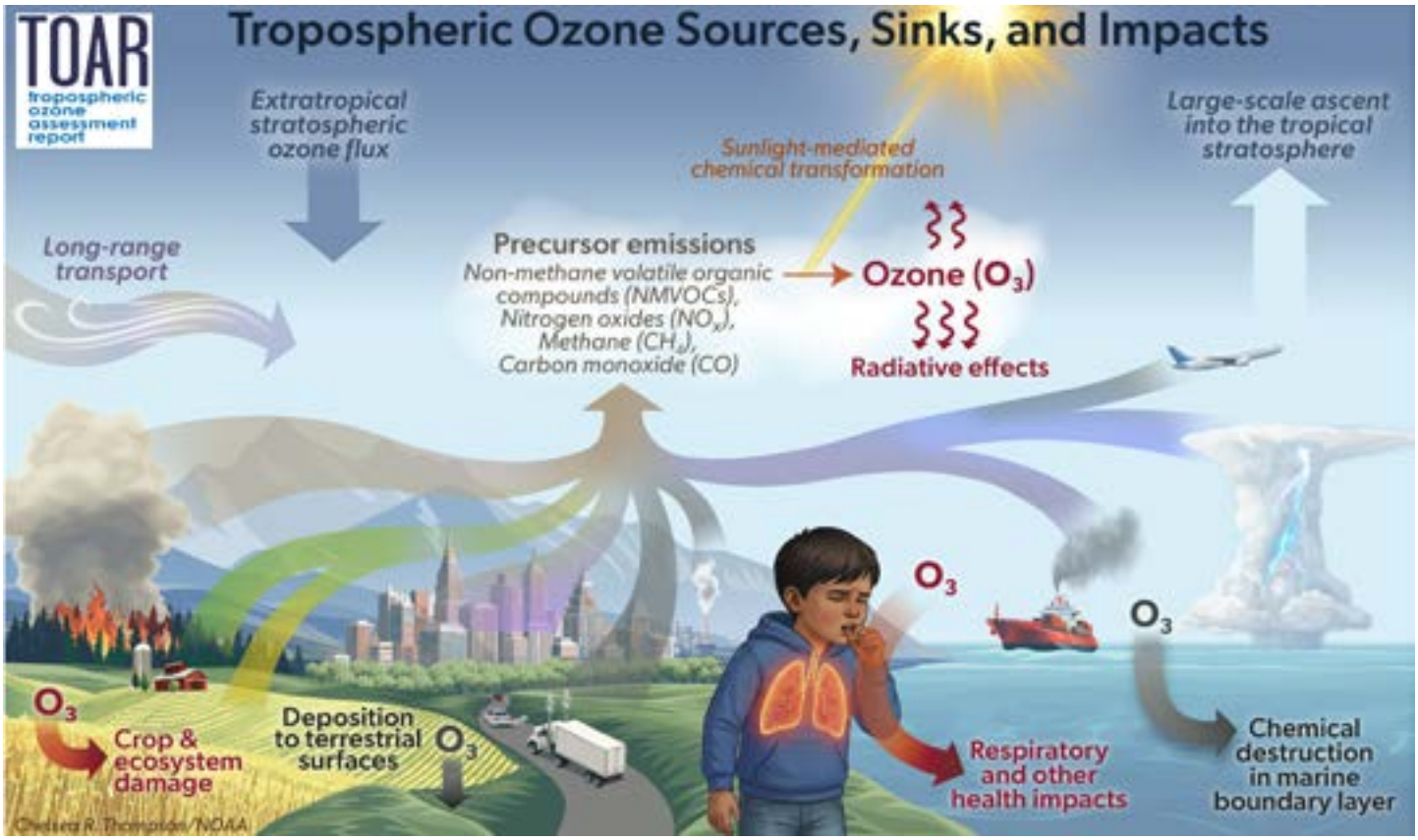
Project: Leading and publishing the Tropospheric Ozone Assessment Report Phase-II (TOAR-II)

CIESRDS contributors: Owen Cooper, Kai-Lan Chang, Audrey Gaudel

Relevance to NOAA: TOAR's assessments papers are cited by the IPCC and promote international collaborations.

The Tropospheric Ozone Assessment Report (TOAR) brings together scientists from the global atmospheric research community to produce authoritative, up-to-date assessments of ozone's distribution and trends, with direct relevance to climate, human health, and vegetation. Through this international collaboration, TOAR has generated a substantial body of scientific output—including six peer-reviewed articles and five conference presentations featuring CIRES and NOAA authors—that strengthens understanding of how ozone is changing worldwide and why those changes matter. TOAR assessment papers are frequently cited by major scientific bodies, including the IPCC, underscoring the program's influence and its role in shaping global perspectives on ozone and air quality.

TOAR-II, the current phase of the effort, spans 2020–2026 and is now approaching its conclusion. Its final products will be a series of comprehensive assessment papers to be published in the Transactions of the Royal Society A, offering a synthesized view of ozone science grounded in the latest observations, modeling, and analysis. As TOAR-II wraps up, it leaves behind not only an updated scientific foundation for understanding tropospheric ozone but also a strengthened network of international collaborators committed to advancing atmospheric research.



An artist's rendering of the sources, sinks, and impacts of tropospheric ozone.
Credit: Chelsea Thompson/NOAA CSL

Project: Gaining new insights into fire weather, dynamics, and emissions

CIESRDS contributors: Brian Carroll, Edward Strobach, Maxwell Holloway, Michael Zucker, Richard Marchbanks, Sunil Baidar, Brandi McCarty, Robert Banta, Amanda Makowiecki

Relevance to NOAA: This project provides first-of-their-kind observations of active wildfires, clarifying how wildfires and their associated smoke plumes behave in real time. Results from this project will improve weather forecasts and information used by first responders on the ground who need to make quick decisions about firefighting strategy and evacuations.

The California Fire Dynamics Experiment (CalFiDE) was a six-week study to explore wildfire behavior and how wildfires respond to spatially and temporally evolving wind fields in California. CIESRDS researchers on this project collected measurements of active wildfires in real time from aircraft, trucks, and satellites simultaneously. Airborne infrared imagery collected from the NOAA Twin Otter aircraft provided fire intensity and spread information, while mobile Doppler lidars on the aircraft and a truck provided wind profiles over the fire and throughout the region. Chemistry measurements taken by the aircraft provided insight into fire emissions and air quality impacts. The researchers collected data during five fires throughout northern California and southern Oregon in the summer of 2022.

So far, CIESRDS researchers have used the data collected during CalFiDE to link measurements of fire intensity and spread to atmospheric dynamics and smoke plume chemistry. Their preliminary results from the campaign show how wildfire smoke cools the surface and atmosphere below the smoke by absorbing and scattering sunlight and how this affects local weather and air chemistry. They have also gained insight into how smoke plumes spread across the top of the planetary boundary layer. The team has made the data available to the public, published six journal articles, and given seven conference presentations. Over the next five years, the researchers will collaborate with the wildfire research community to learn from these unique datasets and plan future experiments.

An aerial view of California's Mosquito Fire seen from the NOAA Twin Otter aircraft during the 2022 CalFiDE campaign.
Credit: Nick Pawlenko/NOAA

Project: Measuring airborne trace gases and aerosols for insights into fire weather, dynamics, emissions, and photochemistry

CIESRDS contributors: Jeff Peischl, Kristen Zuraski, Alison Piasecki, Michael Robinson, Ken Aikin

Relevance to NOAA: CalFiDE combined measurements of wildfire and smoke chemistry, weather conditions, and smoke plume dynamics. The data improved understanding of how pollutants like ozone are formed and dispersed, and can ultimately help refine air quality forecasts and inform first responders.

The California Fire Dynamics Experiment (CalFiDE) was a six-week study in summer 2022 to explore wildfire behavior and its response to spatially and temporally evolving wind fields in California. Researchers deployed advanced instrumentation aboard the NOAA Twin Otter research aircraft to measure a suite of atmospheric chemistry compounds.

CIESRDS researchers on this project used CalFiDE data to study how wildfire emissions lead to ozone formation in and around smoke plumes. Their results show ozone production rates vary from fire to fire, and ozone production depends on hydroxyl radical concentrations in the first two hours after combustion, but depends on nitrogen oxide concentrations downwind of the fire. The researchers also established a collaborative partnership and coordination with the California Department of Forestry and Fire Protection (CalFire).

Over the next five years, the researchers will analyze data from lofted smoke plumes to determine ozone production efficiencies and their dependence on aerosol shading, along with emission factors and fluxes. They will also analyze vertically-resolved smoke plumes to understand mixing, dynamics, dispersion, and chemistry of emissions and their influence on surface-level air quality.

CIESRDS scientists provided measurements from NOAA sampling platforms during the CalFiDE study.
Credits: Brian Carroll/CIESRDS and Chelsea Thompson, Steven Brown, and Alan Brewer, NOAA CSL

Project: Collecting airborne and ground-based observations to support informed state and local agency air pollution decision-making

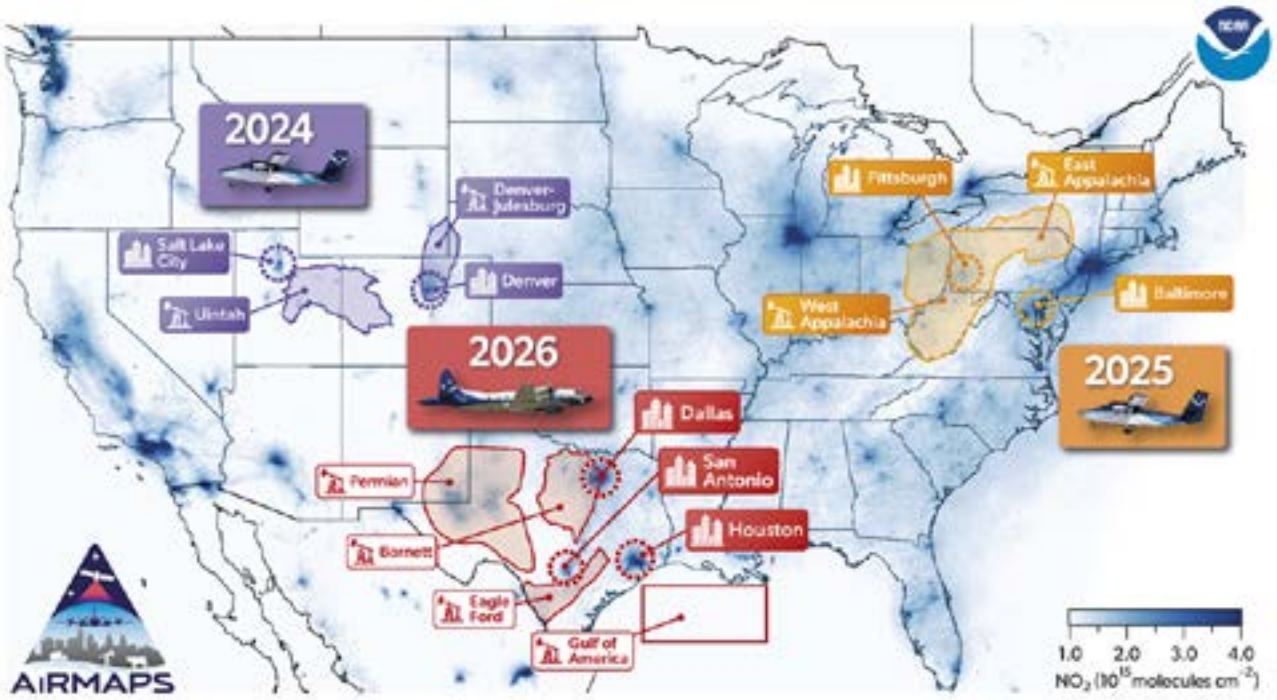
CIESRDS contributors: Sunil Baidar, Brian Carroll, Christoph Senff, Nathan Malarich, Maxwell Holloway, Michael Zucker, Richard Marchbanks, Brandi McCarty, Robert Banta, Edward Strobach, Yelena Pichugina, Jeff Peischl, Kristen Zuraski, Michael Robinson, Victoria Treadaway, Nate Howard, Chris Jernigan, Ilana Pollack, Nell Schafer, Wyndom Chace

Relevance to NOAA: This project supports a collaborative effort between NOAA Oceanic and Atmospheric Research (OAR) and National Environmental Satellite, Data, and Information Service (NESDIS) to provide the most quantitatively accurate account of greenhouse gas and pollutant emissions across the United States. This work advances the science of how air pollution forms, providing important information to state and local agency decision-makers grappling with persistent air quality challenges.

CIESRDS researchers have partnered with NOAA colleagues to lead the Airborne and Remote Sensing Multi-Air Pollutant Surveys (AiRMAPS) project, a series of studies taking place from 2024 to 2026 across the United States to provide quantitative emissions data of major air pollutants and methane from selected urban, agricultural, and oil and gas production areas. AiRMAPS data will provide actionable information to support state and local strategies for improved regional air quality and a quantitative assessment of emissions from a significant fraction of oil and gas production regions.

In 2024, the researchers collected data from NOAA aircraft and ground-based mobile platforms in Colorado's Denver-Julesburg Basin and Utah's Uinta Basin (areas of oil and gas production), and the urban areas of Denver and Salt Lake City. In 2025, they collected data from aircraft and ground-based mobile platforms in Baltimore and the Marcellus Shale region of the Appalachian Basin. The researchers plan to conduct a final survey in summer 2026, collecting data over Texas and New Mexico that will support the Texas Commission for Environmental Quality.

Findings from these projects are helping to clarify how weather, chemical processes, and human activities interact to affect air quality, offering insights that can inform future mitigation strategies and support efforts to improve public health. Over the next five years, the researchers will analyze and publish results from these campaigns, working extensively with collaborators and local stakeholders to translate scientific understanding into actionable knowledge.



This graphic shows the locations and dates of data collection for the AiRMAPS project superimposed on a map of nitrogen dioxide concentrations in the United States as measured by satellite data in summer 2023. The shaded areas and dashed circles show oil and gas (O&G) basins and urban areas for AiRMAPS surveys by year and aircraft (NOAA Twin Otter and NOAA WP-3D).

Credit: Chelsea Thompson/NOAA CSL

Project: Advancing trace gas emissions quantification

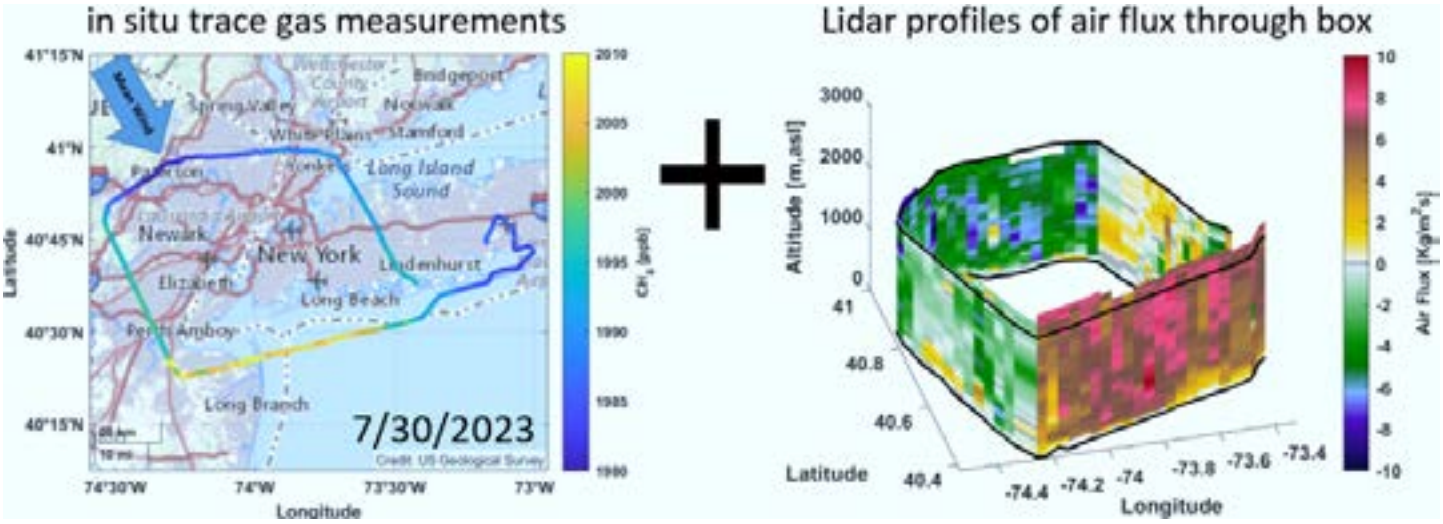
CIESRDS contributors: Nathan Malarich, Sunil Baidar, Christoph Senff, Brian Carroll, Maxwell Holloway, Michael Zucker, Richard Marchbanks, Robert Banta

Relevance to NOAA: This research quantifies atmospheric trace gas emissions, helping NOAA understand their impacts on human health and the economy.

Trace gases are atmospheric gases existing in very low concentrations, typically making up less than 1 percent of the atmosphere. Trace gases include water vapor, methane, ethane, ozone, and nitrous oxide. CIESRDS researchers on this project conduct airborne field campaigns across key regions of the United States to measure wind profiles and boundary layer heights—critical information for quantifying trace gas emissions using mass balance techniques.

Since 2022, they have conducted studies focusing on methane and ethane, trace gases important to the oil and gas sector, as well as trace gases that influence urban air quality, such as nitrous oxide and ozone, providing updated constraints on emission inventories that in some cases are more than a decade old. Their work has produced publicly available datasets, five conference presentations, and multiple manuscripts in preparation, reflecting growing scientific momentum and community interest in this topic.

Over the next five years, the researchers will continue analyzing and publishing results from these field projects in close collaboration with other scientists and state agencies, helping translate observations into actionable insights. They anticipate potentially leading one to two additional field campaigns, further strengthening the scientific basis for evaluating and managing U.S. emissions.



Scientists measured New York City emissions with traditional in situ airborne instrumentation (left) and the new value-added airborne wind profiling (right), which eliminates key assumptions by informing full profiles of winds and boundary layer height.
Credit: Sunil Baidar and Nathan Malarich/CIESRDS and NOAA CSL

Project: Investigating aerosol emissions and chemistry in U.S. megacities and marine environments

CIESRDS contributors: Jeff Peischl, Kristen Zuraski, Alison Piasecki, Michael Robinson, Nate Howard, Chris Jernigan, Ilana Pollack, Nell Schafer, Wyndom Chace, Victoria Treadaway, Morgan Selby, Sarah Albertin, Caroline Womack, and Chelsea Stockwell

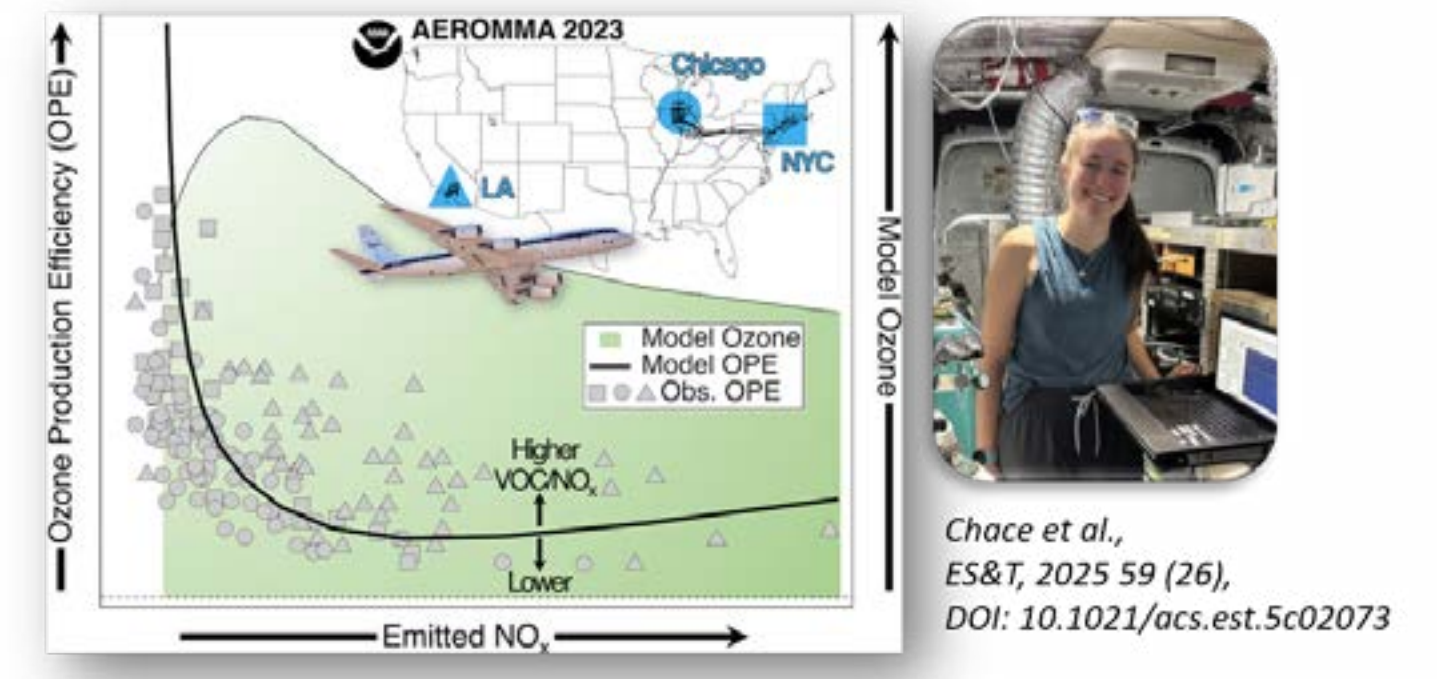
Relevance to NOAA: This project created a first-of-its-kind "street-level-to-space" dataset that combines satellite, airborne, and ground observing systems with state-of-the-art instrumentation and models to investigate human and marine emissions of atmospheric gases that impact air quality and climate. This work advances NOAA's mission to understand and predict changes in climate, weather, oceans, and coasts; it also improves NOAA's weather forecasts and informs air quality policy.

CIESRDS researchers on this project participated in the 2023 Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas (AEROMMA) and Coastal Urban Plume Dynamics Study (CUPiDS) field campaigns, two comprehensive studies led by NOAA's Chemical Sciences Laboratory investigating emissions that alter tropospheric composition and impact air quality and climate over North America.

In addition to collecting critical atmospheric composition data during AEROMMA and CUPiDS, the researchers also validated data from NASA's Tropospheric Emissions: Monitoring of Pollution (TEMPO) satellite. Since September 2022, they have helped researchers understand the modern urban atmosphere following decades of reductions in vehicle emissions, sulfur chemistry in marine environments, and novel satellite data. They have released final

datasets to the public and communicated their findings through seven peer-reviewed publications (with many more in preparation), 50+ conference/workshop presentations, and 20+ press releases. One of their key findings is that ozone production efficiency varies greatly depending on the concentration of nitrogen oxides in three major U.S. cities (New York, Chicago, and Los Angeles).

Over the next five years, CIESRDS scientists will continue to analyze the composition of the modern urban atmosphere and focus on emerging sources such as cooking and volatile chemical products and their role in ozone formation. This work also includes providing scientific understanding for NOAA's Unified Forecast System and other models.



CIESRDS graduate student Wyndom Chace analyzed airborne AEROMMA observations to show that ozone production efficiency (OPE) has increased in New York City with decreased emissions of nitrogen oxides, but remained constant in Los Angeles, providing insights for ozone pollution control strategies.
Credit: Wyndom Chace/CIESRDS

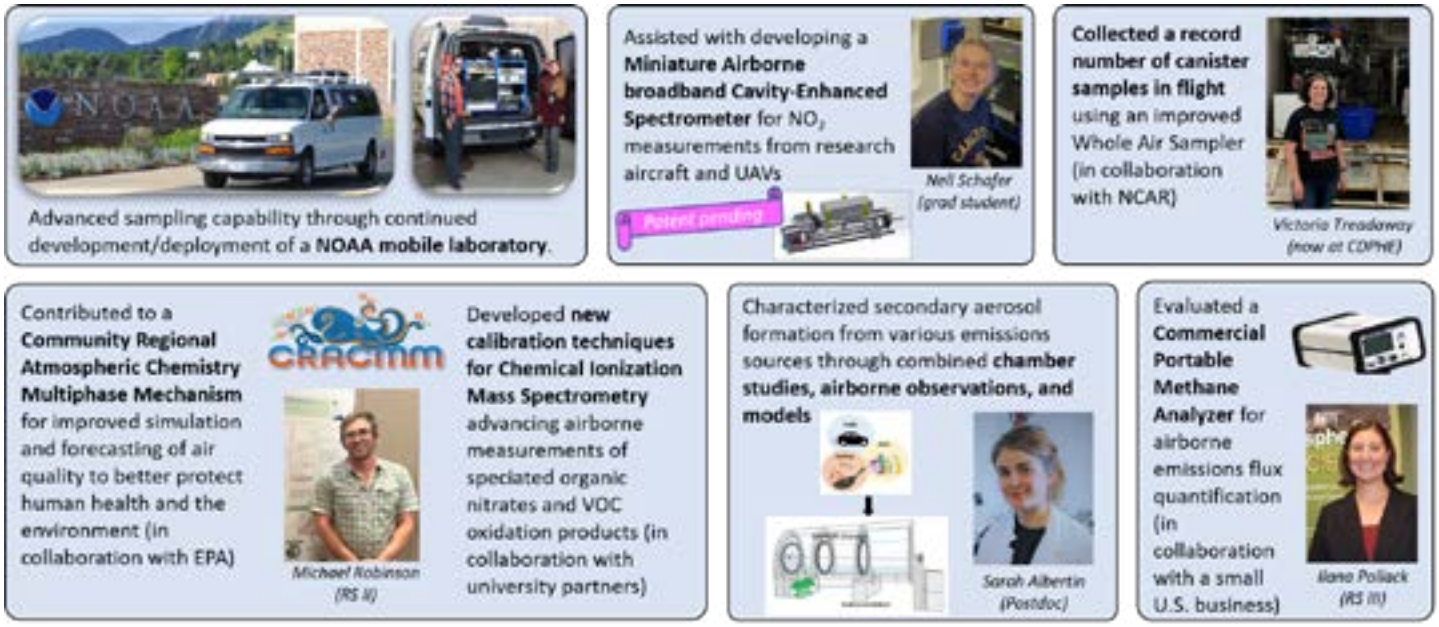
Project: Advancing state-of-the-art atmospheric measurements and analysis methods through collaboration and mentorship

CIESRDS contributors: Ilana Pollack, Kristen Zuraski, Nell Schafer, Victoria Treadaway, Morgan Selby, Michael Robinson, Chris Jernigan, Sarah Albertin, Nate Howard, Ken Aiken, Chelsea Stockwell, and Caroline Womack

Relevance to NOAA: The team collaborates with federal, industry, and academic partners to advance state-of-the-art instrumentation and analysis that becomes shared knowledge. This includes technology transfer, commercializing instruments, and mentoring to research operations and leverage unique NOAA Chemical Sciences Laboratory tropospheric chemistry measurements.

The team partners with federal, industry, and academic collaborators to advance state-of-the-art instrumentation, models, and analysis methods to improve how we use scientific tools and enhance knowledge about the lower atmosphere. Key advances include a patent-pending Miniature Airborne Spectrometer for nitrogen dioxide and new calibration techniques for airborne volatile organic chemicals and organic nitrate measurements via Chemical Ionization Mass Spectrometry.

Collaboration with the Environmental Protection Agency improved air quality forecasting via the Community Regional Atmospheric Chemistry Multiphase Mechanism. Combined chamber and airborne data analysis yielded new insights into secondary aerosol formation. The five-year objectives aim to advance new and existing measurement capabilities to improve research operations.



CIRES Tropospheric Chemistry Program scientists collaborate with federal, industry, and academic partners to advance state-of-the-art instrumentation and analysis methods.

Credit: Ilana Pollack/CIESRDS

Project: Collecting combined measurements of aerosol composition and size distribution to constrain stratospheric aerosol processes

CIESRDS contributors: Michael Lawler, Ming Lyu, Adam Ahern, Maya Abou-Ghanem, Samuel Taylor, Anthony Fodel, Tegan Brown, Dan Law, and Rudra Pokhrel

Relevance to NOAA: This work shows that human activity influences the composition of stratospheric aerosols by introducing debris from spacecraft re-entry. Although the result of this changing composition is unknown, it is likely to increase in importance as space launches are increasing in frequency.

Stratospheric aerosols affect Earth's global radiative balance and the ozone layer directly by scattering sunlight back into space and indirectly by influencing cloud formation. This team is part of the SABRE (Stratospheric Aerosol Budget and Radiative Effects) project and uses instruments onboard a high-altitude aircraft to better understand stratospheric aerosol composition, size, and the processes that dictate their physical characteristics. This work identifies the sources of particles in the stratosphere and the relative contributions of those sources to the stratosphere's total aerosol load.

So far, the team has designed and developed the PALMS-NG instrument, the next-generation version of NOAA's Particle Analysis by Laser Mass Spectrometry (PALMS) instrument. The team also updated a version of the Nucleation Mode Aerosol Sizing Spectrometer (NMASS) instrument. Both instruments were deployed successfully on two missions - one in Alaska in 2023 and one in Houston in 2025.

The researchers have published several papers on their results, with one focusing on the fate of stratospheric aerosols that originate in the polar vortex. The results of this study showed that essentially all particles entering the stratosphere through the polar vortex and mixing with background air were made of sulfuric acid, with a small amount of metals derived from meteors and satellites burning up in the upper atmosphere.

Over the next five years, the researchers will continue to investigate how stratospheric aerosols form, with a deployment planned in Panama in 2026, aiming to collect data near the equator where many of these processes take place.

CIESRDS researcher Mike Lawler installs the PALMS (Particle Analysis by Laser Mass Spectrometry) instrument into the nose of the WB-57 for the 2022 SABRE field campaign.
Credit: Chelsea Thompson/NOAA CSL

Project: Investigating the feasibility of marine cloud brightening

CIESRDS contributors: Jianhao Zhang, Jung-Sub Lim, Takanobu Yamaguchi, Michael Diamond, Prasanth Prabhakaran, Isabel McCoy

Relevance to NOAA: Improved understanding of how marine cloud brightening would operate in real atmospheric conditions supports evidence-based decision-making for evaluating climate intervention techniques and advances NOAA's mission to understand and predict changes in climate, weather, oceans, and coasts.

This project provides the scientific foundation to assess the viability, effectiveness, and risks of marine cloud brightening (MCB) as a potential strategy for climate intervention. MCB involves spraying fine aerosols like sea salt into low-lying ocean clouds to make them brighter and more reflective, sending more sunlight back into space and reducing global temperatures.

CIESRDS researchers on this project use models and observations to investigate how aerosols could be generated and delivered to marine clouds. They also investigate the microphysical feedbacks and how atmospheric circulation would respond to this process. Since September 2022, the team has published six journal papers and led one workshop report, with one publication providing a framework to help organize and prioritize future MCB research.

Over the next five years, the team will refine the scientific basis for MCB and evaluate its performance, feasibility, and risks in modeled but realistic real-world scenarios. They also plan to target studies of summertime MCB applied to Arctic mixed-phase stratocumulus clouds as a potential strategy to slow sea ice loss and protect the polar climate system.

A diagram of the current state of scientific knowledge of marine cloud brightening (MCB). The scientific consensus is that research on MCB should proceed on all proposed physical science, ethical, and social science checkpoints simultaneously.
Credit: Michael Diamond/CIESRDS and Chelsea Thompson/NOAA CSL

Project: Distinguishing solar radiation management from natural variability

CIESRDS contributors: Jianhao Zhang, Yaosheng Chen

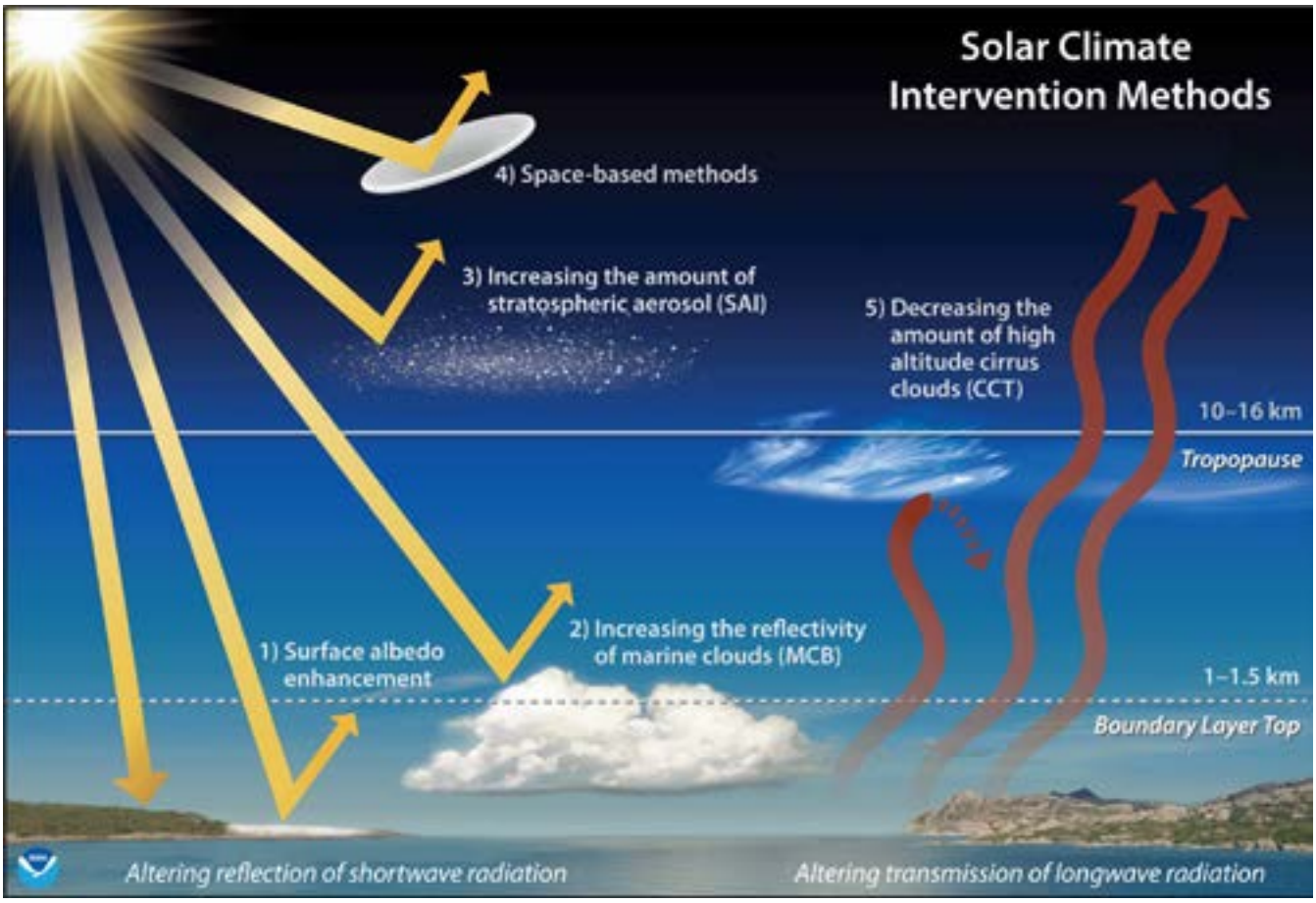
Relevance to NOAA: This project improves NOAA's ability to distinguish solar radiation management (SRM) signals from natural climate variability. This work ensures that any deployment of SRM could be scientifically verified and transparently monitored. NOAA and the scientific community can then evaluate its effectiveness and maintain accountability in climate intervention decisions.

Solar radiation management (SRM) refers to proposed techniques to cool Earth's surface by reflecting a small fraction of sunlight back into space. SRM methods currently being researched include stratospheric aerosol injection and marine cloud brightening.

One challenge for scientists studying SRM is determining whether its effects on climate can be distinguished from natural variability. This makes robust detection assessment essential for responsible deployment and evaluation.

CIESRDS researchers on this project assess the detectability of SRM signals using satellite remote sensing data, meteorological reanalysis, global climate model simulations and data-driven statistical approaches. Since September 2022, the researchers have published a high-impact paper on the detectability of deliberate aerosol perturbations for climate intervention that resulted in four news articles and four invited talks. They also secured funding to investigate the detectability of stratospheric aerosol injection.

Over the next five years, the researchers will use climate simulations to quantify how clearly they can distinguish stratospheric aerosol injection signals from natural variability. They will also extend this work to scenario-based global simulations of marine cloud brightening to determine how confidently they can detect and attribute climatic impacts.



An illustration of different solar radiation management techniques and how they could work.
Credit: Chelsea Thompson/NOAA CSL

Project: Investigating the effects of stratospheric aerosol injection

CIESRDS contributors: Jake Gristey, Takanobu Yamaguchi

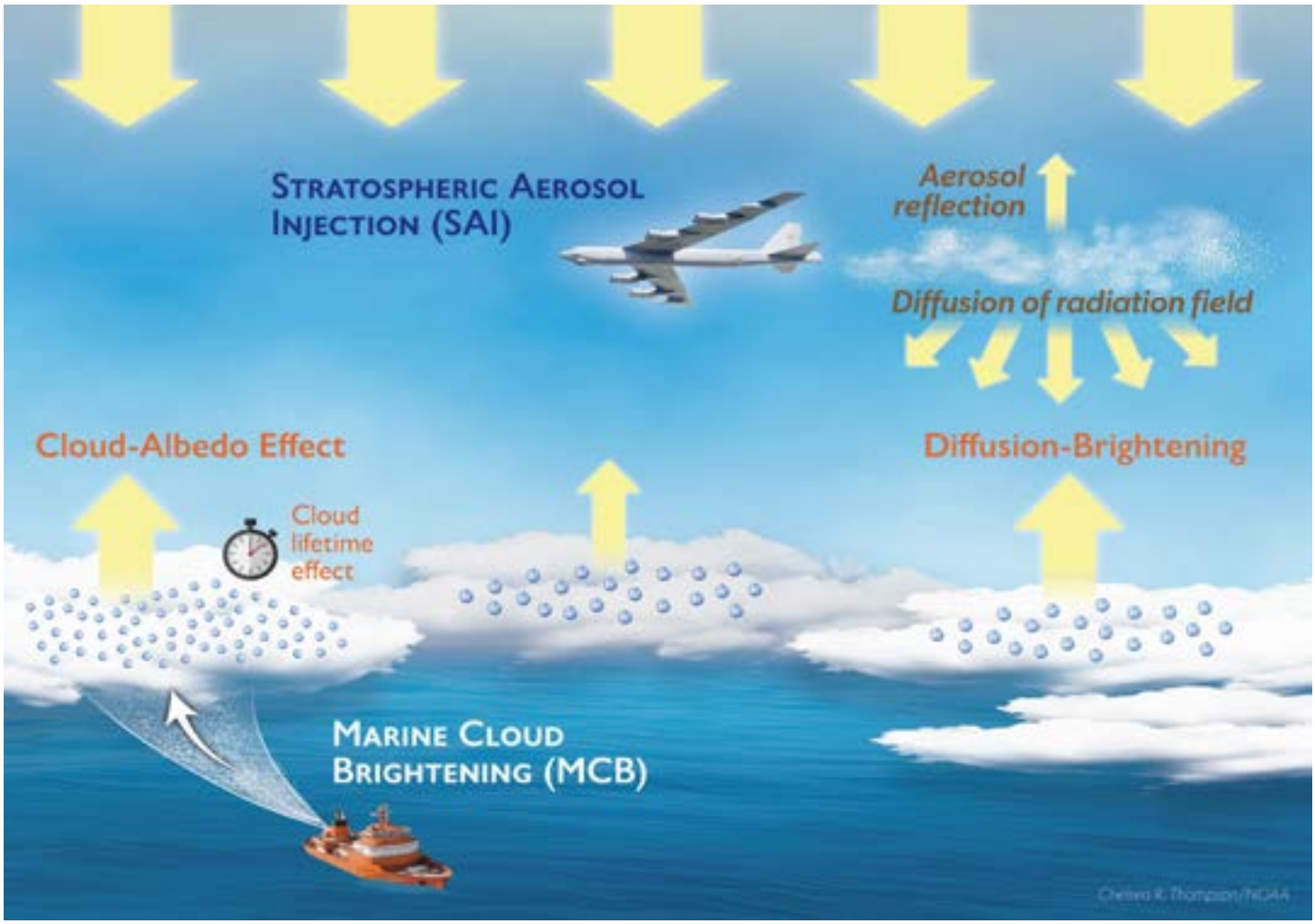
Relevance to NOAA: This research reveals a new pathway for stratospheric aerosol injection (SAI) to influence marine clouds. This work quantifies this new mechanism, so NOAA and the community will have better tools to assess the climate risks, benefits, and tradeoffs of SAI strategies.

Stratospheric Aerosol Injection (SAI) is a proposed solar radiation management technique to cool Earth's surface by spraying reflective particles, such as sulfur dioxide, into the upper atmosphere to reflect sunlight and cool the planet.

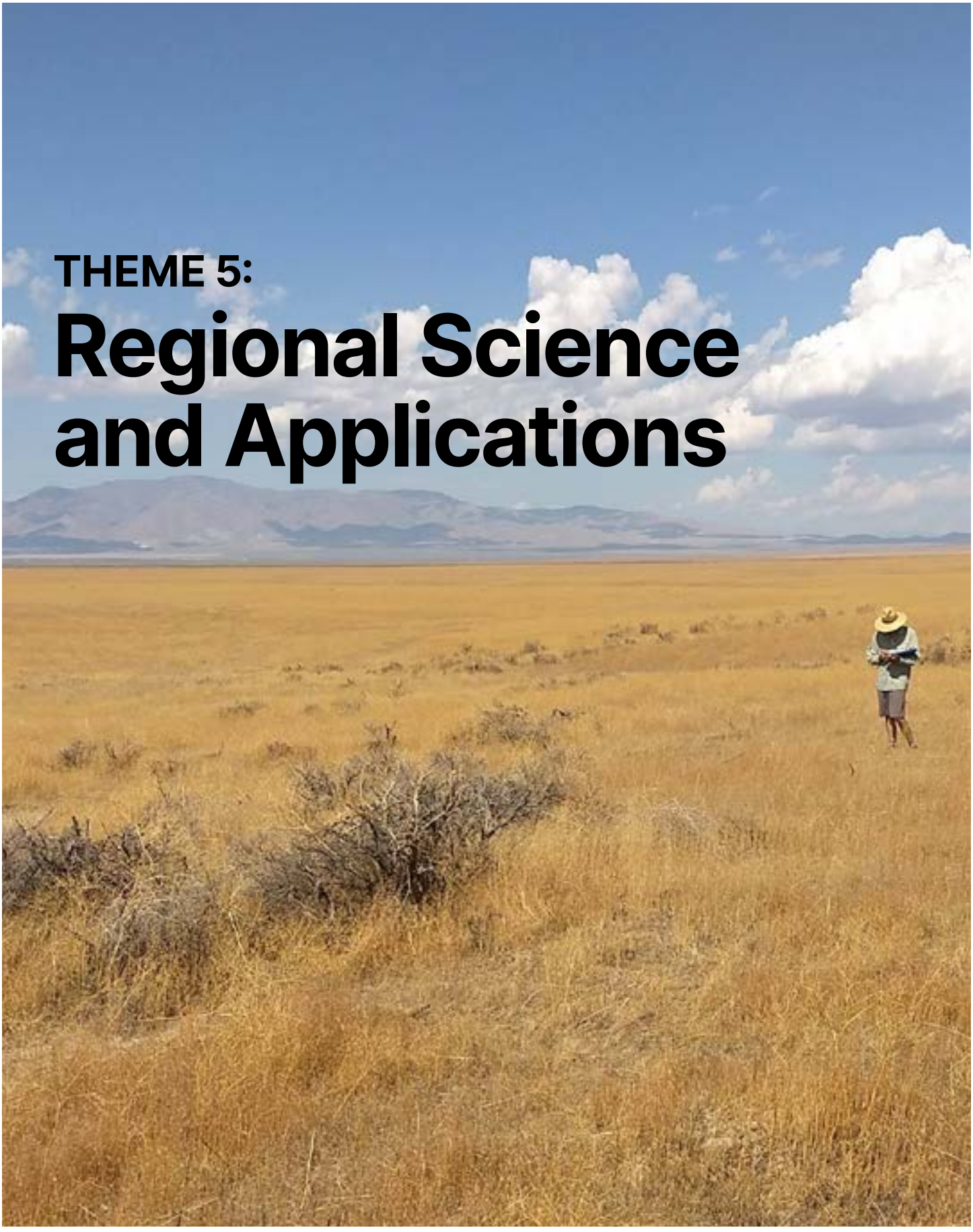
CIESRDS researchers on this project use climate models to estimate the global magnitude of SAI impacts on Earth's atmospheric circulation and high-resolution, large-eddy simulations to investigate how SAI affects shallow convection (cumulus clouds that don't produce precipitation).

Since 2022, the researchers have published a high-impact paper showing that SAI could indirectly make marine clouds brighter, meaning SAI could have a larger cooling effect than scientists previously thought.

Over the next five years, the researchers will use climate model output to quantify the global magnitude of SAI-induced marine cloud brightening and assess its potential climatic significance. They will also use high-resolution, large-eddy simulations to investigate how radiative enhancement interacts with cloud–turbulence dynamics.



An illustration showing how injecting particles into the stratosphere to deflect some of the sun's rays would also brighten marine clouds and enhance cooling.
Credit: Chelsea Thompson/NOAA CSL



THEME 5:

Regional Science and Applications

A scientist studies a post-fire plant community in Nevada. The dead shrubs in the foreground survived the fire, but subsequently died from drought stress because invasive grasses that dominate the post-fire landscape changed the soil hydrology.

Credit: Adam Mahood/CIRES

REGIONAL SCIENCE AND APPLICATIONS

CIESRDS has developed unique expertise in regional science and applications because the impacts of climate variability and change—and drought, specifically—are felt so strongly at regional scales. Key CIESRDS work in this realm includes transitioning research products to operations, developing decision support tools for the National Weather Service, and advancing research on hydrologic extremes.

In late 2025, the National Weather Service's Climate Prediction Center operationalized the Evaporative Demand Drought Index (EDDI), a drought early warning tool developed by CIESRDS scientists. EDDI provides forecasters with early warning of agricultural drought conditions, detection of flash drought, and warning of wildfire risk.

CIESRDS scientists are instrumental members of NOAA's National Integrated Drought Information System (NIDIS), which monitors drought conditions continuously, supports proactive (mitigation) and reactive (emergency) responses, triggers actions within state and local drought response plans, and ensures coordination between federal, state, and local governments.

Most recently, CIESRDS staff at NIDIS built an online Mississippi River Basin Drought and Water Dashboard, which provides real-time drought and water level information for the entire Mississippi River basin. The dashboard is an efficient communications and decision-support resource for state and local governments and the private sector, helping them proactively prepare for and mitigate the impacts of drought and low water in their communities.

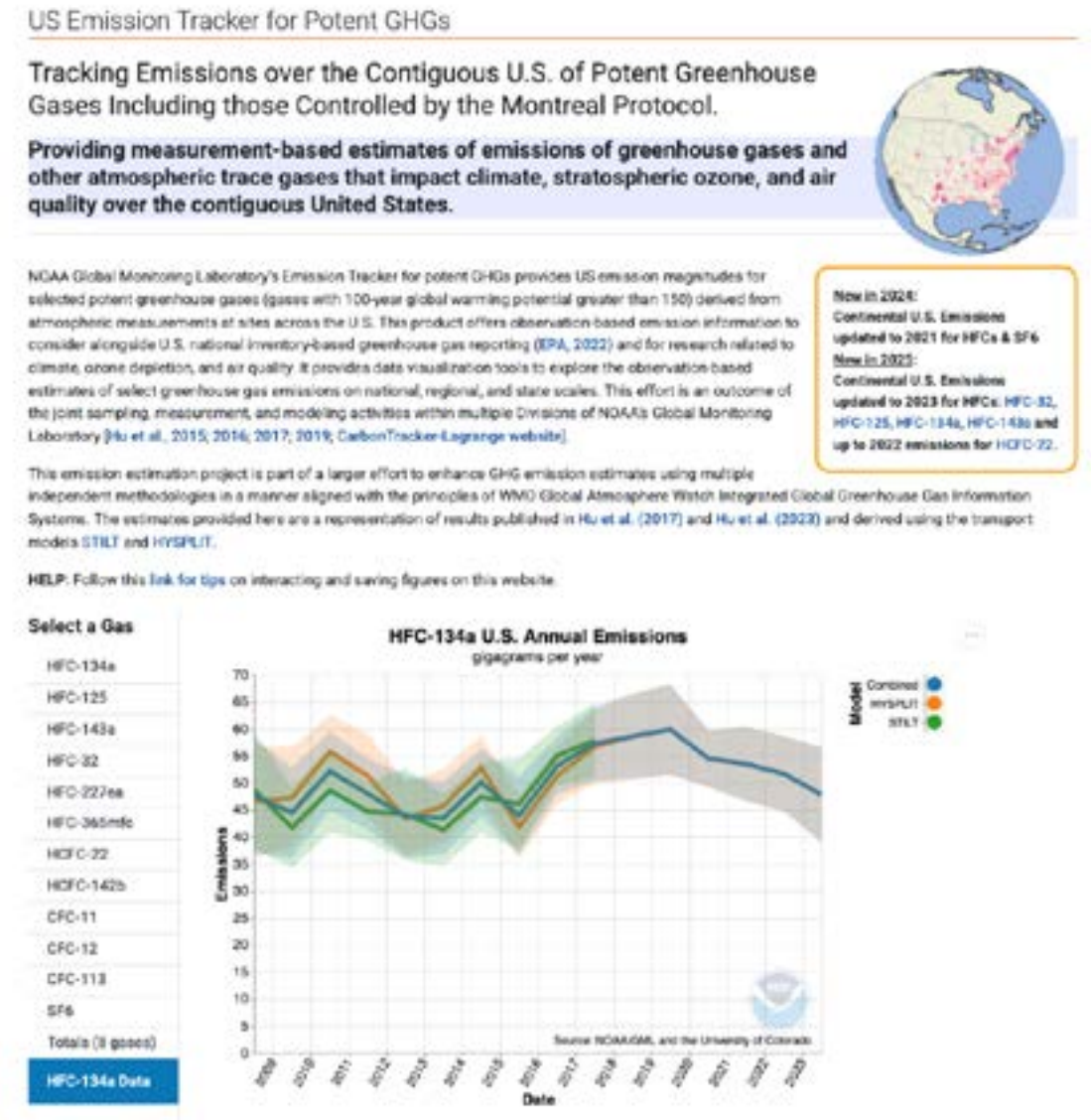
CIESRDS scientists also conducted a field campaign in Colorado's West Elk Mountains to advance weather and water prediction capabilities in areas with complex terrain.

Project: Tracking emissions of potent greenhouse gases

CIESRDS contributors: Geoff Dutton

Relevance to NOAA: This project strengthens NOAA's mission by providing independent, observation-based estimates of U.S. greenhouse gas emissions, including substances regulated by the Montreal Protocol.

This project delivers observation-based estimates of U.S. emissions of potent greenhouse gases—many regulated under the Montreal Protocol—using NOAA Global Monitoring Laboratory's (GML) long-term atmospheric measurements and advanced transport modeling. Annual updates incorporate new measurements for hydrofluorocarbons (HFCs), sulfur hexafluoride, and HCFC-22 to provide independent evaluations of national inventory reports. NOAA's emission tracker offers transparent, policy-relevant emissions data and interactive visualization tools. Since 2022, the team has provided periodic updates of regional emissions. Over the next five years, the team will routinely update regional emissions of ozone-depleting substances.



Website for U.S. Emission Tracker for Potent GHGs.
Credit: NOAA GML

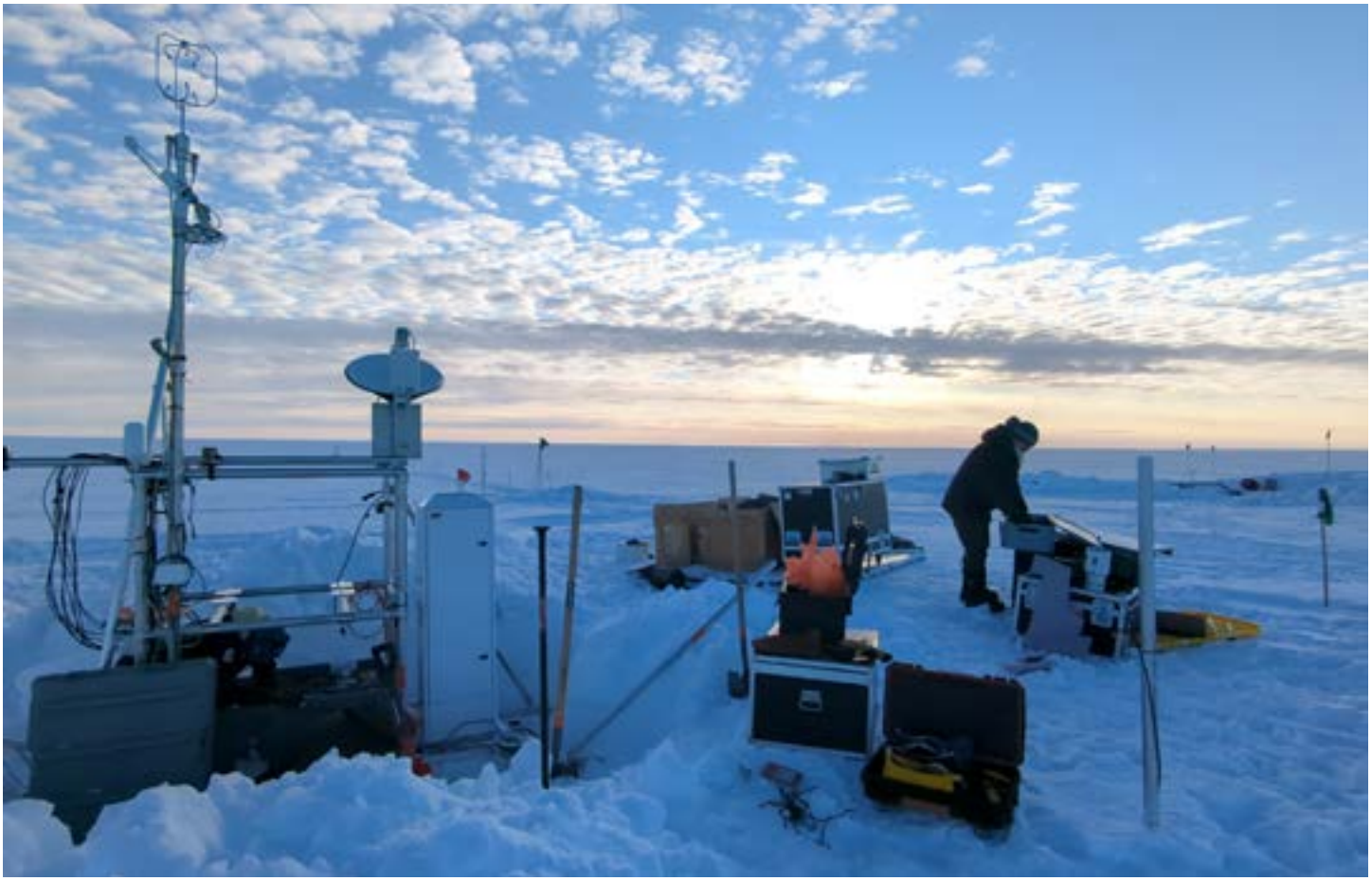
Project: Quantifying seasonal and conditional variability of the Arctic surface energy budget

CIESRDS contributors: Matthew Shupe, Anne Sledd, Michael Gallagher, Ola Persson

Relevance to NOAA: The project advances process understanding that underpins NOAA's goal to improve forecasts of weather, climate, and sea ice in support of Arctic communities, operations, and management.

This project quantifies all components of the surface energy budget over sea ice and other Arctic surfaces. By combining observational and modeling perspectives, the project is able to characterize the seasonal, regional, and condition-dependent processes that drive variability in the energy budget, with implications for cryospheric stability.

Since 2022, the team has produced eight datasets, 28 conference presentations, and 13 journal articles. Over the next five years, the researchers will synthesize observations across different Arctic domains, quantify energy responses to variability in clouds, and advance understanding and model parameterizations of surface turbulent heat exchange. These efforts will provide the generalized knowledge and advanced model assessments needed to improve predictive capabilities of Arctic weather and sea ice.



Researchers set up instruments in Greenland to measure Arctic energy flux.
Credit: Anne Sledd/CIESRDS

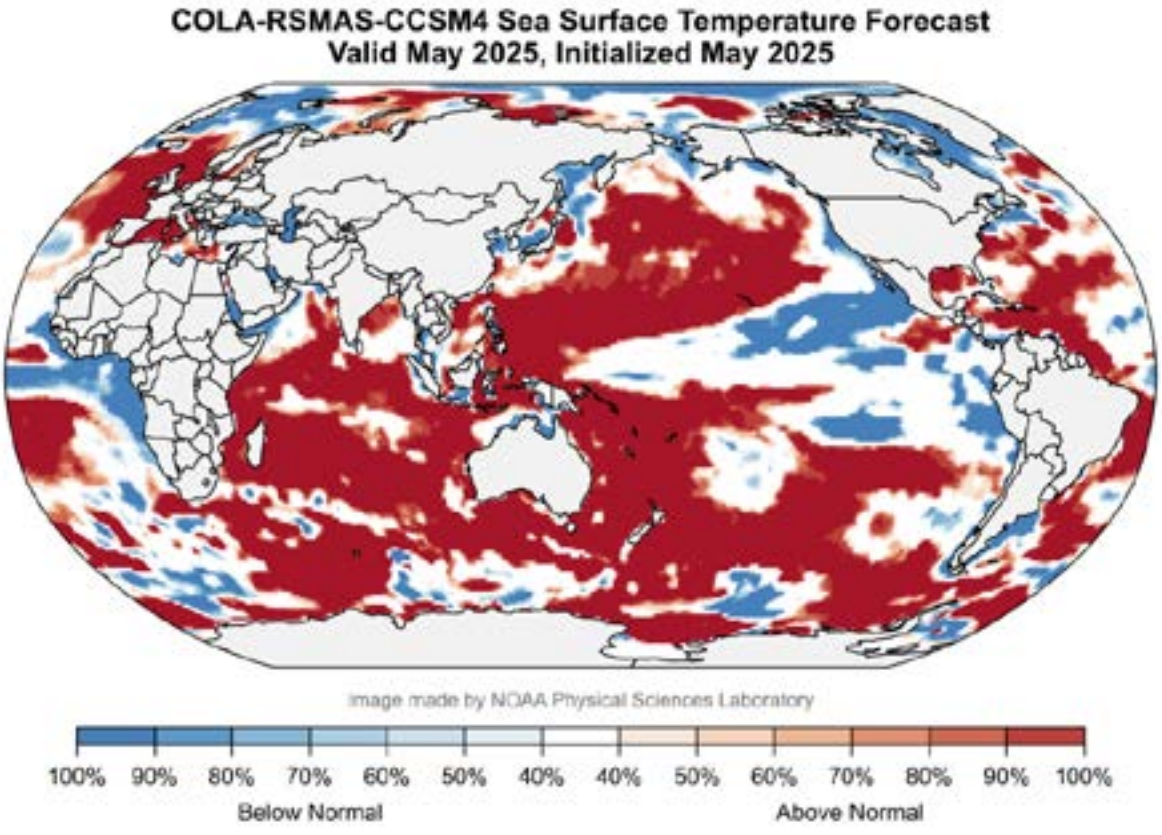
Project: Improving drought and climate forecasts for food-insecure regions

CIESRDS contributors: Mike Hobbins, Rachael Robinson, Kinya Toride

Relevance to NOAA: This project improves drought and climate forecasts for food-insecure regions around the globe, enabling scientists to warn communities of potential food shortages up to 12 months in advance. This empowers governments and humanitarian organizations to take proactive measures, reducing hunger risk and strengthening resilience for millions of vulnerable people worldwide.

CIESRDS scientists in NOAA's Physical Sciences Laboratory support the Famine Early Warning System Network (FEWS NET) by providing hydroclimatic monitoring and forecasting to improve food security in vulnerable regions of Africa, Central Asia, and Central America. Key products include seasonal forecast applications that advise on acute food insecurity up to 12 months in advance, a global daily evaporative demand dataset for the FEWS NET science community, and a webpage featuring four forecasted variables from five North American Multi-Model Ensemble (NMME) models focused on food-security-relevant regions.

Since 2022, the team has strengthened global food security by delivering hydroclimatic monitoring and forecasting for FEWS NET in Africa, Central Asia, and Central America. Their work enables seasonal forecast applications that predict acute food insecurity up to 12 months ahead of time, supports decision-making with a global daily evaporative demand dataset, and provides a dedicated webpage featuring four key forecast variables from five NMME models for food-security-critical regions. These tools empower stakeholders to act early and mitigate hunger risks. In the next five years, the project will incorporate a new decomposition of evaporative demand into drought and wildfire research and products, improving predictive capabilities and risk assessment. This advancement will engage new users across drought, food-security, and wildfire science and management communities, fostering broader adoption and informed decision-making for climate resilience.



North American Multi-Model Ensemble (NMME) Monthly to seasonal forecasts. This is output from the Center for Ocean-Land-Atmosphere Studies (COLA)-Rosentiel School of Marine, Atmospheric, and Earth Science (RSMAS)-Community Climate System Model (CCSM) of forecasts of sea surface temperature.

Credit: NOAA PSL

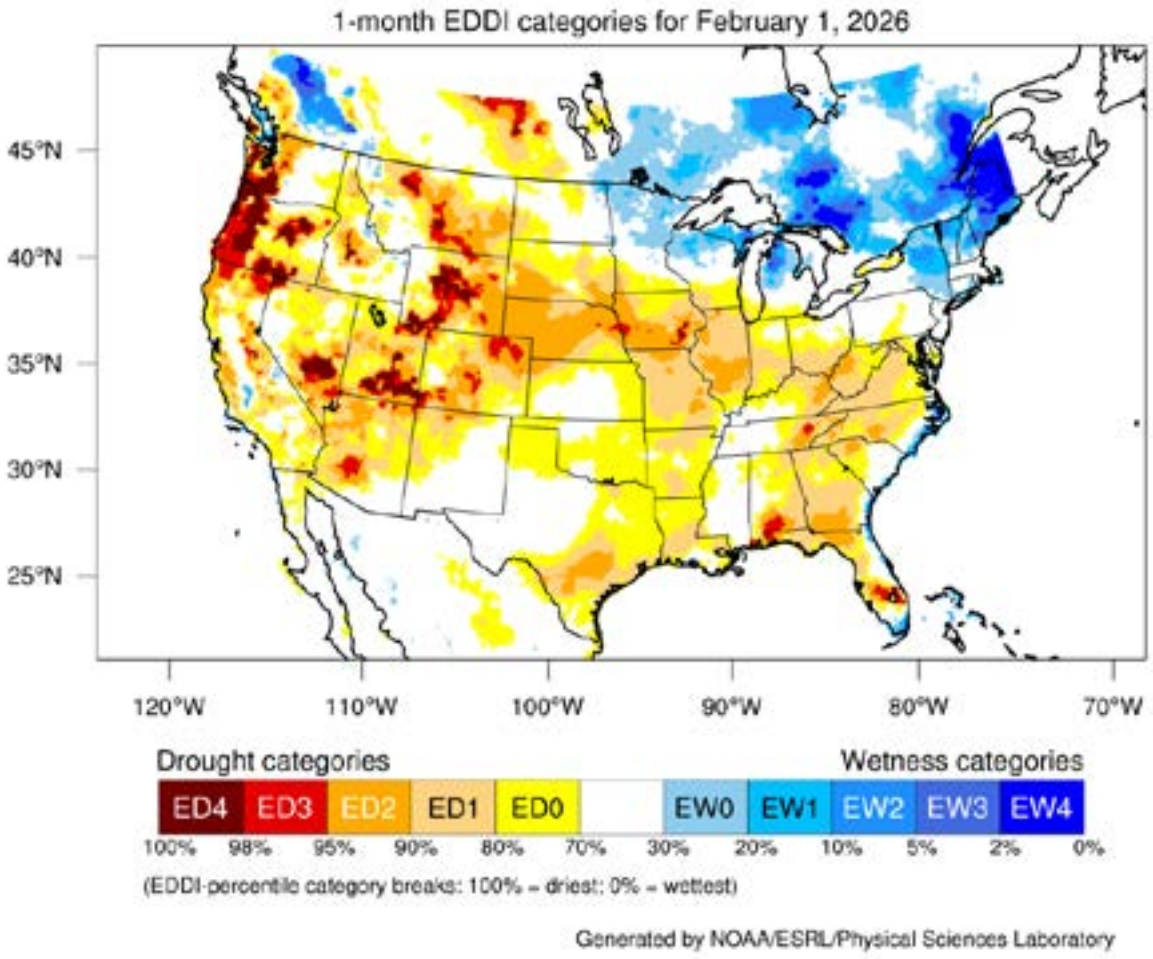
Project: Operationalizing hydrologic extreme tools

CIESRDS contributors: Kinya Toride

Relevance to NOAA: By advancing drought and wildfire prediction tools, this project enables earlier warnings and more accurate risk assessments, protecting agriculture, water resources, and communities. These innovations empower decision-makers to mitigate food insecurity, reduce economic losses, and safeguard lives, strengthening resilience against climate extremes across the U.S. and beyond.

CIESRDS scientists in NOAA's Physical Sciences Laboratory develop hydrologic extreme tools for NOAA and the National Weather Service (NWS). A notable tool they have developed is the Evaporative Demand Drought Index (EDDI), which supports drought monitoring, early warning, flash drought detection, and wildfire risk assessment. A successful two-year research-to-operations process transitioned EDDI to NWS's Climate Prediction Center, where it now informs national drought outlooks and forecast capabilities. The team has also created value-added products like EDDI-change maps and driver decomposition.

Since 2022, the research-to-operations process delivered groundbreaking outcomes, including the world's first analytical decomposition of evaporative demand, enabling diagnosis of land-atmosphere exchange drivers. Over the next five years, the team will create an end-to-end testing framework to improve NWS ensemble streamflow predictions. Future upgrades will include full North American coverage, 1-kilometer resolution, and 7-hour latency, dramatically enhancing accuracy, timeliness, and utility for water resource management and hazard preparedness.



One-month Evaporative Demand Drought Index (EDDI) categories for February 1, 2026. West is mostly dry, red hues; Midwest mixed; Northeast and upper Midwest wet, blue hues.

Credit: NOAA PSL

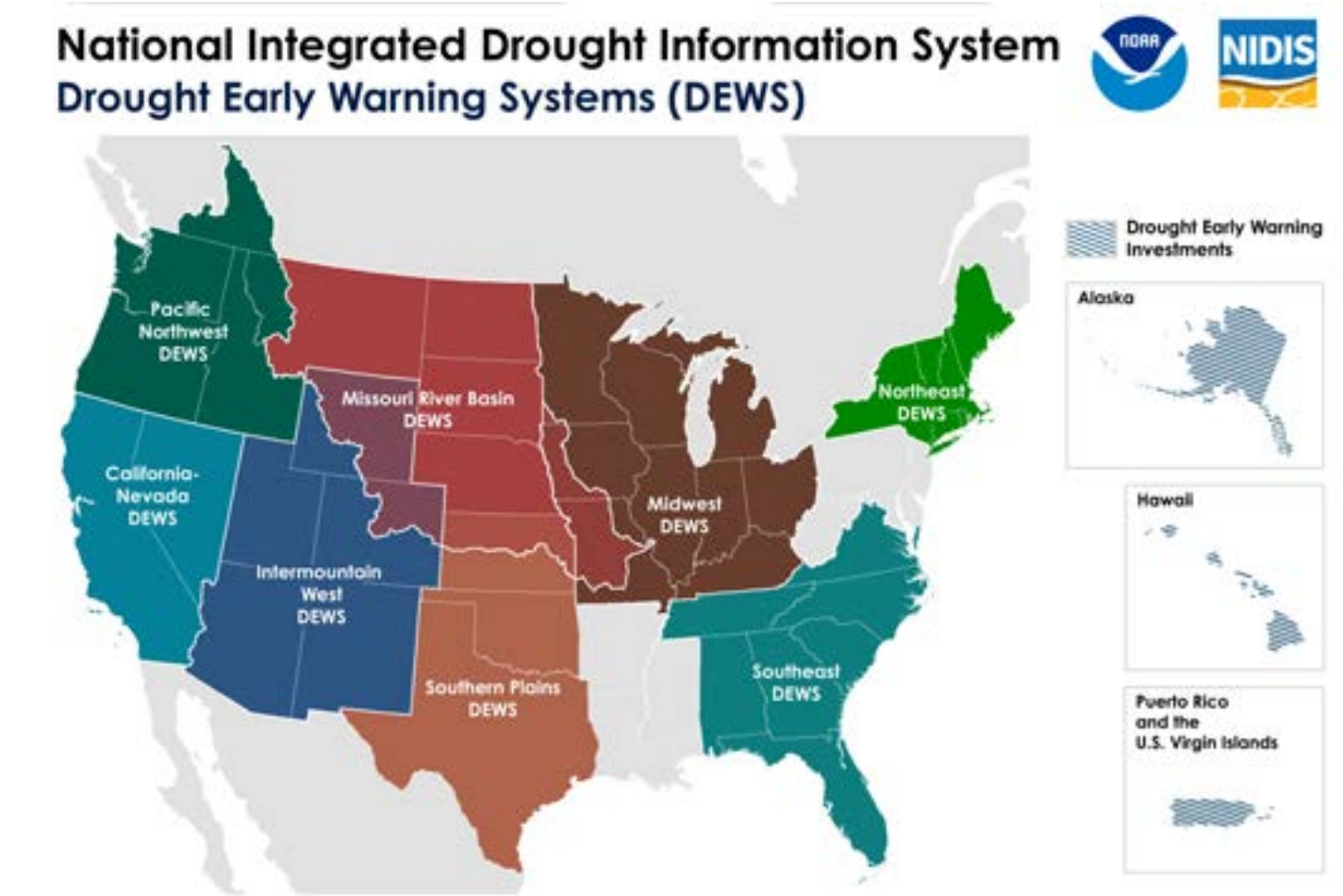
Project: Leading regional drought early warning systems

CIESRDS contributors: Amanda Sheffield, Molly Woloszyn, Jason Gerlich, Joel Lisonbee, Crystal Stiles, Elise Osenga, Adam Lang, Kelsey Eigsti, Eleanor Hasenbeck, Britt Parker, Gretel Follingstad

Relevance to NOAA: This project provides effective drought early warning systems and allows NOAA to provide real-time, actionable data to improve long-term drought resilience and preparedness across the United States.

This project improves the capacity of farmers, ranchers, water suppliers, wildfire managers, and other decision-makers to plan for, forecast, monitor, and cope with the impacts of drought. This is accomplished through a network of partners that work together to prepare a region for drought. The National Integrated Drought Information System (NIDIS) monitors conditions continuously, supports proactive (mitigation) and reactive (emergency) responses, triggers actions within state and local drought response plans, and ensures coordination between federal, state, and local governments.

NIDIS is the lead NOAA program responsible for drought early warning information. This project is a crucial contribution from CIESRDS to NIDIS's mission. Since 2022, the team released 135 drought status updates and 72 drought.gov news articles, hosted 93 drought webinars and 10 in-person drought early warning system meetings, as well as regularly reaching over 17,000 people via listserv outreach and over 21,500 people via social media. Over the next 5 years, NIDIS will continue to provide the nation with the best available drought early warning information, supporting proactive drought management and coordination amongst federal, Tribal, state, and local partners. They will continue to support and integrate the best available drought monitoring and prediction information available.



Map of NIDIS Drought Early Warning Systems (DEWS). DEWS is a network of regional and national partners that share information and coordinate actions to help communities in the region cope with drought.
Credit: NIDIS

Project: Developing the Mississippi River Basin Drought & Water Dashboard

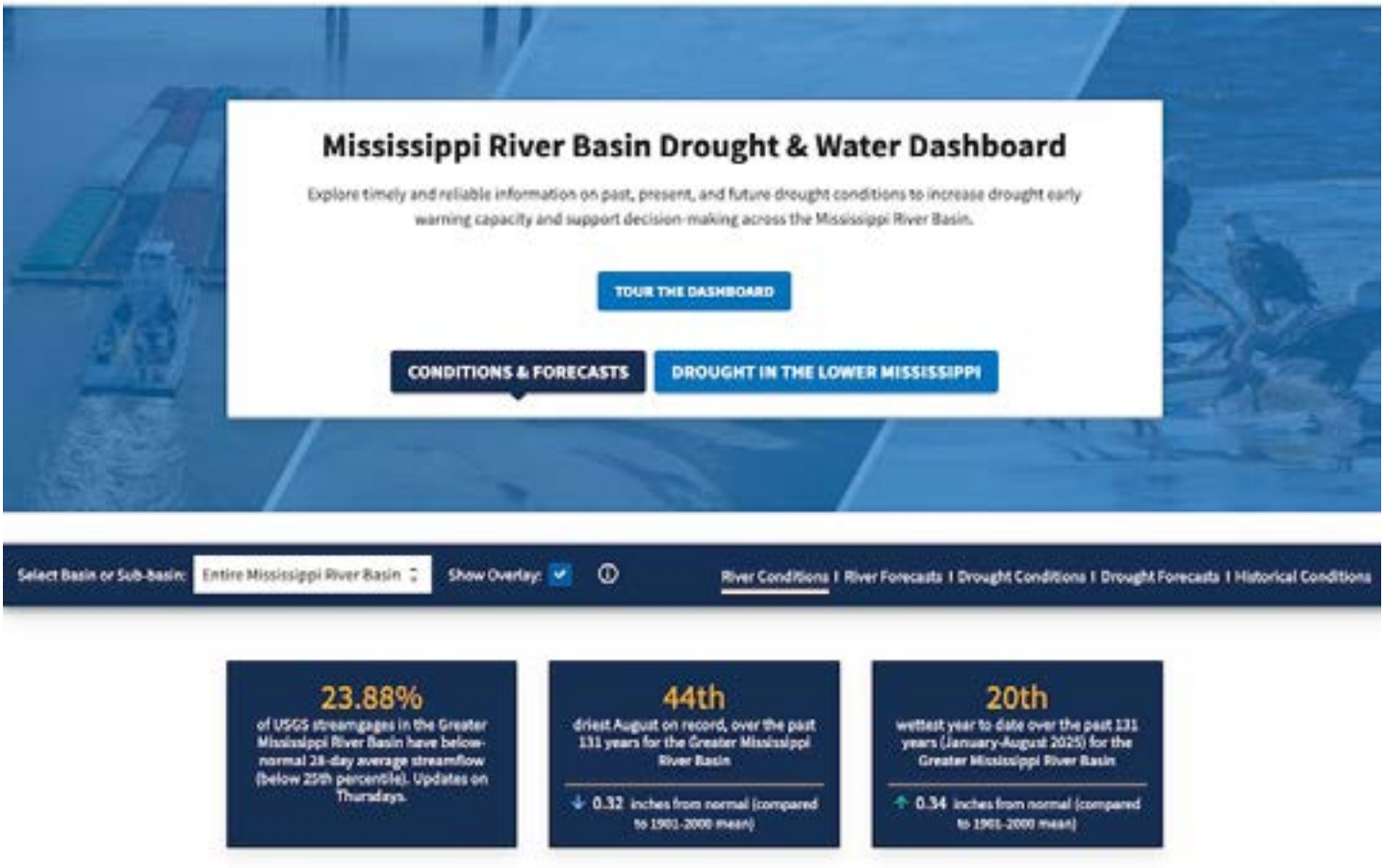
CIESRDS contributors: Kelsey Eigsti, Molly Woloszyn, Eleanor Hasenbeck

Relevance to NOAA: This dashboard provides an efficient communications and decision-support resource for state and local governments and the private sector. The tool helps entities proactively prepare for and mitigate the impacts of drought and low water in their communities. The tool forwards the mission of NOAA to provide a "continuous delivery of a range of…data sets for use by public, private, and academic sectors."

The Mississippi River Basin Drought and Water Dashboard was developed to allow users to view timely river and drought conditions for the entire 31-state Mississippi River Basin, as well as sub-basins. It was co-developed with partners and users across the basin and integrates federal agency river and drought data in one place. The dashboard provides actionable, user-friendly, and reliable information essential for risk-informed decision-making across the Mississippi River Basin.

In late 2024 and early 2025, team members engaged stakeholders to inform development of the dashboard. Launched in September 2025, the dashboard was developed by NIDIS/CIESRDS and built by the U.S. Drought Portal team at NOAA's NCEI, in close collaboration with the National Weather Service, the U.S. Army Corps of Engineers, the U.S. Coast Guard, the U.S. Geological Survey, state and local government agencies, and industry organizations.

Over the next five years, project team members will be able to operationally provide timely drought information to the basin as well as evaluate its ability to inform decisions, mitigate drought impacts, and improve drought early warning in the region.



Screenshot of the Mississippi River Basin Drought and Water Dashboard.
Credit: NIDIS/drought.gov

Project: Establishing atmospheric river observatories and other weather stations across the U.S.

CIESRDS contributors: Don Murray, Paul Johnson, Dave Costa

Relevance to NOAA: This project improves understanding of weather processes and various forecast models, specifically relating to water. Data generated by this project improve NOAA weather models, contributing to better public flood warnings, and more. Data and products derived from the data are shared with researchers and the general public.

This project established a set of distributed weather stations across parts of the United States. Observed data includes meteorological, radar, rainfall, winds, and more. Data and plots are available to weather forecasters and researchers for use in operational forecasting and in research projects. Since 2022, this data has been used for NOAA operational forecast models and numerous journal publications. The data is also used for model verification and to help improve model physics. There have been two million pageviews a year of the dashboard. Over the next five years, the researchers will make the observational data self-describing and ready for machine learning while creating data downloads that are more intuitive and useful. The team also hopes to add additional stations while making model comparisons easier.

PSL observation network. Green dots indicate data received in the last 3 hours, yellow indicates no data in the last 3 hours, and red indicates no data in the last 12 hours.
Credit: NOAA PSL

Project: Advancing weather and water prediction capabilities in areas with complex terrain

CIESRDS contributors: J. Hamilton, Gijs de Boer, Dave Costa

Relevance to NOAA: The project aims to learn more about the weather processes in the United States, particularly snow and water. The project advances weather and water prediction capabilities in areas with complex terrain, where forecasting can be challenging. This will allow NOAA's National Weather Service to improve their forecast models and provide improved products for the general public, such as warnings or water and snow forecasts.

CIESRDS researchers on this project conducted the Study of Precipitation, the Lower Atmosphere and Surface for Hydrometeorology (SPLASH) field campaign in 2023, which involved installing a comprehensive, state-of-the-art observing network in the East River watershed in Colorado's West Elk mountains. Their goal was to advance weather and water prediction capabilities in areas with complex terrain. The team created a webpage that allowed the researchers and others to view important information during the project. The page allowed users to download the processed data, understand the experiment's set up, and read about the project goals. The team has written a number of publications using the data, and archived over40 datasets.. Using the datasets, researchers now have access for research or other purposes, and the data will help determine what processes needed more research.

Researchers install instruments near Crested Butte, Colorado to improve water prediction in complex terrain.
Credit: Patrick Cullis/NOAA

THEME 6:

Space Weather Science and Prediction

Solar activity caused auroras on Earth as far south as 40 degrees North (across the middle of the continental United States) in 2025.
Credit: Garrett Campbell/NSIDC

SPACE WEATHER SCIENCE AND PREDICTION

NOAA's Space Weather Prediction Center (SWPC) is the nation's source of space weather forecasts and information on solar events that can impact Earth and its surrounding space environment. CIESRDS scientists and developers have been instrumental to SWPC's successes, streamlining data processing and transitioning forecast products from research to operations, ensuring users receive timely, actionable space weather information. This work ultimately serves decision-makers who seek to mitigate the significant societal, economic, health, and national security impacts of severe space weather.

Key CIESRDS work in this realm includes calibrating and validating space weather monitoring instruments aboard NOAA satellites, preparing for future space weather satellite missions, developing a next-generation coronal mass ejection analysis tool, and building a global total electron content model of Earth's ionosphere.

A major CIESRDS success has been providing support for the Space Weather Follow-On Lagrange 1 (SWFO-L1) satellite, NOAA's new dedicated space weather satellite that provides 24/7 monitoring of solar activity. SWFO-L1 launched in September 2025 and reached its final orbit at the Earth-Sun Lagrange Point 1 (L1) in January 2026. It is the world's first operational satellite dedicated to space weather monitoring and forecasting.

CIESRDS scientists developed the product generation system for the Compact Coronagraph 1 (CCOR-1) instrument on the GOES-19 satellite and transitioned it to operations in April 2025, work for which the team received a 2025 NESDIS Outstanding Science and Research Team Award. NESDIS provides secure and timely access to global environmental data and information from NOAA satellites to promote and protect the nation's security, environment, economy, and quality of life. CIESRDS researchers take raw data from NESDIS's constellation of weather and environment-monitoring satellites and create vital products and services used by the National Weather Service, the Space Weather Prediction Center, U.S. researchers, the commercial sector, and private citizens. CCOR-1 is the world's first operational coronagraph generator, providing NOAA with the first truly operational observations of the solar corona.

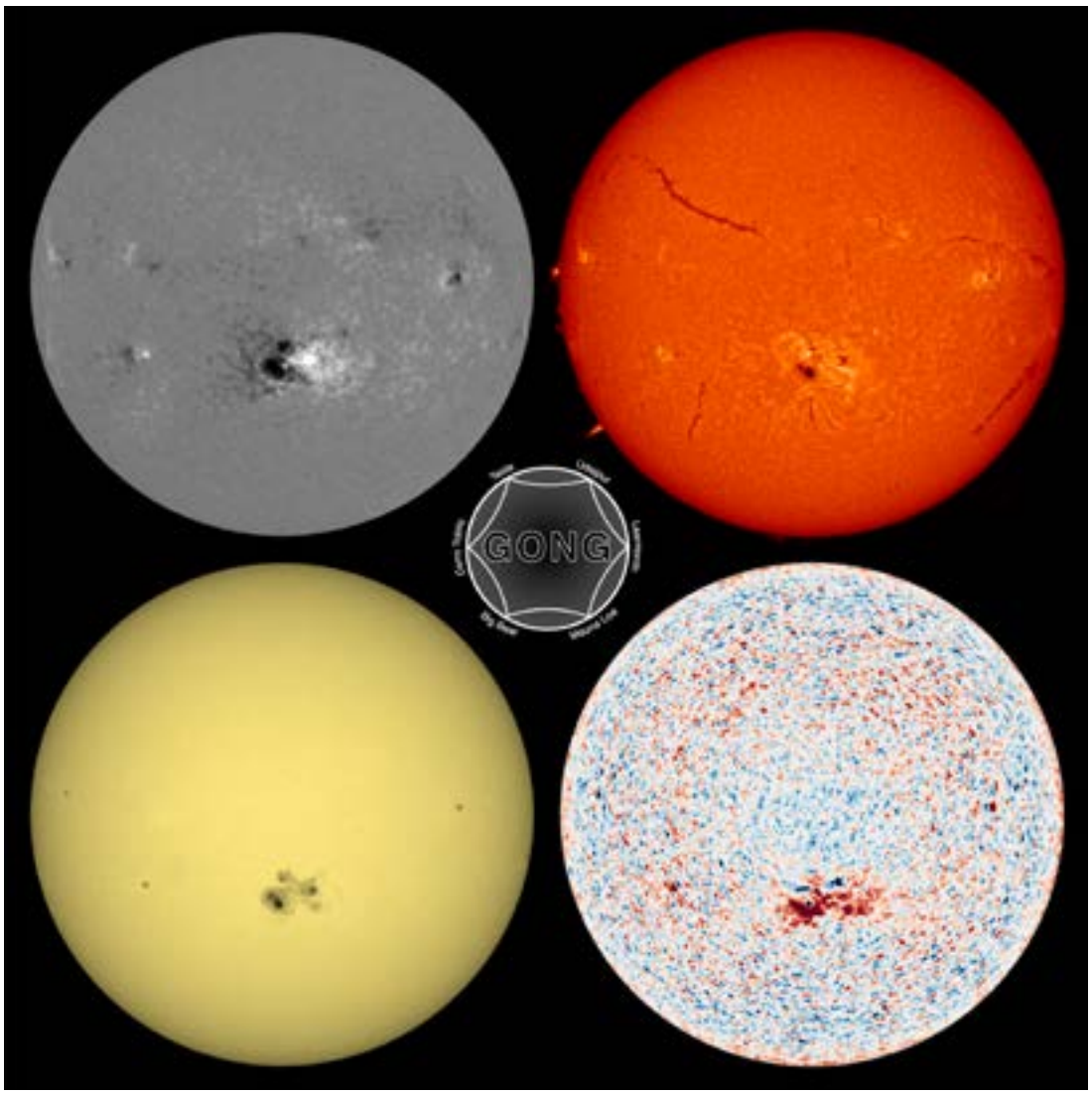
Project: Global Oscillations Network Group (GONG) data processing

CIESRDS contributors: Andy Marble, Owen Ahlers

Relevance to NOAA: This work provides initial early warning of extreme solar activity that can seriously impact Earth and its surrounding space environment, improving NOAA space weather forecasts.

The Global Oscillations Network Group (GONG) network consists of six identical ground-based telescopes spread around the Earth designed to have 24/7 observations of the Sun. The GONG network produces four different solar images every minute to create 71 distinct data products and generate over 14 million data files per year.

Since 2022, CIESRDS researchers have conducted ten reprocessing campaigns for GONG data, implemented over 20 patches/upgrades used by NOAA Space Weather Prediction Center (SWPC) forecasters to monitor solar activity, and provided input to SWPC's solar wind model. The researchers operationalized GONG data processing at SWPC in 2021 and continue to monitor and maintain the system. They unified the SWPC and National Solar Observatory codebase in 2022, developed new prototype visualization tools in 2023 and 2024, and fully containerized the data processing in 2024 and 2025. Over the next five years, they will support operations of the GONG network for at least 10 years and modernize legacy languages in the GONG codebase.



GONG's four views of the Sun (clockwise from top-left): magnetic field strength, h-alpha core intensity, doppler velocity field, continuum intensity.
Credit: Andy Marble/CIESRDS

Project: Product generation and operational support for the Space Weather Follow On (SWFO) satellite

CIESRDS contributors: Jeff Johnson, Nathan Miles, Marty Aubrey, Mark Nakasone, Michael Burek, Ratina Dodani

Relevance to NOAA: This project enhances the robustness of solar coronagraph imagery and provides reliable advanced warnings of Earth-directed solar storms that could harm human infrastructure. The project ultimately advances and improves NOAA's space weather forecasting capabilities, protecting lives and property.

CIESRDS scientists provide support for NOAA's Space Weather Follow-On Lagrange 1 (SWFO-L1) satellite, NOAA's new dedicated space weather satellite that provides 24/7 monitoring of solar activity. SWFO-L1 launched in September 2025 and reached its final orbit at the Earth-Sun Lagrange Point 1 (L1) in January 2026. It is the world's first operational satellite dedicated to space weather monitoring and forecasting.

The team developed the product generation system for SWFO-L1's Compact Coronagraph 1 (CCOR-1) instrument, the world's first operational coronagraph generator. These coronagraphs will provide NOAA with the first truly operational observations of the solar corona.

The scientists developed the CCOR-1 system currently aboard the GOES-19 satellite and transitioned it to operations in April 2025. The team plans to transition the CCOR-1 and other instruments on SWFO-L1 to operations in spring 2026. They will develop new forecaster applications that use the new data, support operations of SWFO-L1 and CCOR-1 for the next 10 years, handle upcoming end-of-life transitions for the ACE and DSCOVR satellite instruments, and perform a cloud migration of SWFO-L1 and CCOR-1 systems.

Rendering of SWFO-L1 spacecraft with a CME spewing from the Sun.
Credit: NOAA and BAE Systems

Project: Providing space weather measurements from NOAA Geostationary Operational Environmental Satellites (GOES)

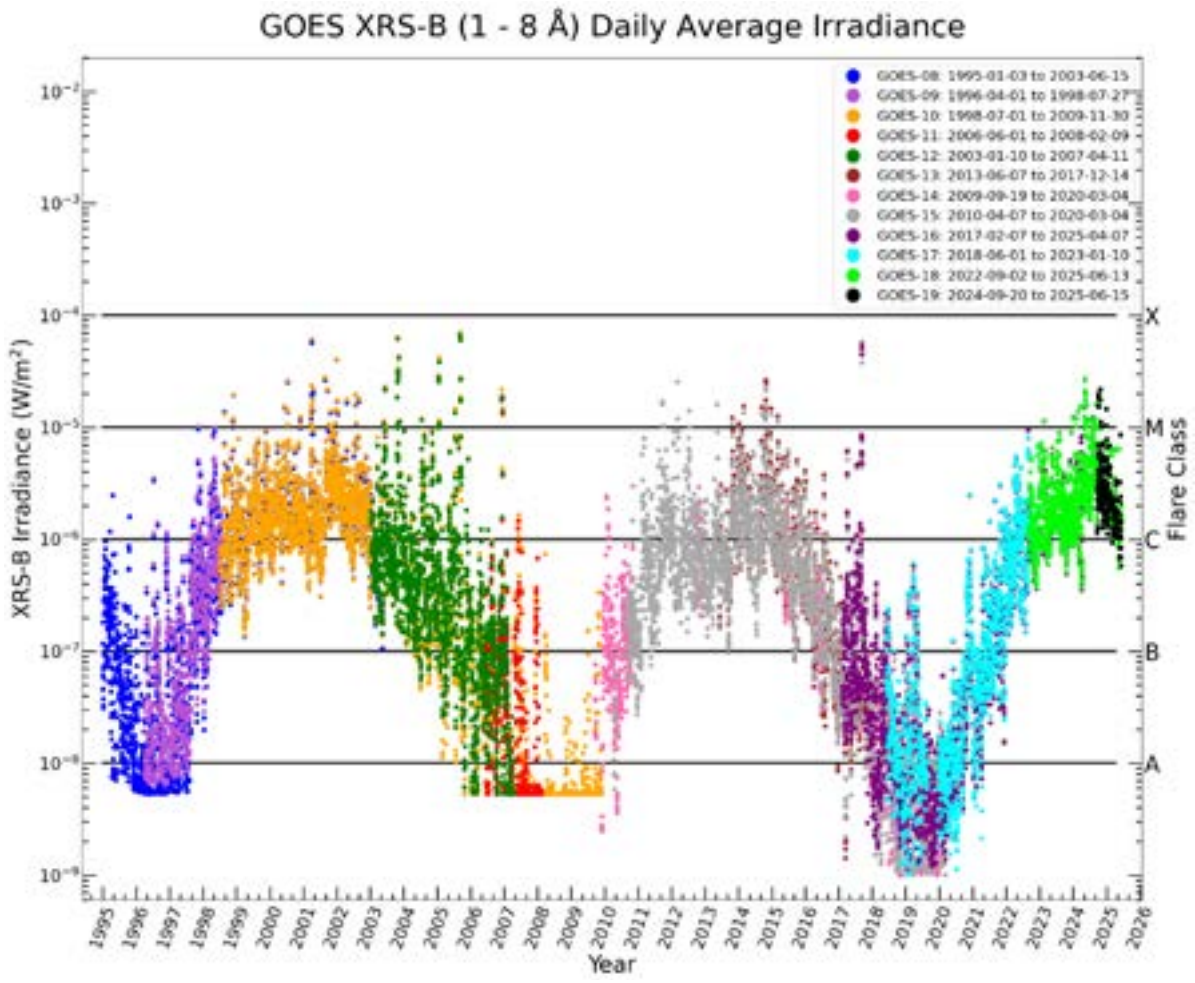
CIESRDS contributors: Robert Allsopp, Kimberly Baugh, Christian Bethge, Athanasios Boudouridis, Stefan Codrescu, Jonathan Darnel, Kevin Hallock, Kosta Horaites, Nathan Howard, Fadil Inceoglu, Alison Jarvis, Brian Kress, Trevor Leonard, Elysia Lucas, Janet Machol, Ann Marie Mahon, James Mothersbaugh III, Josh Riley, Juan Rodriguez, Vicente Salinas, Donald Schmit, Aspen Davis, Andrew Wilson, Pamela Wyatt

Relevance to NOAA: NOAA and other agencies use GOES space weather data for situational awareness and forecasting to protect key technologies such as satellites, power grids, and communications.

This project provides operational and science-quality data products to the Space Weather Prediction Center (SWPC) from NOAA Geostationary Operational Environmental Satellites (GOES) space weather measurements. There have been 19 GOES satellites since 1975, each carrying up to eight space weather instruments. The team's work includes writing algorithms, data validation and calibration, anomaly analysis, automated data processing, data publication and archiving, and scientific support for international agencies and the public.

Since 2022, the team has calibrated and validated data products from two new satellites now in operational use by SWPC. The team has led 26 formal hour-long validation reviews for GOES instruments with NASA and NOAA and published 25 journal articles related to GOES data. The team published improved calibrations and multiple data products for GOES measurements going back to 1995. The team also developed several new composite AI-ready data products.

Over the next five years, they will continue to improve, generate, and support space weather data products for GOES satellites.



Daily average solar irradiance measured by GOES satellites since 1995.
Credit: NOAA

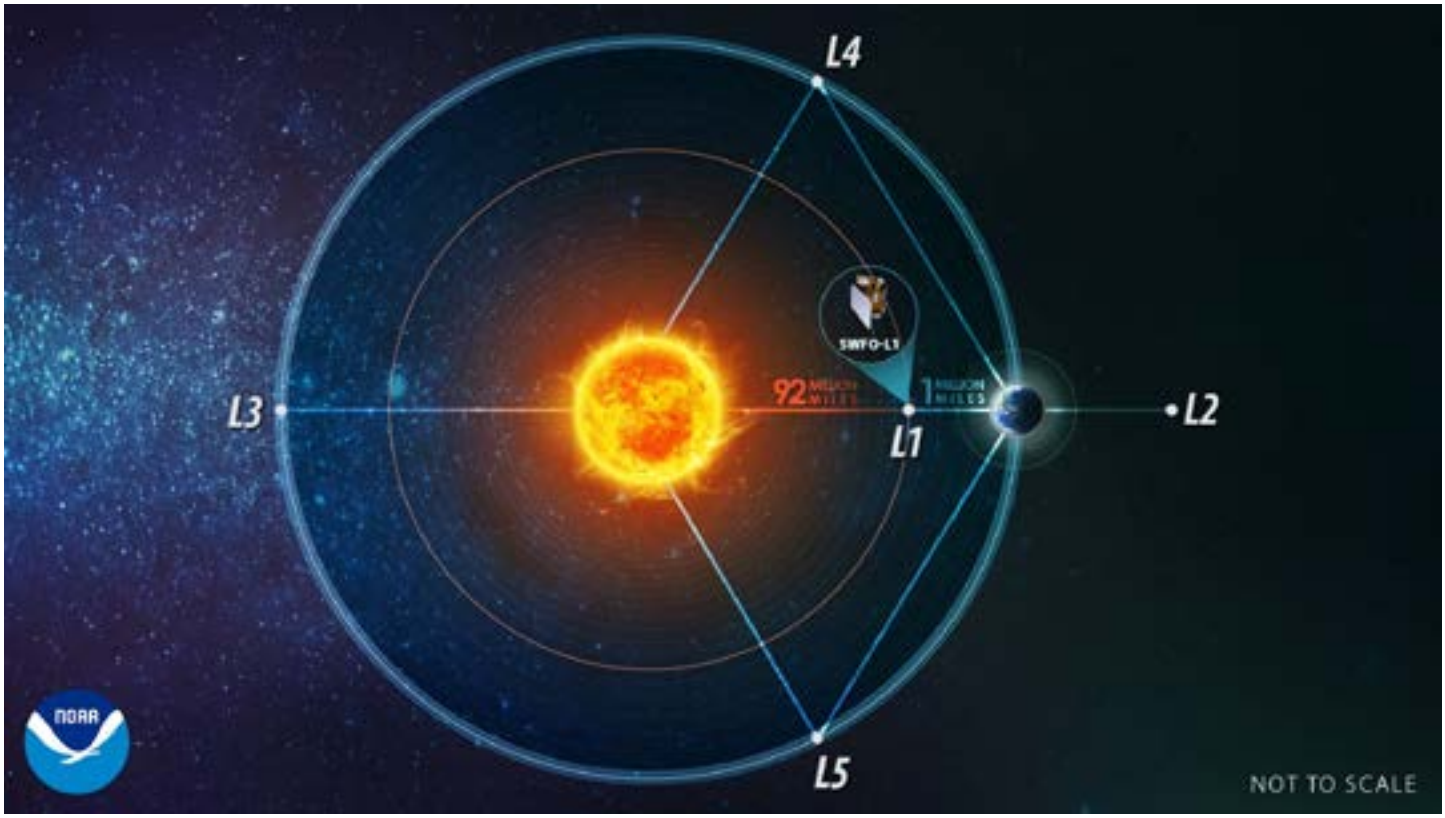
Project: Observing space weather with the Space Weather Follow-On L1 (SWFO-L1) satellite

CIESRDS contributors: Robert Allsopp, Christian Bethge, Athanasios Boudouridis, Gabriel Dima, Scot Elkington, Tyler Gardner, Kevin Hallock, Kosta Horaites, Nathan Howard, Alison Jarvis, Brian Kress, Elysia Lucas, Janet Machol, Jack McKinstry, James Mothersbaugh III, Josh Riley, Juan Rodriguez, Vicente Salinas, Donald Schmit, Aspen Davis, Xue Wei, Andrew Wilson

Relevance to NOAA: The measurements from the Space Weather Follow-On L1 (SWFO-L1) instruments allow for continuous observation and advanced warning of solar storms with potential impacts on Earth to satellites and power grids, improving NOAA space weather forecasts and allowing NOAA to protect lives and property.

The Space Weather Follow-On L1 (SWFO-L1) satellite launched in September 2025, carrying four space weather instruments. It is the first NOAA satellite devoted solely to space weather. An additional SWFO-L1 instrument had been launched a year earlier on the GOES-19 satellite. CIESRDS researchers with the National Centers for Environmental Information space weather team lead data product algorithm development, calibration, validation, and reprocessing efforts for SWFO-L1 instruments.

The NOAA Space Weather Prediction Center (SWPC), other international agencies, and the scientific community use this data operationally. The team has developed multi-level (raw- through derived-quantity) data calibration algorithms. Prior to launch, the team developed calibration and trending plans and successfully completed multiple rounds of end-to-end testing. After launch, the team provided calibrations, validation, and anomaly assessments for all of the instruments and their associated data products. Over the next five years, the team will continue to calibrate, validate, process, and release data for SWFO-L1 measurements and make corrections for unexpected issues that arise with the instruments.



From its location one million miles towards the Sun from the Earth, SWFO-L1 makes advanced measurements of the solar wind coming from the Sun.
Credit: NOAA NESDIS

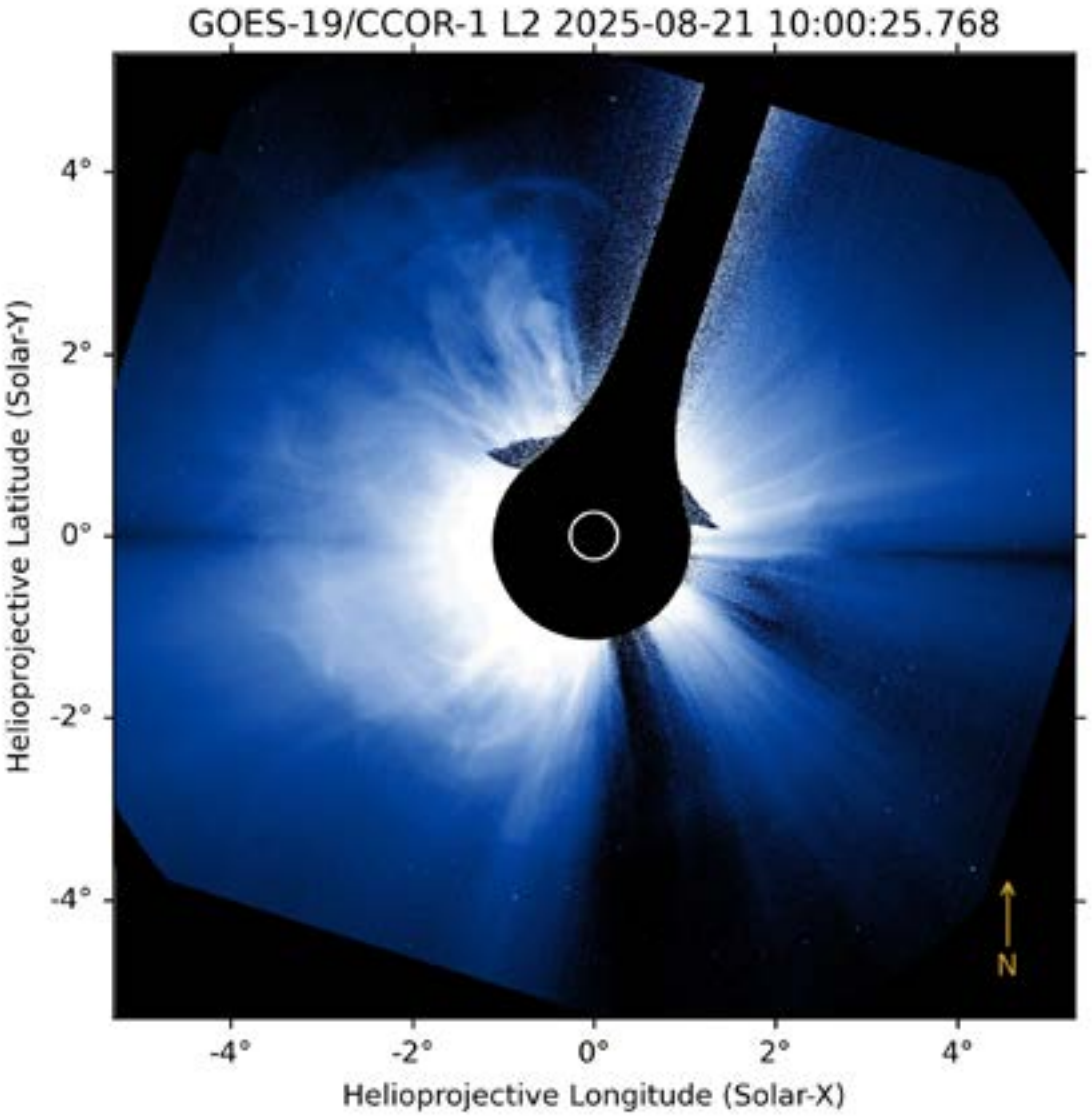
Project: Observing the Sun with Compact Coronagraph 1 (CCOR-1)

CIESRDS contributors: Christian Bethge, Gabriel Dima, Tyler Gardner, Kevin Hallock, Elysia Lucas, Josh Riley, Vicente Salinas, Donald Schmit, Andrew Wilson

Relevance to NOAA: Coronagraph images are used in Space Weather Prediction Center (SWPC) numerical forecasts of the timing and magnitude of potential space weather impacts to Earth.

Coronagraphs image the outer region (corona) of the Sun and block the bright central region to observe solar emissions such as coronal mass ejections (CMEs). A CME is plasma headed towards Earth where it could impact satellites and power grids. The Compact Coronagraph 1 (CCOR-1) instrument is NOAA's first operational coronagraph and is aboard the Geostationary Operational Environmental Satellites 19 (GOES-19) launched in June 2024.

This project team led work on algorithms, image processing, calibration, validation, and data release for CCOR-1. This data is used by SWPC to provide space weather warnings. CCOR-1 data was declared ready for Operations on February 25, 2025, and is the first space weather data processing pipeline fully executed in the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) cloud environment. The team received a 2025 NESDIS Outstanding Science and Research Team Award. Over the next five years, the team will improve the data processing for CCOR-1 and provide validated algorithms to SWPC. They will publish updated versions of the data for other users.



Coronal mass ejection from the Sun observed by the Compact Coronagraph 1 (CCOR-1) instrument aboard the GOES-19 satellite.
Credit: NOAA

Project: Processing space environment data in the cloud

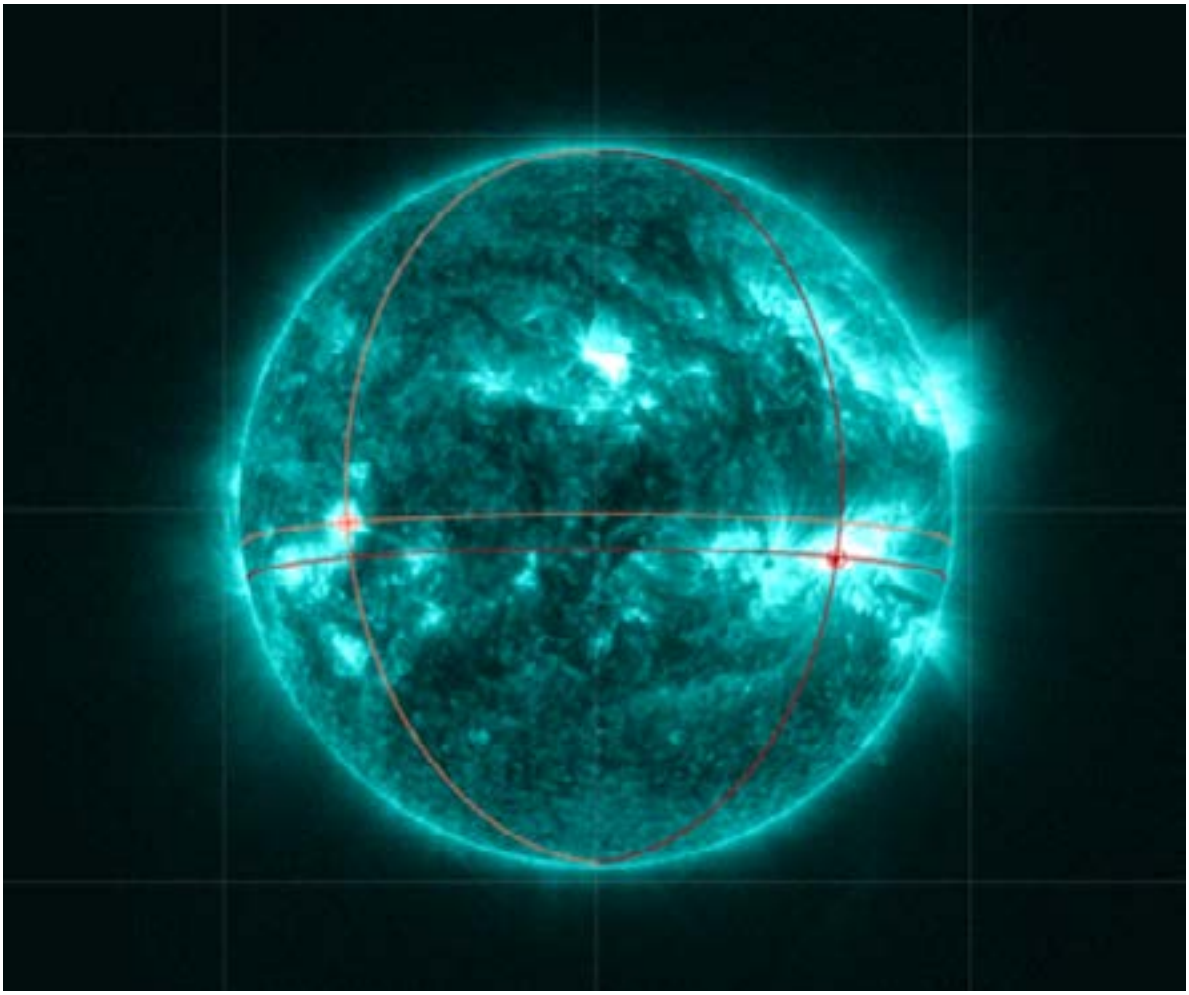
CIESRDS contributors: Robert Allsopp, Christian Bethge, Stefan Codrescu, Kevin Hallock, Nathan Howard, Ann Marie Mahon, Jack McKinstry, Josh Riley, Vicente Salinas, Xue Wei, Andrew Wilson

Relevance to NOAA: This project modernizes the data processing, access, and archive for NOAA space weather data and fulfills a NOAA National Environmental Satellite, Data, and Information Service (NESDIS) requirement. Data processing in the cloud can be many times faster than on in-house computers, so this modernization more easily allows for reprocessing for software and calibration upgrades.

This project's goal is to move the NOAA National Centers for Environmental Information space weather team's extensive data processing and data access to the NOAA cloud environment in support of a NOAA NESDIS requirement.

So far, the team has completed a pilot project to develop cloud processing for two GOES instruments. They created a cloud-native Space Weather Portal (SPOT) for public data access. SPOT uses a modern interface, allows for a dynamic time series, and provides plots and movies.

The team also built cloud-based processing for data from the new Space Weather Follow On-Lagrange 1 (SWFO-L1) satellite. The team has begun to move the processing for other instruments to the cloud. Over the next five years, they will work to complete this transition and improve the features for the Space Weather Portal (SPOT).



An image of the Sun with the location of flares indicated.
Credit: Credit: NOAA SWPC

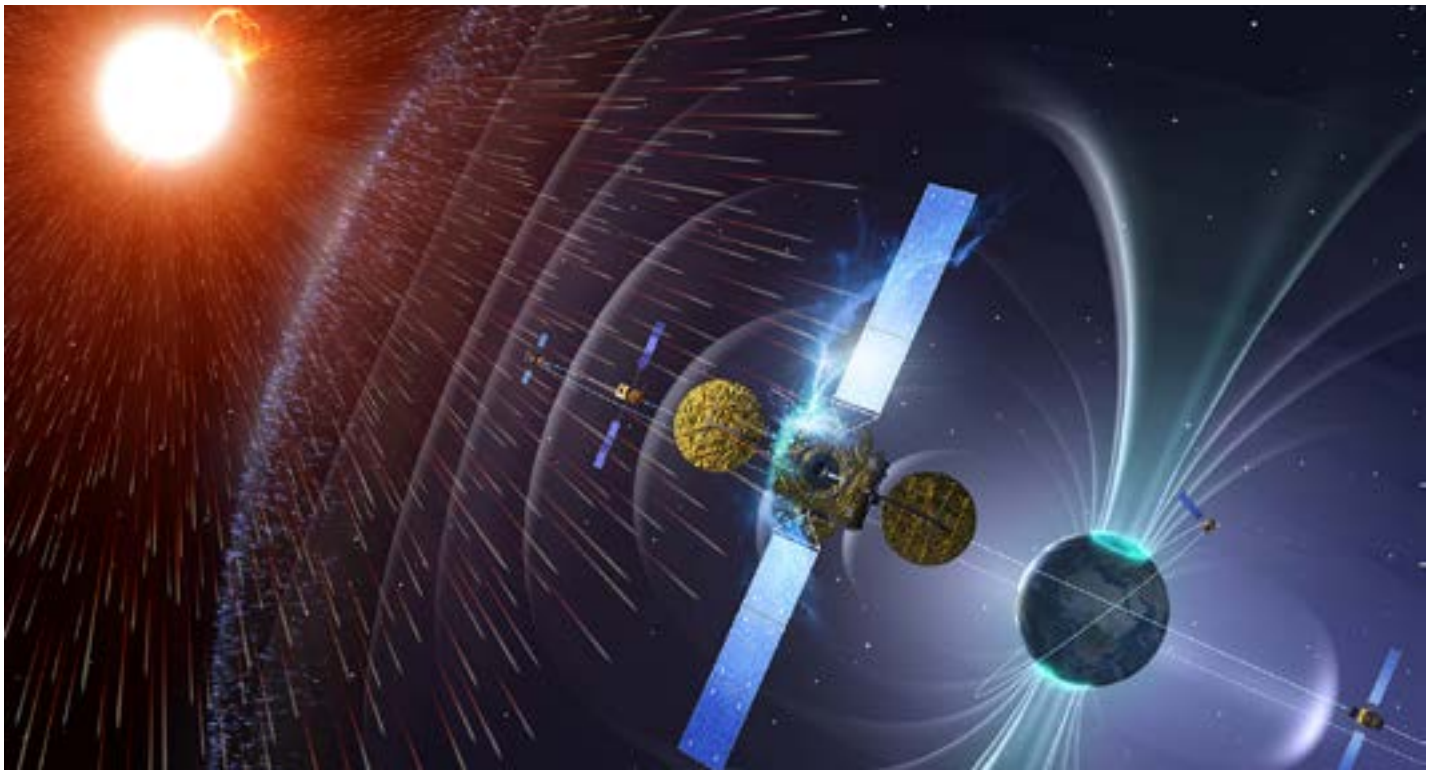
Project: Preparing for new space weather satellite missions

CIESRDS contributors: Christian Bethge, Athanasios Boudouridis, Gabriel Dima, Scot Elkington, Tyler Gardner, Kevin Hallock, Kosta Horaites, Nathan Howard, Brian Kress, Janet Machol, Josh Riley, Juan Rodriguez, Donald Schmit, Aspen Davis, Andrew Wilson

Relevance to NOAA: CIESRDS scientists with the NCEI space weather team work on pre-launch preparation for calibration, validation and data processing for upcoming space weather satellite missions. These missions are essential to provide NOAA with information to protect life and property from the impacts of space weather events.

For this project, CIESRDS scientists with the NCEI space weather team work on pre-launch preparation for calibration, validation and data processing for upcoming space weather satellite missions. These future satellites include the SOLAR-2 mission (scheduled for launch in 2029), VIGIL (scheduled for launch in 2031), GEO-1 (scheduled for launch in 2032), and SOLAR-3 (scheduled for launch in 2032).

The team is involved in the planning of data processing, calibration, and validation for these upcoming missions. As an example, for SOLAR-2, the team reviewed over 25 documents including plans for ground processing, algorithms, validations, and calibrations. They are starting to review similar documents for the other missions, and will continue this work over the coming five years. After each satellite launches, there will be additional calibration, validation, and processing work.



An artist's rendering of space weather satellites collecting data from between the Sun and Earth.
Credit: European Space Agency

Project: Developing a next-generation coronal mass ejection analysis tool

CIESRDS contributors: Mark Miesch, George Millward, Charlotte Martinkus

Relevance to NOAA: Coronal mass ejections (CMEs) are among the most hazardous of space weather events, posing potential risks to such technologies as the power grid, telecommunications, satellite navigation, aviation, and human spaceflight. The Python/javascript CME Analysis Tool (PyCAT) developed at CIESRDS will be an essential tool, used daily by SWPC forecasters to predict if and when a CME may impact Earth and how severe that impact may be.

The CME Analysis Tool (CAT) has been an essential part of NOAA Space Weather Prediction Center (SWPC) operations since 2011, when it was introduced with the WSA-Enlil solar wind model to predict if and when CMEs might impact Earth. CAT allows forecasters to interactively fit multi-perspective coronagraph observations to an idealized CME Cone model for assimilation into WSA-Enlil.

PyCAT is a next-generation reimagining of CAT that exploits modern technologies such as containerized microservices, browser-based interactivity, and an event database. CIESRDS scientists created the pyCAT software application from scratch in 2022 and developed it to match the main capabilities of the previous CAT tool. In March 2025, it became operational at the UK Met Office. SWPC forecasters are currently validating and evaluating pyCAT. The researchers expect it to transition to SWPC operations in summer 2026, at which time they will share it with SWPC partners, followed by an open source release. Future work will enhance capabilities in response to forecaster feedback.

PyCAT user interface, showing multi-perspective coronagraph images from four spacecraft instruments and interactive sliders for fitting these observations to a 3D CME Cone model.
Credit: NOAA SWPC

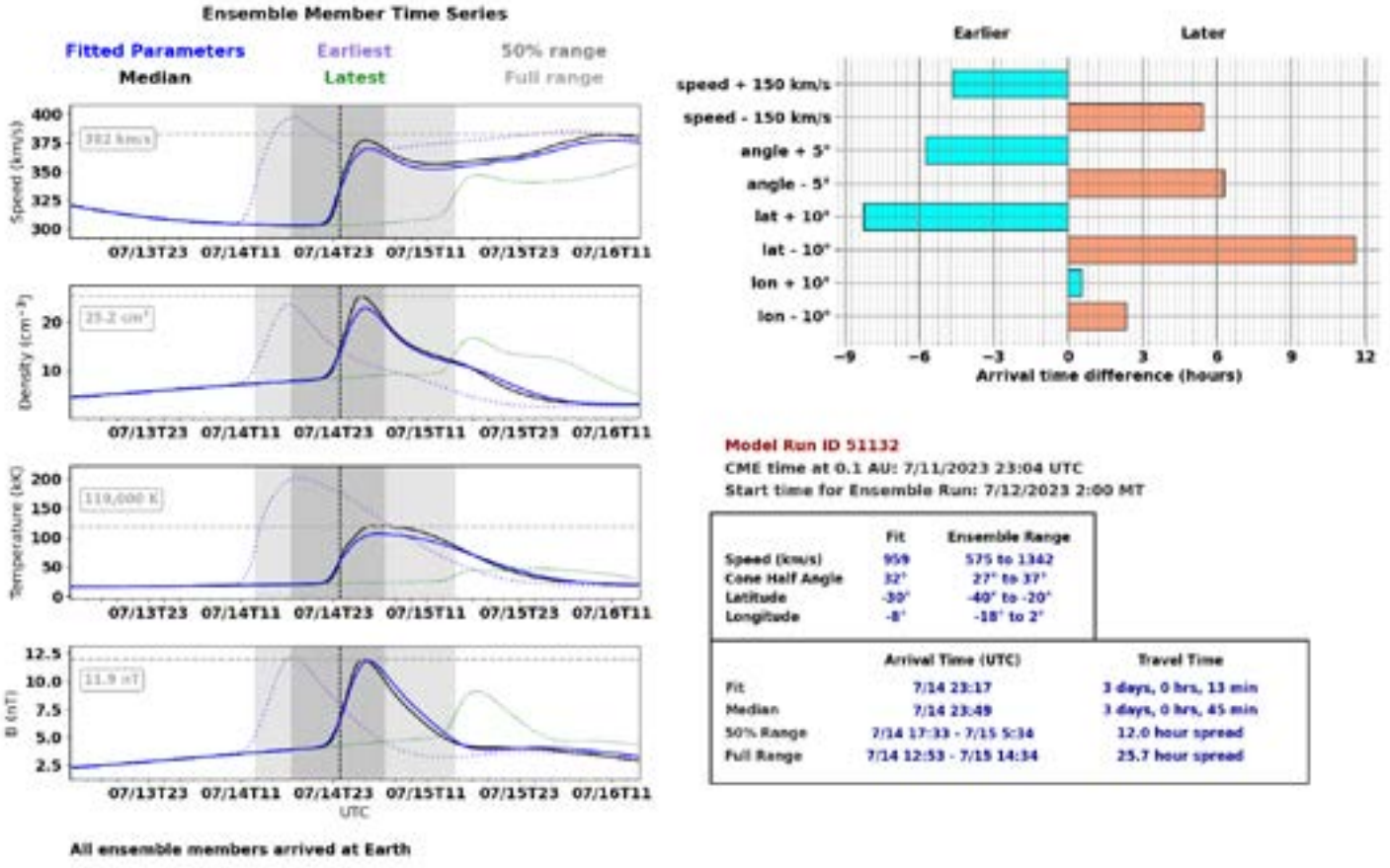
Project: Improving local ensemble-based prediction of coronal mass ejections

CIESRDS contributors: Mark Miesch, Andrew Marble

Relevance to NOAA: Coronal mass ejections (CMEs) are among the most hazardous of space weather events. This application improves the timeliness of CME arrival prediction and supports NOAA Space Weather Prediction Center's increasing prioritization of probabilistic, risk-based forecasting by using ensemble methods to quantify uncertainties.

WSA-Enlil is a 3D, magnetohydrodynamic numerical model used by NOAA Space Weather Prediction Center's (SWPC) since 2011 to predict the arrival time and severity of CMEs that impact Earth. The operational WSA-Enlil model runs on NOAA's Weather and Climate Operational Supercomputing System (WCOSS) with a turnaround time of about two hours. This application provides a lower-resolution version of WSA-Enlil that runs locally with a 30-minute turnaround time, with improved uncertainty quantification by means of ensemble methods. The research version of the application had been running at SWPC in 2019. Since 2022, CIESRDS researchers have revived and updated the code, implemented it on a new development platform, created new graphical outputs, and created an automated pipeline to run the code on demand and deliver results to forecasters.

CIESRDS researchers met initial goals of re-implementing the code on a development system and establishing an automated concept of operations. Next steps include the calibration of the ensemble results, testbed evaluation, and transition to an operational platform. After that, the ensemble approach could be extended to operational higher-resolution runs on NOAA's WCOSS supercomputing platform.



Graphical display of the results of the Ensemble-based CME Application, directed at forecasters. Information highlighted includes the range of arrival times spanned by the ensemble and the sensitivity of the arrival time to the fitted CME parameters.
Credit: NOAA SWPC

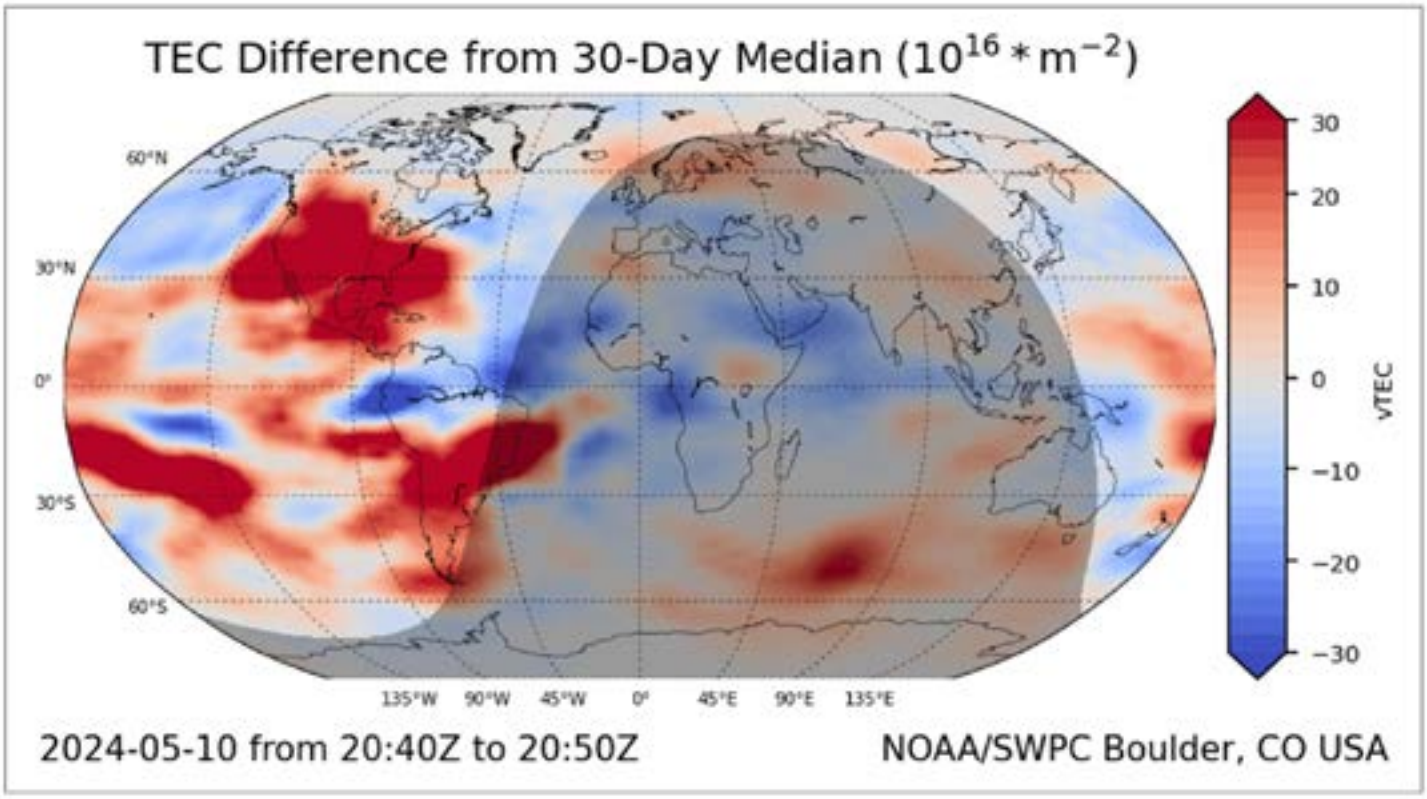
Project: Developing the Global Total Electron Content (GloTEC) model

CIESRDS contributors: Dominic Fuller-Rowell, Ratina Dodani, Tim Fuller-Rowell

Relevance to NOAA: The Global Total Electron Content (GloTEC) model significantly improves NOAA's ability to monitor space-weather impacts on Global Navigation Satellite Systems (GNSS), communications, and navigation systems. Its near-real-time global products support aviation, defense, and commercial sectors by providing accurate ionospheric corrections, reducing positioning errors, and enabling situational awareness during geomagnetic storms.

GloTEC is a global total electron content data assimilation system that combines ground-based GNSS observations and space-based radio occultation measurements to produce a real-time, 3D specification of electron density in the ionosphere. Developed at CIESRDS in collaboration with NOAA's Space Weather Prediction Center, the system enhances operational awareness of ionospheric variability and supports a broad range of users reliant on precise GNSS positioning, navigation, and communication systems.

Since 2022, GloTEC transitioned from research to operations at SWPC, providing global ionospheric maps every 10 minutes with around 15-minute latency. The system now ingests ground-based GNSS and COSMIC-2 radio-occultation data in real-time and produces derived products, such as total electron content, peak electron density, and the height of the peak. CIESRDS researchers have completed documentation, validation, and visualization tools, and presented results at multiple scientific meetings, strengthening NOAA's ionospheric monitoring capabilities. Future development will focus on increasing observational data sources, improving uncertainty quantification, and refining the near-real-time concept of operations.



Results from the GloTEC model are shown for a time period during the extreme geomagnetic storm on May 10-11, 2024. Red indicates an enhancement of the total electron content over North and South America, which produced disruptions in GNSS navigation and communications.

Credit: NOAA SWPC

Project: Validating a real-time solar particle prediction model

CIESRDS contributors: Kimberly Moreland, Hazel Bain, Jaclyn Stickrod, Charlotte Martinkus

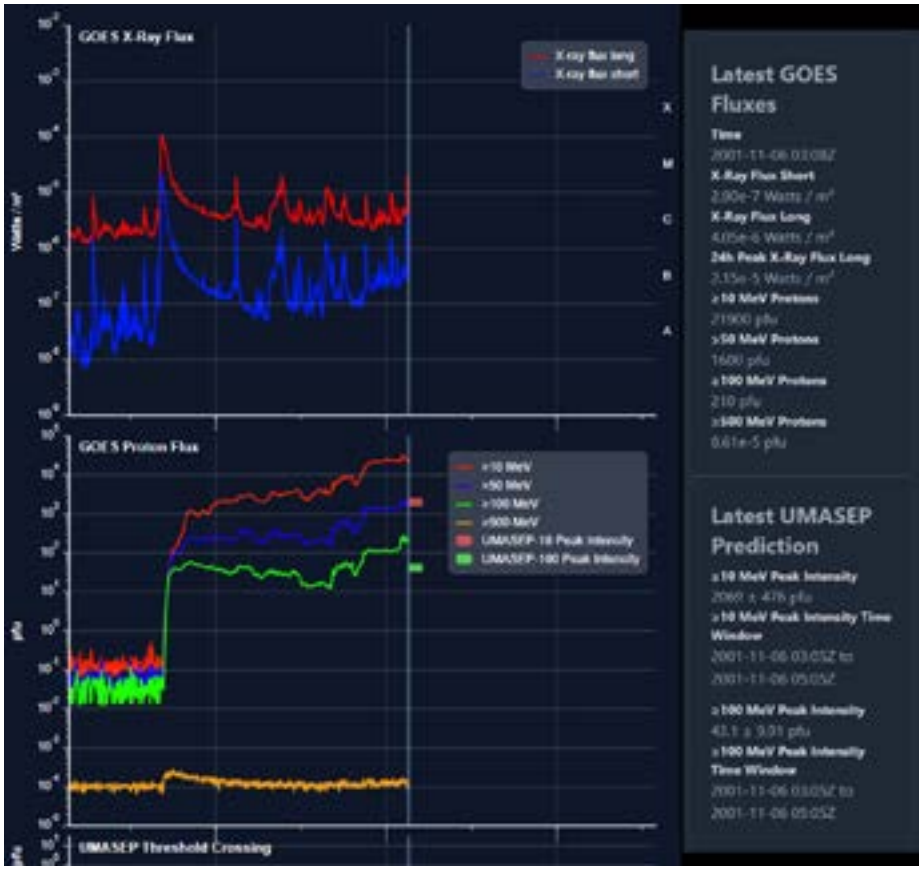
Relevance to NOAA: The University of Malaga Solar Energetic Particle model (UMASEP) is a real-time solar energetic particle prediction model. The model adds the capability of predicting the peak flux intensity during a solar energetic particle (SEP) event and is crucial for human space exploration (i.e., NASA's Artemis II and beyond) because it enables proactive protection of astronauts, informed mission planning, optimized spacecraft and habitat design, and improved operational safety against harmful radiation exposure.

CIESRDS scientists work to validate the University of Malaga Solar Energetic Particle model (UMASEP), a real-time solar energetic particle prediction model. During solar energetic particle events, protons and electrons are accelerated to high energies (Megaelectronvolts) by solar flares and coronal mass ejections, posing significant radiation hazards to satellites, astronauts, and high-altitude aviation. The team's work aims to improve NOAA Space Weather Prediction Center's (SWPC) space radiation environment forecasting for human space exploration, commercial space, and the satellite industry.

This work verifies that the model enhances SWPC's baseline skill for two critical prediction quantities: forecast lead time and peak proton flux. The validation confirms UMASEP's maturity, supporting its transition through the operations-to-research, research-to-operations pipeline for eventual integration into SWPC operational forecasting.

CIESRDS work validating UMASEP confirms that the model improves the NOAA SWPC baseline skill in forecasting solar energetic proton events. For ≥ 10 Megaelectronvolt events, UMASEP adds 40 minutes of forecast lead time over the SWPC baseline. For ≥100 Megaelectronvolt events, it significantly increases the probability of detection by 40 percent while maintaining a low false alarm ratio. The model also predicts the peak particle flux intensity in different energies, aiding in solar storm warnings.

The NASA Space Radiation Analysis Group threshold requirements prompted validation of ≥50 Megaelectronvolt UMASEP predictions, which is now nearly complete. Looking forward, CIESRDS researchers plan to validate additional solar energetic particle models, including SEPSTER, SEPMOD, REleASE, and the machine-learning MEMPSEP, all operating or transitioning to real-time runs at NASA's Community Coordinated Modeling Center.



The University of Malaga Solar Energetic Particle model was featured in the 2025 NOAA/NASA Artemis-II Human Spaceflight Testbed Exercise, as shown here, for a mock emergency based on a real event.
Credit: NOAA and NASA

Project: Developing geoelectric modeling products

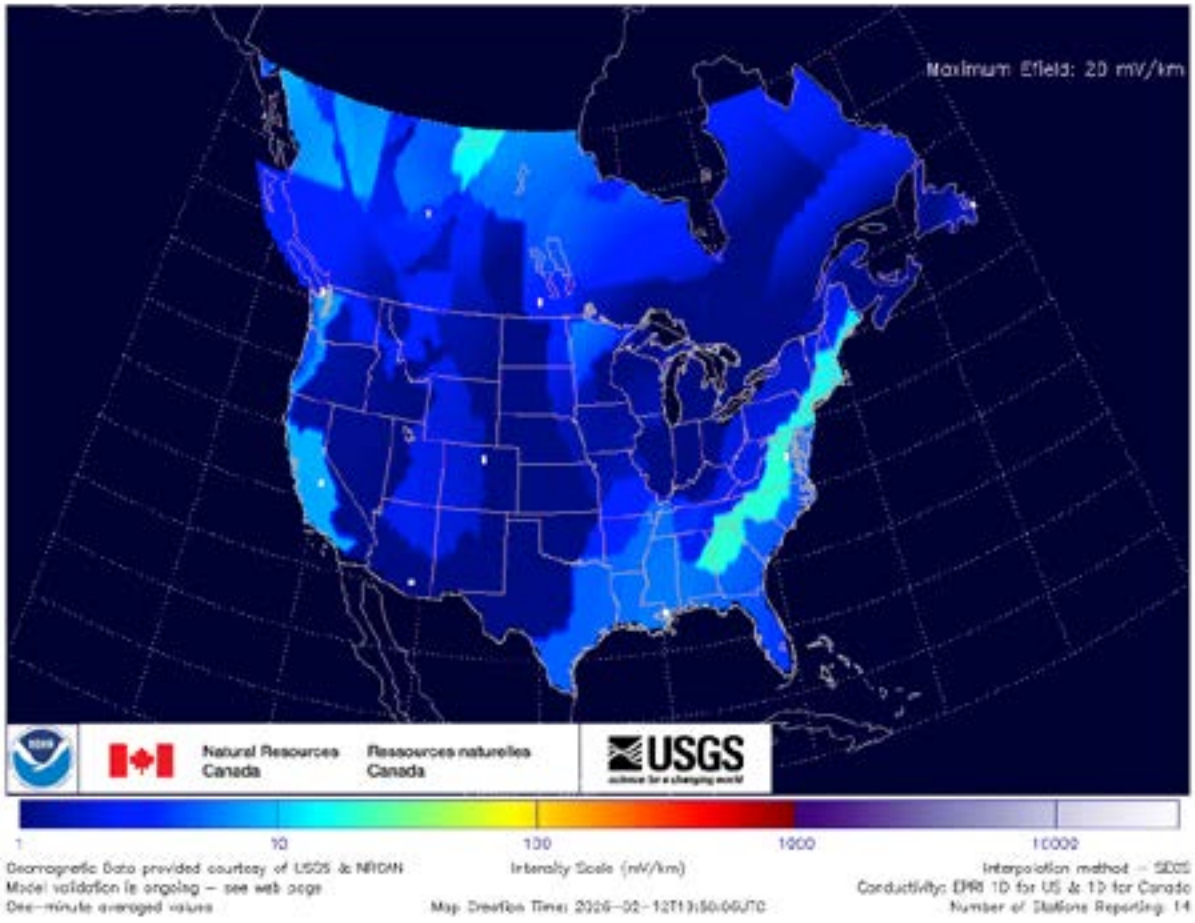
CIESRDS contributors: Jordan Guerra, Chris Balch, Ratina Dodani

Relevance to NOAA: This project improves NOAA Space Weather Prediction Center's abilities to monitor space weather impacts on human infrastructure, reducing risks to such technologies as the power grid, telecommunications, satellite navigation, aviation, and human spaceflight.

The NOAA-USGS Geoelectric Model is a collaboration between the U.S. Geological Survey (USGS) Geomagnetism Program and the NOAA Space Weather Prediction Center (SWPC), with support from Natural Resources Canada (NRCan). The model has been operational since 2019, providing real-time monitoring of geoelectric fields over the continental United States and Canada during geomagnetic storms, supporting the day-to-day operations at SWPC, and providing relevant geoelectric information for end users.

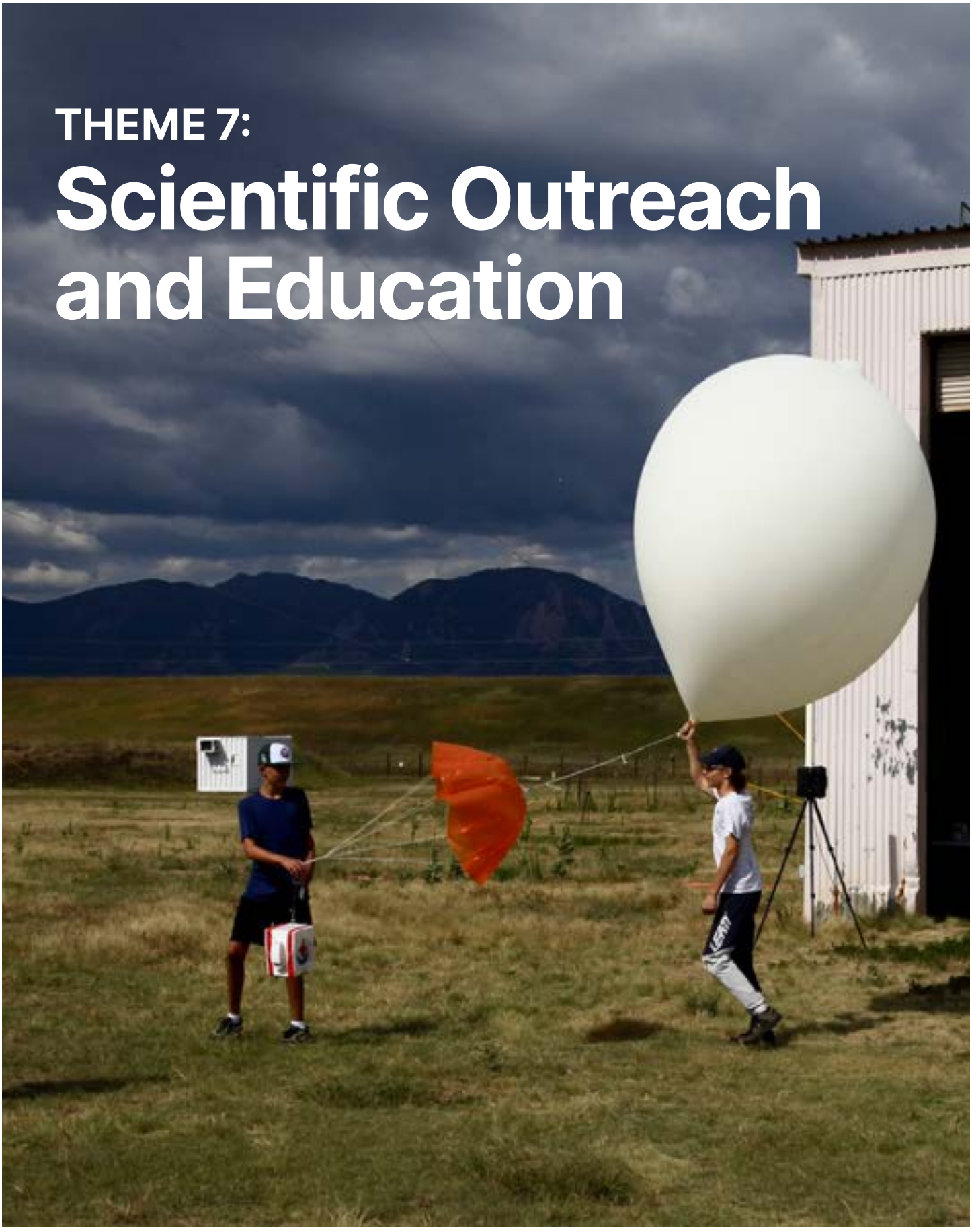
The US-Canada version of the geoelectric model became public in summer 2023. CIESRDS researchers published two validation papers using geomagnetically induced current measurements and anticipate submission of two more. The coverage in the ground conductivity module was completed, constructed from magnetotelluric observations (a method using natural electromagnetic fields from lightning and solar activity to image Earth's subsurface electrical resistivity).

Future goals include expanding the input network of magnetic observations to increase coverage and reduce errors. Another goal is the modernization of the technological platform that supports the model, to enhance efficiency and accuracy in the calculations and to optimize the model's output. This modernization includes more interactive tools. The next few years will also see the further development of the predictive capabilities of the model, leveraging it for use in probabilistic forecasting and risk assessment.



The US-Canada-1D geoelectric field model uses 1D conductivity models over the lower 48 United States and over Canada up to 60 degrees latitude, with output spatial resolution of 1/2 degree in latitude and longitude.
Credit: NOAA SWPC

THEME 7:
Scientific Outreach and Education



CIESRDS researchers launch an ozonesonde balloon from Boulder's Marshall Mesa Field Site. The balloon carries instruments to more than 30km (100,000 feet) above the surface while sending measurements of atmospheric ozone and meteorological data back to a ground station in Boulder. Credit: Patrick Cullis/CIESRDS

SCIENTIFIC OUTREACH AND EDUCATION

CIESRDS devotes considerable effort to scientific outreach and education, aiming to improve public understanding of science, integrate the transformative technologies of artificial intelligence and machine learning, and support early-career scientists. This work is substantially leveraged by support from other sponsors and advanced by CIRES centers and labs including the Center for Education, Engagement, and Evaluation (CEEE), which connects educators, learners, and communities with environmental and Earth system science, and the Environmental Data Science Innovation and Impact Lab (ESIIL), an NSF-funded synthesis center enabling a global community of researchers to develop data-driven solutions to pressing environmental challenges.

A key aspect of CIESRDS work on outreach and education is the advancement of NOAA's Science on a Sphere (SOS) platform. SOS is a room-sized animated globe that shows dynamic visualizations of Earth processes. SOS makes complex global phenomena like climate, weather, and ocean currents intuitive and engaging for audiences of all ages. SOS illustrates environmental science through over 600 datasets and is installed in 195 exhibits in 27 countries. An estimated 60 million people engage with SOS every year.

CIESRDS work in this realm includes expanding and improving the SOS experience, creating classroom lessons using SOS data, and studying the effectiveness of SOS learning experiences. CIESRDS researchers are creating and distributing Data Lens, formal classroom lessons that use art and arts-based research-backed observation methods for scrutinizing SOS datasets; testing SOS's effectiveness as a learning tool, comparing it to flat, 2D visualizations; testing if learning differs with still or animated visualizations on SOS; and understanding how visitors learn and engage with the SOS kiosk through an observational study of visitors.

Project: Expanding the Science on a Sphere® user network through installations

CIESRDS contributors: Adrian Chase, Alex Kirst, Beth Russell Wehe, Hilary Peddicord, Shilpi Gupta

Relevance to NOAA: An estimated 60 million people engage with Science on a Sphere® (SOS) every year, raising awareness about NOAA's science. SOS is a room-sized, global display system that projects visualizations of planetary data onto a six-foot-diameter sphere. The program provides training that equips users to skillfully use the software and accurately share science, gathering feedback that informs SOS software development.

Since September 2022, this team has hosted two workshops to share best practices, provide technology updates, and showcase content. The SOS users network currently has over 400 members, and 100 institutions and seven countries were represented at SOS workshops. Since 2022, the team has completed 17 SOS installations. In the next five years, the team plans to organize two or three SOS Collaborative Users Network workshops and add new distributors to further the reach of SOS into new regions.

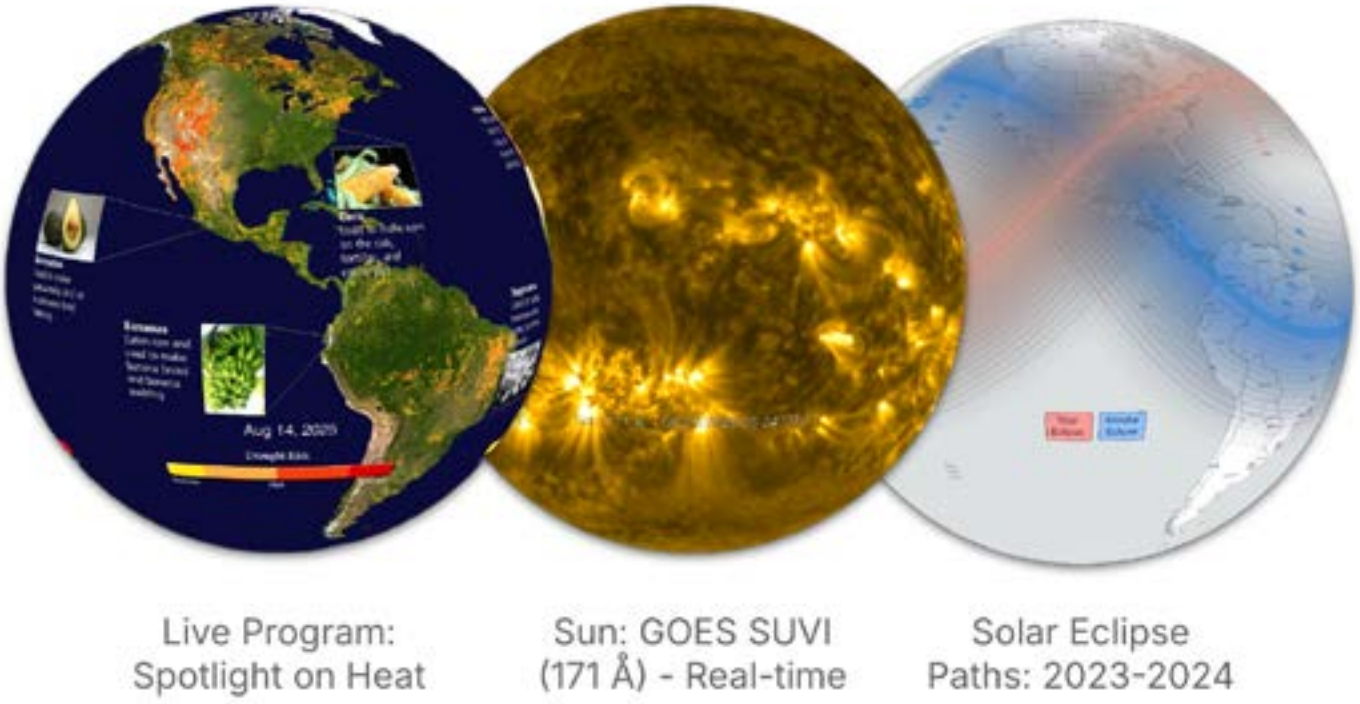
An SOS presentation during the 2024 SOS Users Collaborative Workshop at the Wild Center in Tupper Lake, New York.
Credit: WILD Center, Tupper Lake, NY

Project: Improving data visualizations for Science on a Sphere®

CIESRDS contributors: Alex Kirst, Beth Russell Wehe, Hilary Peddicord, Shilpi Gupta

Relevance to NOAA: Science on a Sphere® (SOS) delivers responsive visuals tied to current events (e.g., solar eclipses), keeping content timely and engaging. This project improves clarity and aesthetics of data visuals to help audiences better understand complex topics.

An estimated 60 million people engage with Science on a Sphere® (SOS) every year, raising awareness about NOAA's science. SOS is a room-sized, global display system that projects visualizations of planetary data onto a six-foot-diameter sphere. SOS incorporates direct feedback from educators and partners to shape best practices and content priorities. Collaborating with external contributors diversifies and enriches the SOS dataset catalog. This team's efforts have focused on expanding and improving the SOS data experience: creating timely, high-quality visual content, and fostering collaboration. Since 2022, the team has added 46 datasets and created four scripted presentations. They have also created in-house datasets: two static and three real-time datasets. Goals for the next five years include modernizing the data pipeline and SOS data catalog, adding real-time datasets to SOS Explorer (SOSx) Mobile, and further expanding the catalog to include real-time datasets.



Left image: This Science On a Sphere® live program uses global datasets for audiences to explore how rising temperatures are experienced differently around the world, why cities can feel hotter than their surroundings, and how extreme heat links to drought, fire, and food security.
Credit: Shilpi Gupta/CIESRDS

Project: Developing research-backed data literacy resources for teachers

CIESRDS contributors: Beth Russell Wehe, Hilary Peddicord, Shilpi Gupta

Relevance to NOAA: The project creates activities for understanding complex scientific data and equips teachers with innovative teaching techniques, highlighting timely Science on a Sphere® maps and NOAA Education resources, providing access to NOAA's vast collections. Using Data Lens regularly may help to increase students' data literacy skills.

The Science on a Sphere® (SOS) education team is creating and distributing Data Lens, formal classroom lessons that use art and arts-based, research-backed observation methods for scrutinizing SOS datasets. This resource is inspired by NSF-funded formal education research focused on data literacy.

Since 2022, the team has created 12 lessons, delivered 12 conference and professional development presentations to teachers and educators, and reached roughly 1,100 teachers through monthly emails featuring new lessons. Over the next five years the team will continue to develop resources for teachers and provide professional development, expand the teacher user-base for SOSx, and increase the use of SOS within NOAA.

Example of Data Lens modules.
Credit: Hilary Peddicord/CIESRDS

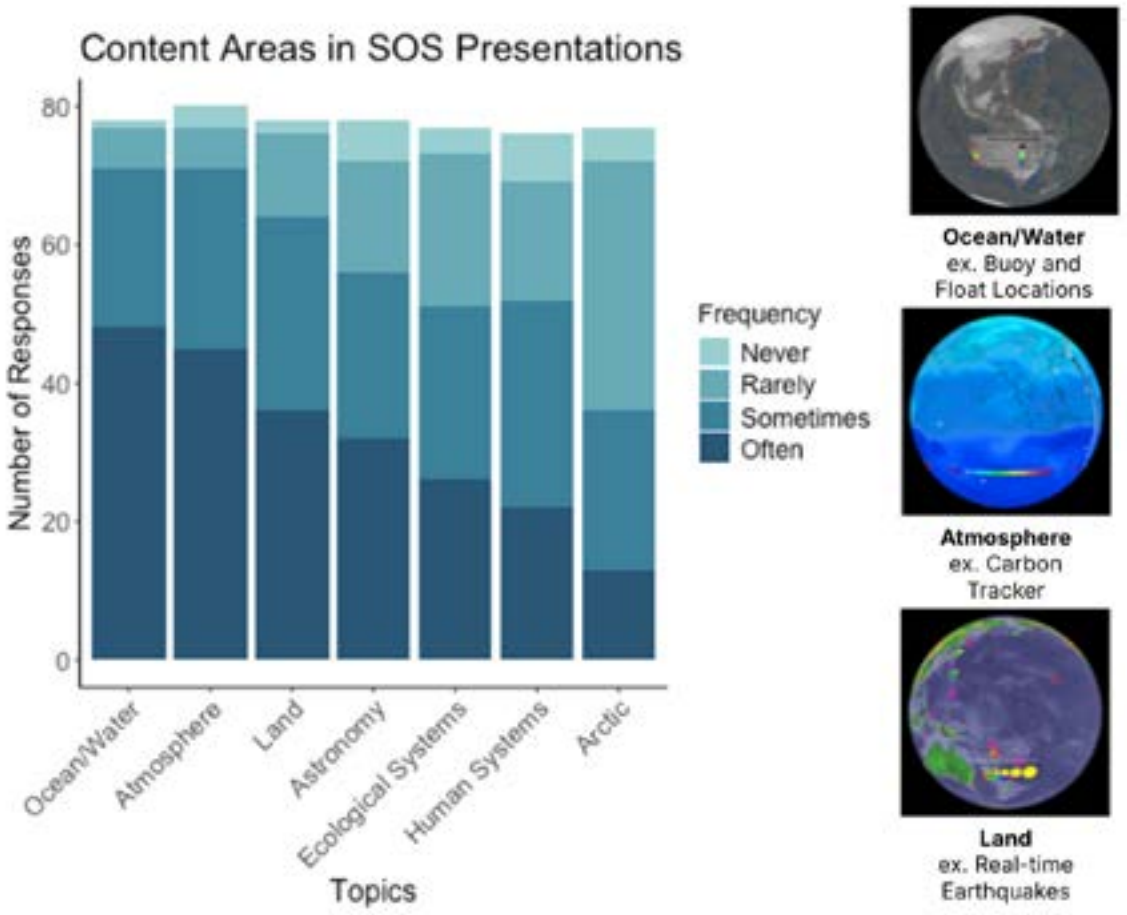
Project: Conducting research and evaluation to inform future Science on a Sphere® work

CIESRDS contributors: Alex Kirst, Beth Russell Wehe, Hilary Peddicord, Shilpi Gupta

Relevance to NOAA: This project will advance researchers' understanding of Science on a Sphere® (SOS) as a learning tool while informing the SOS team's work on new content, software design, and educational programming for the SOS network.

This project involves conducting several studies on the effectiveness of Science on a Sphere (SOS): An in-depth study of SOS and SOS Explorer (SOSx) usage through a cross-site evaluation; empirically testing SOS's effectiveness as a learning tool, comparing it to flat, 2D visualizations; testing if learning differs with still or animated visualizations on SOS; and understanding how visitors learn and engage with the SOS kiosk through an observational study of visitors.

Since 2022, 92 institutions have participated in the SOS cross-site evaluation, 189 University of Colorado undergraduates participated in the learning study, and the team anticipates there were about 70 visitor groups observed during the kiosk study. Over the next five years, the team will publish results to the SOS network from the three projects, use results from evaluation to inform future development, and conduct needs assessments to understand barriers and opportunities to improve the SOS data catalog and platforms.



Respondents to the cross-site evaluation report the areas of content presented on their SOS and SOSx installations.
Credit: Grace Bennet-Pierre/CIESRDS

Project: Maintaining Chemical Sciences Laboratory publications and communications

CIESRDS contributors: Cathy Burgdorf Rasco

Relevance to NOAA: This project supports NOAA scientific priorities by communicating the Chemical Sciences Laboratory science, and providing the resources to back up findings — including field campaign overviews, datasets, journal article tracking, and timely news.

NOAA Chemical Sciences Laboratory (CSL) publications and communications project publishes news stories, often highlighting a recently published journal article, to communicate CSL's research and further identify field activities, datasets, or awards and recognition. Since 2022, the publications have served as a basis for legislation and as a record and metrics for CSL research. Over the next five years, the team will support the engineering needs of CSL for instrumentation deployment for field campaigns, provide successful IT user support for CSL staff, develop a web presence for publishing, maintain the publication internal review and notification process, and produce quarterly publication reports. Additionally, the project will manage submissions to the NOAA Central Library Internal Repository and further develop a CSL data management plan.

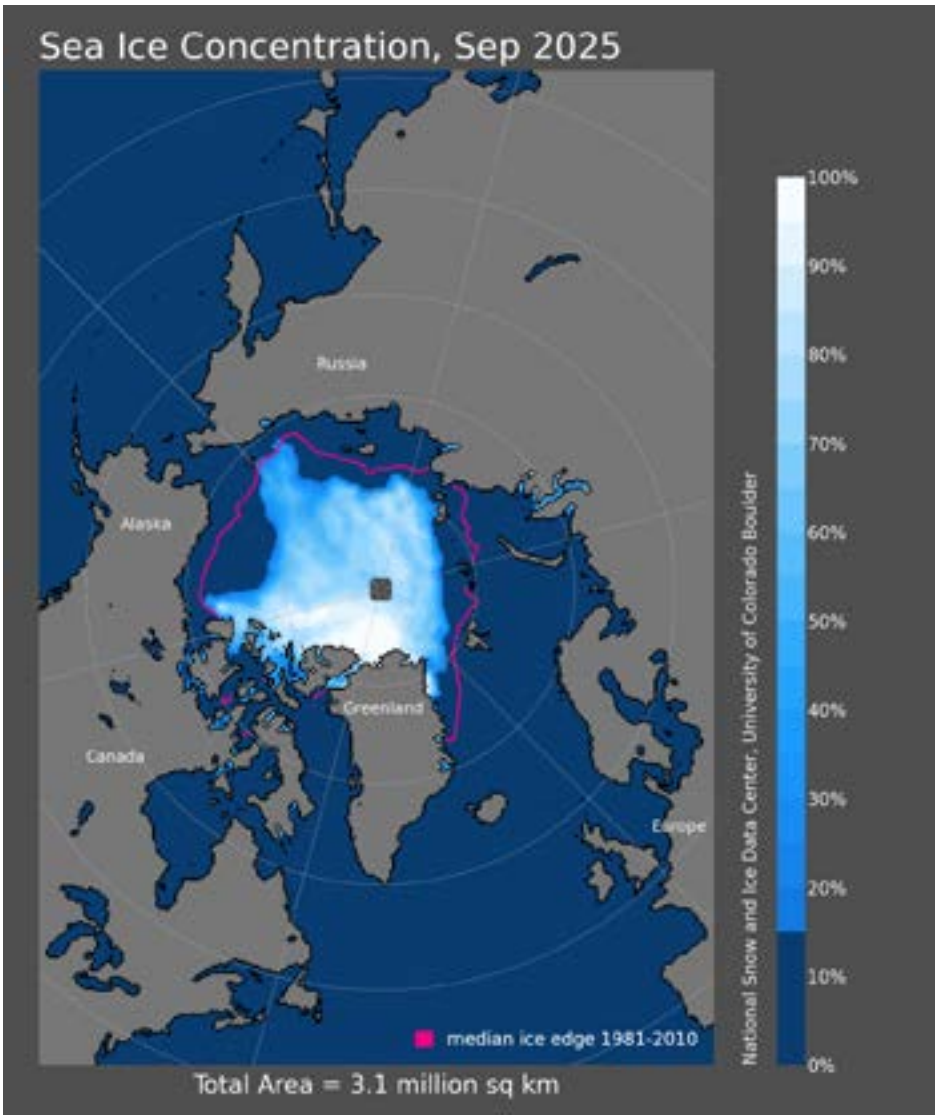
A wooden shelf filled with neatly arranged reports, some spiral-bound, others with glossy covers, showcasing a mix of corporate and nature-themed designs.
Credit: CIESRDS

Project: Refactoring the Sea Ice Index processing code for long life and efficient maintenance

CIESRDS contributors: Ann Windnagel, Florence Fetterer, and Danica Cantarero

Relevance to NOAA: The Sea Ice Index supports society by showing changes with clarity and simplicity in a major component of Earth's energy balance. The index is used in NOAA's annual Arctic Report Card, the annual Bulletin of the American Meteorological Society's State of the Climate, and NOAA's Science on a Sphere® (SOS).

The Sea Ice Index provides a quick look at daily and monthly polar sea ice extent values and trends going back to 1978. It turns a complex component of the cryosphere into a clear, comparable record linking science, education, and policy. In the past, the processing code for this product was not well maintained due to funding constraints. In 2022, NOAA provided support for re-factoring the code after it failed. Since 2022, the Sea Ice Index, with nearly 3,000 registered users, has been used by academic researchers, satellite services, educators, the media, and the general public. In the summer of 2025, the team refactored code, which allowed for the quick adoption of new data. This year, over 100,000 users engaged with Sea Ice Index interactive tools, roughly 30,000 users downloaded files, with 1.13M views in the Sea Ice Today site. NCEI decommissioned the Sea Ice Index in March 2025, so there is no longer dedicated support to maintain it. The five-year goal is to secure funding to maintain the product and its interactive tools and websites.



Sea ice concentration image from the Sea Ice Index.
Credit: NOAA@NSIDC

Project: Building Tribal drought resilience

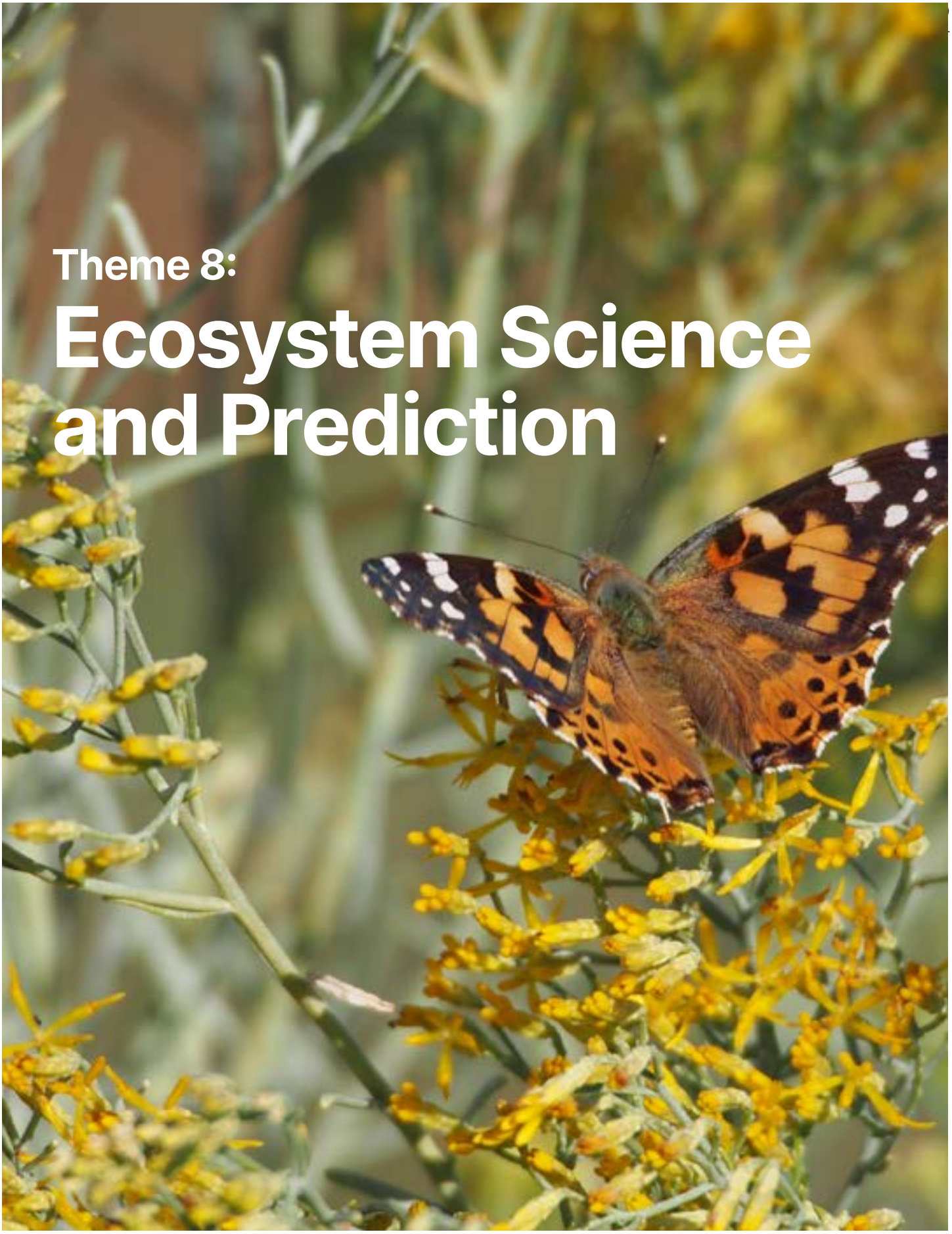
CIESRDS contributors: Crystal Stiles

Relevance to NOAA: This project supports NIDIS's mission of serving and consulting with all relevant partners, including Tribal Nations.

The National Integrated Drought Information System (NIDIS) works regularly to build drought resilience among Tribal communities. After the release of the NIDIS Tribal Drought Engagement Strategy in 2021, NIDIS partnered with CIESRDS to hire a full-time tribal engagement coordinator. A major accomplishment was the 2023 Workshop for Building Drought Resilience in a Changing Climate with Upper Columbia and Missouri Basin Tribes.

Since 2022, NIDIS's Tribal Drought Engagement Strategy resulted in a new full-time Tribal engagement coordinator and a new workshop with 100 attendees, including representatives from 16 Tribal nations. This coordinator implements strategy as well as outcomes from the workshop with NIDIS. The coordinator also leads NIDIS's efforts on the topic as well as a drought tribal community including a tribal engagement newsletter (with more than 1,400 subscribers) and nine Coping with Drought funded research projects. Over the next five years, this effort will continue to support Tribal drought planning and preparedness activities. Team members will continue to implement the workshop outcomes through in-person engagement, networking, and newsletters while also maintaining a tribally focused research environment.

Attendees of the 2023 Workshop for Building Drought Resilience in a Changing Climate with Upper Columbia and Missouri Basin Tribes.
Credit: Crystal Stiles/NIDIS



Theme 8:

Ecosystem Science and Prediction

A Painted Lady butterfly lands on rabbitbrush. Credit: Jeff Lukas

ECOSYSTEM SCIENCE AND PREDICTION

A basic, physical understanding of the environment is essential to evaluating ecosystem health—whether in western forests or along U.S. coastlines. CIESRDS scientists use their expertise to analyze physical systems and develop insights, predictions, and projections that drive ecosystem processes and inform management decisions.

On land, a key focus is compiling a tree ring fire scar network and database of past fire activity for North America. This work aims to catalog all tree ring-based fire scar sites throughout North American forests and compile them into a single-source, spatially-gridded dataset of annual fire activity across U.S. and Canadian forests. The results will allow scientists to quantify variability in past fire activity, increase understanding of climate and human drivers of fire and fire regime change, contextualize current trends and extremes in wildfire activity, and model future fire risk.

In the ocean, researchers are developing multi-month forecasts of marine heatwaves and ocean acidification extremes to help fisheries managers and marine sanctuary staff protect vulnerable species and ecosystems along U.S. coastlines.

This work is substantially leveraged by support from other sponsors and advanced by CIRES centers including the Environmental Data Science Innovation and Impact Lab (ESIIL).

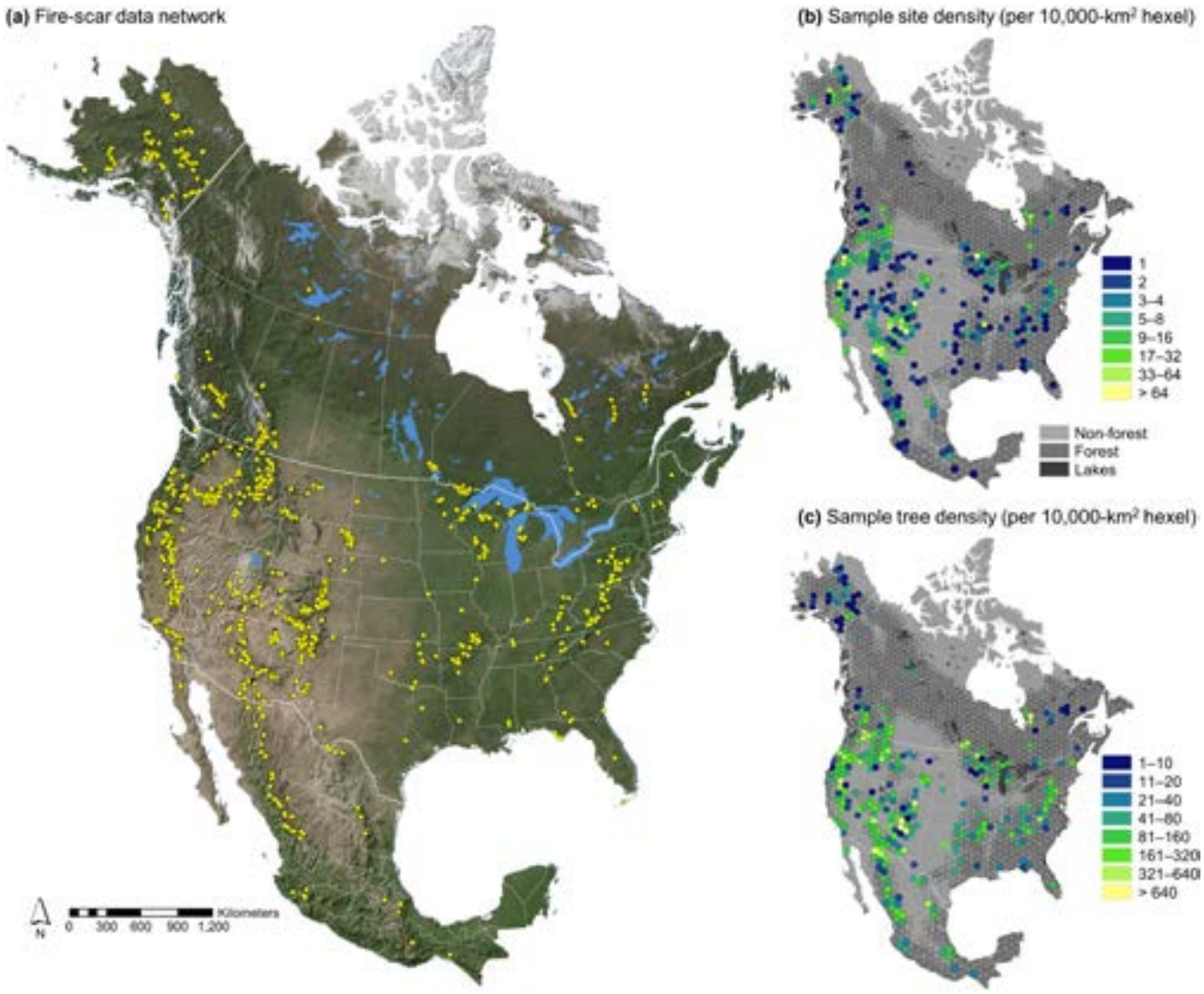
Project: Compiling a North American tree ring fire scar network

CIESRDS contributors: Christopher Guiterman

Relevance to NOAA: This project makes a major contribution to understanding environmental variability and the risks of wildfires. By enhancing understanding of fire-climate-human interactions, this project provides new insights that serve NOAA's goals to advance stewardship and conservation of natural resources and communities, especially those in the wildland-urban interface (WUI).

This project aims to compile all possible tree ring-based fire scar sites throughout North American forests to quantify variability in past fire activity, increase our understanding of climate and human drivers of fire and fire regime change, contextualize current trends and extremes in wildfire activity, and model future fire risk.

Outcomes to date include a dataset of gridded fire history throughout North America, six publications, and nine conference presentations. Over the next five years, researchers intend to complete a set of publications on work that includes scaling rules for fire regimes, human contributions to the collapse of historical fire regimes, and a reconstruction of burned areas and projections of future fire risk for the western United States. The team aims to build the first historical estimates of smoke for the western United States that will inform global change models, such as those used for IPCC, with new estimates of pre-industrial radiative forcing impacts of smoke production.



Map of sites in the North American Fire Scar Network.
Credit: Ekkis Margolis/USGS

Project: Developing an accessible spatiotemporal dataset of fire activity since 1600 over North American forests

CIESRDS contributors: Christopher Guiterman, Calie Payne, Edward Gille

Relevance to NOAA: This project involves developing an accessible spatiotemporal dataset of fire activity since 1600 over North American forests. The data will contribute to understanding environmental variability and change and connects fire to climate and human drivers.

The goal of this project is to convert the North American Tree Ring Fire Scar Network into a single-source, spatially-gridded dataset of annual fire activity across U.S. and Canadian forests, and to combine it with modern fire incidents to produce the first paleo-neo fire continuum dataset for the continent.

The project researchers have fostered a dataset in geopackage format that is accessible across a variety of commonly-used software systems. Researchers expect data publication in 2026 along with a journal article describing its release. Goals over the next five years include expanding across Mexico with enhanced satellite imagery of fire occurrence; interpolating fire activity across unsampled areas; and developing new sites in unsampled areas to fill spatial gaps.

patial representation of historical forest fire activity captured by the North American Gridded Fire Product.
Credit: Chris Guiterman/CIESRDS

Project: Exploring climate extremes and coastal impacts in the Pacific Ocean

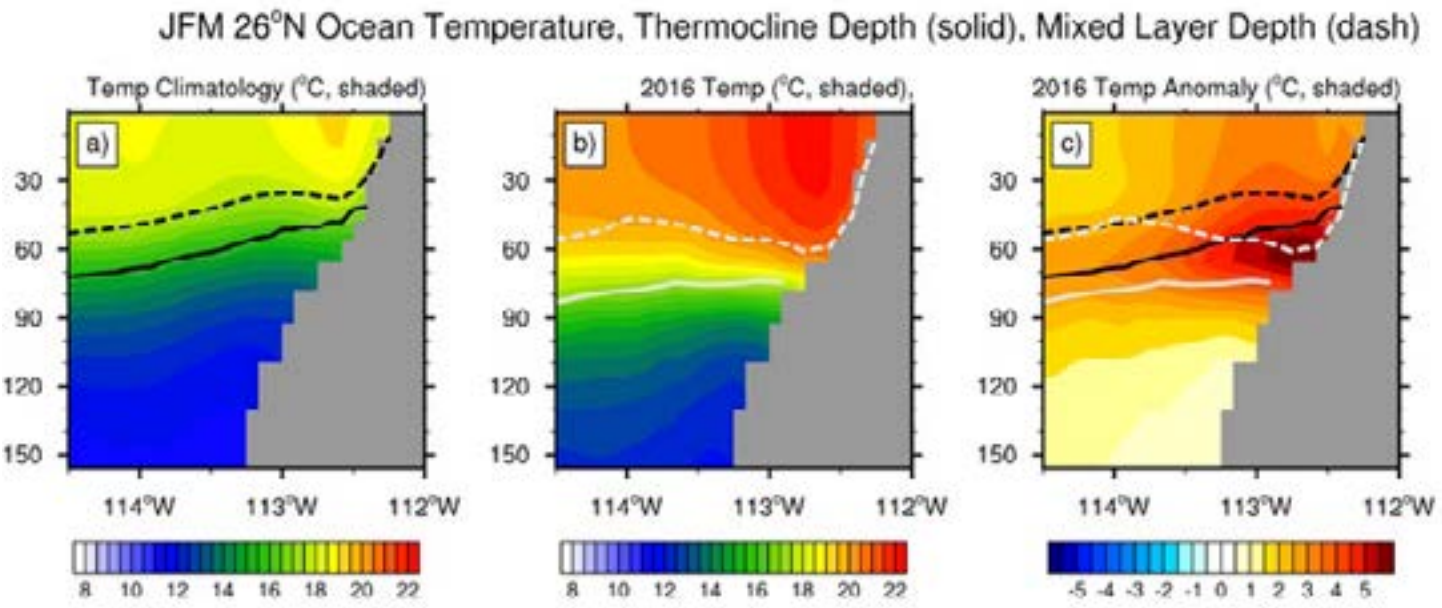
CIESRDS contributors: Antonietta Capotondi, James Scott, Gaelle Hervieux, Chia-Wei Hsu, Tongtong Xu

Relevance to NOAA: This project supports NOAA's mission to conserve and manage coastal and marine ecosystems and resources by informing marine resource managers of processes and predictions that could impact large marine ecosystems of the United States.

Oceanic climate extremes like marine heatwaves, ocean acidity episodes, and hypoxic conditions pose a critical threat to marine life and an increasing challenge to resource management, making climate information of paramount importance to inform decision-making. This project can inform marine managers through process understanding and regional predictions by using global datasets to assess large-scale precursors of extreme conditions together with regional ocean physical and biogeochemical models and observations to determine local impacts on marine species.

The project team has created a web portal to provide information about past and future conditions for U.S. coastal regions; created a marine heat wave monitoring and prediction website; published 16 peer-reviewed publications, including pieces on an increase in marine heatwaves without significant changes in surface ocean temperature variability; created multi-month forecasts of marine heatwaves and ocean acidification extremes; synthesized a global overview of marine heatwaves in a changing climate; conducted a survey of coastal conditions around the continental United States using a high-resolution ocean reanalysis; and conducted research on bottom marine heatwaves along the continental shelves of North America.

Over the next five years, researchers intend to document regional characteristics of extreme events, especially at the sites of U.S. West Coast sanctuaries and assess relationships with basin-scale modes of variability and use regional dynamical and statistical models to identify sources of predictability of climate and biogeochemical variables along the U.S. West Coast.



The climatology and changes in the ocean temperature as a function of depth west of Baja California illustrating the large changes in mixed layer depth (MLD), thermocline depth (TD), and virtual temperature gradients during a strong El Niño event. Cross sections at 26°N during January-February-March (JFM) of the temperature (°C, shading), MLD (dashed line), and TD (solid line) for (a) climatology and (b) 2016. (c) Temperature anomalies during JFM 2016 (°C, shading) and the MLD (dashed) and TD (solid) for the climatology (black) and during 2016 (gray).

Credit: Michael Alexander/NOAA PSL

Project: Leading global methane trends and budget studies

CIESRDS contributors: Xin Lan, Youmi Oh, Ben Riddell-Young, Santanu Halder

Relevance to NOAA: This project improves scientific understanding of human emissions and ecosystem processes related to the changing global methane budget. It is in line with NOAA foundational goal to improve approaches to modeling the planet and preparedness against environmental threats. It benefits global society by early detection and communication of potential climate feedbacks on the carbon cycle and helps monitor progress on reducing global methane emissions from the energy sector.

The project goal is to lead and contribute to global methane budget studies to improve estimates of methane emissions and sinks and reduce uncertainty in wetland methane emissions estimates and their responses to changing climate.

Outcomes so far include completing in-depth analyses of methane isotope data resulting from a partnership with the Institute of Arctic and Alpine Research (INSTAAR) at the University of Colorado Boulder; leading and publishing three major research articles on the global methane budget; and contributing near-real-time methane data and expertise to NOAA GML's CarbonTracker-CH4 modeling operation.

Upcoming goals include continuing to investigate evolving changes in the global methane budget using methane emissions and isotope data and improving NOAA GML's CarbonTracker-CH4 modeling operation.

Interactive map for the Carbon Tracker-CH4 network. Users click on a marker to learn more about the site.
Credit: NOAA GSL and ESRI

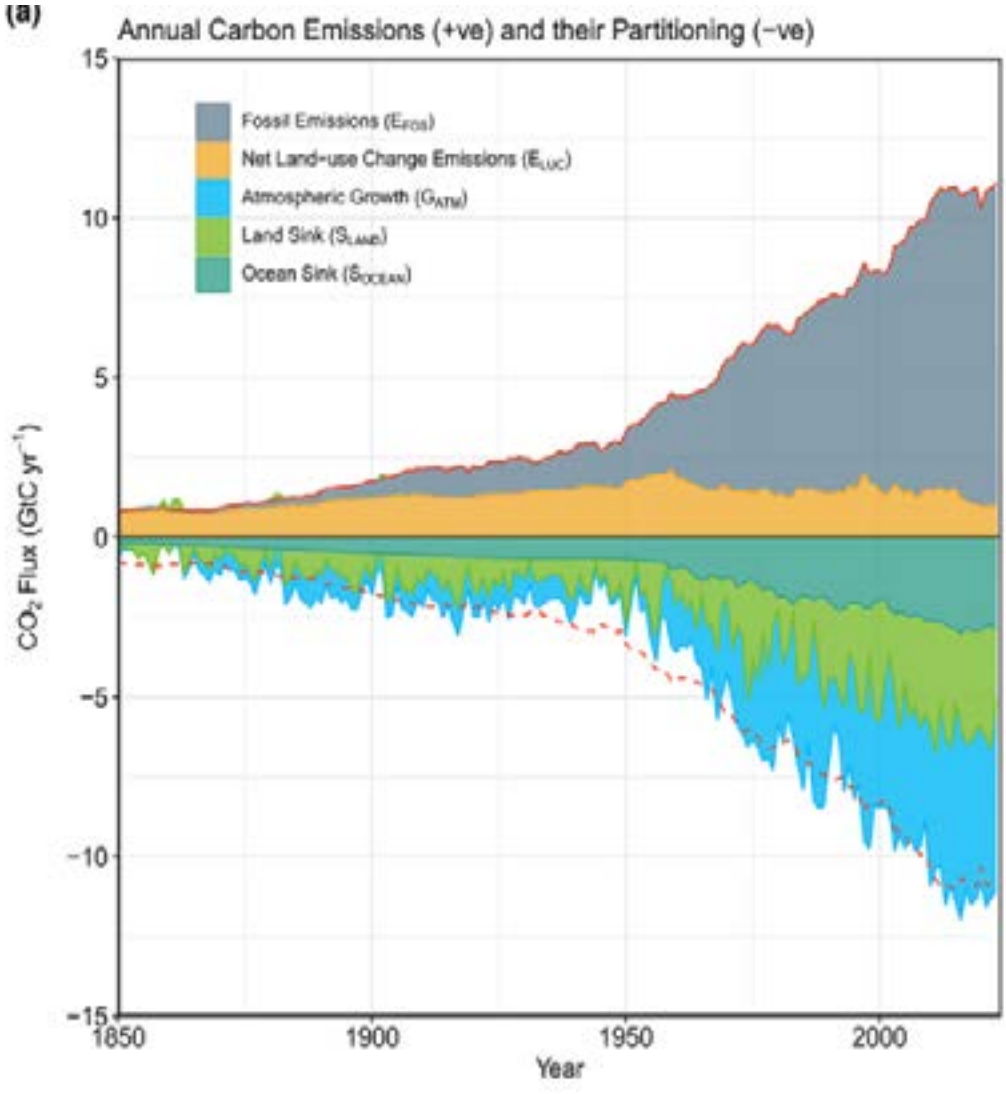
Project: Investigating record-high increases in global atmospheric carbon dioxide in 2024

CIESRDS contributors: Xin Lan, Andrew Jacobson, Aleya Kaushik, Gabrielle Petron

Relevance to NOAA: This project quantifies the climate feedbacks that enhance greenhouse gas emissions, an effort that is essential to improving weather and climate predictions. The project support's NOAA's priorities for increasing preparedness against environmental threats and advancing predictive capabilities.

The project investigates the record-high increase in global atmospheric carbon dioxide observed in 2024, improving scientific understanding of terrestrial and oceanic carbon sink changes and their responses to a changing climate.

Accomplishments so far include conducting in-depth analyses of NOAA Global Monitoring Laboratory carbon monoxide and carbon dioxide data collected from global observatories. Preliminary results suggest that the exceptional carbon dioxide increase in 2024 was likely caused by increased fire emissions from 2023, reduced ocean carbon sinks, and reduced terrestrial carbon sinks. The researchers also contributed a research update to the Global Carbon Budget (Friedlingstein et al., 2025), an annual report that helps scientists monitor the global carbon cycle and serves as a key tool for tracking progress toward climate goals and to the World Meteorological Organization's *Greenhouse Gas Bulletin* for public communication. The scientists will publish research results in the coming year and continue monitoring global carbon budget changes.



Combined components of the global carbon budget as a function of time, for fossil carbon dioxide emissions (EFOS, including a small sink from cement carbonation; grey) and emissions from land-use change (ELUC; brown), as well as their partitioning among the atmosphere (GATM; cyan), ocean (SOCEAN; blue), and land (SLAND; green).
Credit: Pierre Friedlingstein/ University of Exeter

b. Social Sciences/Human Dimensions

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

Social science questions and topics are integrated into CIESRDS-funded research in alignment with several CIESRDS scientific themes, including Future Atmosphere, Climate Science and Prediction, and Ecosystem Science and Prediction. This research is substantially leveraged by funding from other sponsors, amplifying the value of the NOAA investment and extending the reach of NOAA science to new communities and decision-makers.

Risk and Impact Assessments

CIESRDS scientists collaborate with CIRES social scientists to assess societal impacts and risks associated with research outputs, ensuring relevance and usability. For example, the National Integrated Drought Information System (NIDIS) team collaborates closely with social scientists to achieve program goals, including: building leadership and partnerships for a national drought monitoring and forecasting system, integrating key drought indicators for reliable and timely assessments, fostering research on risk and management, providing actionable information for proactive decision-making, and increasing public awareness and education on drought impacts and resilience. This work involves developing user engagement processes, risk and impact assessments, improving graphic web design, and conducting usability studies.

User Feedback and Engagement

CIESRDS teams collect feedback from agencies, universities, companies, and the public regarding the use of data products in forecasting and scientific projects. One method is maintaining usage statistics, which help assess user needs. This feedback informs product development and communication strategies. As an example, in developing the Mississippi River Basin Drought and Water Dashboard, CIESRDS scientists engaged stakeholders across the 31-state basin to inform the dashboard's design. The tool — launched in September 2025 — was co-developed with state and local government agencies, the U.S. Army Corps of Engineers, the U.S. Coast Guard, the U.S. Geological Survey, and industry organizations to ensure it provides actionable, user-friendly information for risk-informed decision-making.

Collaboration with Social Scientists

Social scientists play a key role in improving usability of forecast tools, advising on effective messaging strategies, and guiding forecaster training. CIESRDS teams collaborate with NOAA social science specialists during product development. For example, NOAA and CIESRDS scientists have enhanced the National Weather Service's Winter Storm Severity Index (WSSI) suite—refining definitions, color schemes, and elements—through CIESRDS-funded work. They also work with social scientists to provide guidance on messaging ensemble cluster scenarios via the Cluster Working Group, supporting forecaster training and communication best practices. Additionally, when operationalizing web pages for forecast tools, CIESRDS researchers submit Product Description Documents to the NWS, outlining feedback processes to ensure information is communicated clearly and efficiently.

Human-Centered Research

We directly measure how people learn about climate change through our research and data sets. A CIRES Visiting Postdoctoral Fellow, a psychologist, studies how Science On a Sphere (SOS) is used as a learning tool through surveys, tests, and observational studies. The SOS team also partnered with an undergraduate technical writing class at the University of Colorado Boulder. As part of a group project, students evaluated the software and offered design suggestions for improvement. These findings influence CIESRDS development priorities.

Community Engagement and Citizen Science

CIESRDS hosts projects that involve the public in data collection, integrating citizen science into research workflows. For example, our CIESRDS NCEI team developed CrowdMag, a public engagement product that collects vector magnetic data using smartphone magnetometers, crowdsourcing data to fill gaps in magnetic maps. This team also developed the MagMapper app for the Department of Energy, built entirely on the model of public science participation. The effort is designed to locate Undocumented Orphan Wells (UOWs), which are abandoned oil and gas wells with no known owner responsible for cleanup that aren't recorded in official databases — meaning they leak methane and other pollutants without anyone knowing they exist A crowdsourced bathymetry project provides a robust pathway to integrate non-scientific bathymetry data into the NCEI archive for inclusion in global seafloor maps. The CIESRDS NCEI team also leads workshops and meetings to build capacity and engage communities at the Seabed 2030 South and West Pacific Mapping Meeting, International Hydrographic Organization (IHO) Crowdsourced Bathymetry (CSB) Working Group Meeting, NOAA Office of Marine and Aviation Operations (OMAO) Data Assembly Meeting, and virtually for Northwestern Michigan Community College students.

Data Access and Service Improvement

CIESRDS implements social science approaches to study user behavior and feedback for National Snow and Ice Data Center (NSIDC) data products, driving improvements in technical support, documentation, and accessibility for diverse user groups. These data products serve more than 20,000 annual users from research, education, government, and commercial sectors. The research team communicates directly with users through help desk inquiries and corre-

The Center for Education. Engagement, and Evaluation's We are Water traveling exhibit at The Powerhouse, Durango, CO, is a place where community members can experience, learn, share, and talk about what water means to them. Each piece of the exhibit includes a hands-on activity or game. Photo: CEEE

spondence, documenting how they apply our cryospheric datasets. This feedback has driven service improvements such as technical support for data file issues, guidance on data access, and documentation for users with different technical skills. We also analyze access patterns to measure how well our data accessibility and support services work for different user groups.

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

Grounded on the work of more than 20 social science researchers, many of whom are funded by outside resources CIESRDS has a long-standing reputation for collaborative work that crosses disciplinary boundaries. The newest member of the CIRES/CIESRDS Council of Fellows, for example, focuses on environmental public health. The University of Colorado Boulder consistently supports two to three faculty lines in the social sciences, with investments that significantly strengthen our institute's research and teaching capabilities as they relate to environmental issues. These positions directly align with CIESRDS goals and objectives and bring significant capabilities to the NOAA-CI enterprise. The three nationally recognized CIRES centers listed below are leveraged by CIESRDS and focus on co-produced, usable social science that engages users from the beginning to serve society's needs.

Western Water Assessment (WWA)

This center is a NOAA-funded Climate Adaptation Partnership (CAP)/Regional Integrated Sciences and Assessments (RISA) program that conducts innovative research in partnership with decision-makers in the Intermountain West, helping them make the best use of science and build local and regional resilience. WWA has successfully engaged stakeholders to ensure that CIESRDS and NOAA research informs the decisions of communities, states, utilities, and other entities by enabling people and businesses to plan for and respond to impacts from natural hazards like wildfire, flooding, and drought.

For example, WWA has expanded its work with communities in Colorado, Utah, and Wyoming, with a particular focus on rural communities. Their work has shown that while many of these communities have a strong desire to build resilience, they face challenges that make it difficult to navigate the broad range of existing tools and data sources, access support to optimize the effectiveness of their planning processes, and obtain local and sector-relevant information. WWA hosts workshops in these communities, conducts customized data analyses, and synthesizes existing data to advance community-engaged research projects regarding hazard planning. Research led by WWA has been highlighted at social science conferences, including the American Association of Geographers (AAG) and the American Sociological Association, and WWA's lead social scientist was selected by the AAG as one of their inaugural class of public scholars.

North Central Climate Adaptation Science Center (NC CASC)

This center, funded by the Department of the Interior, is a collaboration with the USGS and five other partners to conduct innovative research, training, and data science supporting ecosystem management in a seven-state region from Colorado to North Dakota. Its ecosystem-related foci includei include habitat fragmentation, ecological drought, invasive species, and species restoration. The NC CASC is also a key focal point in CIRES for work with Tribal Nations on ecosystem management and supports liaison work, training, and education focused on highlighting and expanding Indigenous capacity in ecosystem science, data science, and resource management.

For example, NC CASC has conducted research to assess the strengths and weaknesses of an ecological vulnerability assessment approach for informing decision-making. They review social vulnerability methods in the context of public lands to demonstrate what these approaches can contribute and suggest key design principles for integrated social-ecological vulnerability assessments, considering the context of public lands management, the limits of ecological vulnerability assessment, and existing approaches to social vulnerability assessment methods.

Center for Education, Engagement, and Evaluation (CEEE)

The Center connects environmental science with people to inspire curiosity, community, and action while advancing evaluation and education research to measure the impact of outreach and engagement efforts. In addition to program evaluation, CEEE conducts independent studies, such as a CIRES Innovative Research projects focused on equipping educators and researchers with the skills and training needed to address the psychosocial impacts of climate change. This work aims to foster resilience, promote well-being, and empower future generations to confront climate challenges by identifying effective training models and support systems for managing climate-related emotions. Furthermore, science and outreach conducted through CIESRDS enhances our overall capacity for collaboration with Arctic Tribal Nations, strengthening partnerships and ensuring culturally informed approaches to environmental research and education.

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

CIESRDS funding for social science projects partially supports salaries for the researchers who lead these efforts. Our estimate includes compensation for the Visiting Fellows Program SOS postdoctoral researcher, and the CEEE Director, totaling approximately $600,00. The institute operates within a strong campus-based model, leveraging faculty lines and centers that are supported by CIESRDS and CIRES but largely sustained through external proposals.

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

The major roadblocks to expanding social science in the research plan involve three key elements: funding, training, and opportunities for collaboration to fully leverage the capabilities of social science researchers at CIESRDS. To address our mission of "conducting innovative research that advances our understanding of the global, regional, and local environments and the human relationship with those environments, for the benefit of society," we must be able to determine how our research is received and used by the public, especially frontline communities. Currently, when providing resources for the public, our NOAA-based researchers have limited access to expert campus social scientists to collaborate on embedding social science research questions into their approach. CIRES needs to plan physical science projects and grant proposals that strengthen the integration of social scientists and allow time to develop strong relationships with communities. Building trust over time is critical for community-driven and citizen science projects that would allow our institute researchers to fully gauge how their science addresses local community needs. However, funding for community-engaged research is further limited by the lack of external funding in calls for proposals for social science studies.

Additional funding would allow CIESRDS to offer seminars educating researchers on social science study design, theory, and application. Such training could help distinguish applied social science research (e.g., facilitating co-production of science information, user-based design, needs assessments, and impact studies) from foundational social science work (e.g., understanding decision-making context, science and technology studies that examine how we generate science, studies that examine power dynamics and how they shape values for decision-making, and prioritization of scientific research). Led by our campus-based social scientists, these seminars would help researchers incorporate social science into their project design from the beginning — ensuring they understand the scope, timeline, and resources needed to do it well. Two avenues that create opportunities for collaboration are highlighted in the next question and need the full support of NOAA federal leadership for researchers to engage with their time and energy.

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

CIESRDS will continue to fund and support the centers and social science projects described in this section. CIESRDS also leverages university-funded faculty expertise and actively pursues external funding for complementary research and activities, extending the impact of NOAA's investment. The following two examples provide information on our next steps for integrating social science approaches into existing physical science research projects.

- **CIESRDS' Space Weather Prediction Center** researchers are actively consulting with NOAA social scientists as they develop new products and upgrade existing products on their consumer-facing webpages.
- **CIESRDS' Global Monitoring Laboratory** researchers will continue to incorporate public perception of GHGs as related to climate change and extreme weather events in NOAA lab tours and press communications.

Aligned with the institute's strategic plan, CIRES is working to connect CIESRDS researchers with CU-based social scientists through an annual CIRES-wide interactive workshop. This workshop, titled "The Science Summit," strengthens our internal networks, fosters collaborations, and amplifies existing research, outreach, and engagement efforts. See section 4.f.i for more about this workshop.

3. EDUCATION AND OUTREACH

a. What types of educational activities/opportunities (K-12, undergraduate, and graduate students) does the institute offer on an ongoing basis?

The CIRES Center for Education, Engagement, and Evaluation (CEEE) is an award-winning, nationally renowned, and trusted partner for connecting NOAA, CIESRDS, and CIRES science with educators, learners, communities, and future scientists and for offering workforce development opportunities. As shown in Fig. 1, the CEEE team provides accessible, high-quality environmental science curriculum and informal learning experiences, community building and engagement, meaningful career development, and research and evaluation support to assess the impact of education and science programs. Some CEEE projects supported by CI funding, NOAA funding, and/or involving CIESRDS research scientists are described below to illustrate the breadth of CEEE's work.

These programs advance Strategic Imperative #2 of the CIESRDS Strategic Plan: to train and inspire a diverse and skilled future Earth system and data science workforce for NOAA and beyond.

Fig. 1: CEEE conducts outreach and education across the focus areas shown in this diagram.

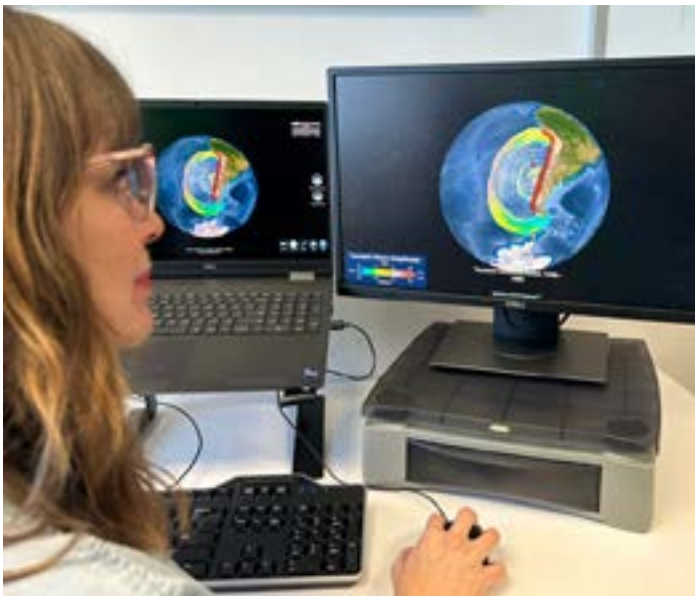
K-12 Programs: Teacher Professional Learning, Curriculum Development, and Student Programs

The Climate Literacy and Energy Awareness Network (CLEAN)

Since 2017, CLEAN has been funded by NOAA and, until summer 2025, served as the official content provider for NOAA's Climate.gov Teaching Climate web portal. Its primary site, cleanet.org, hosted by the Science Education Resource Center (SERC) at Carleton College, remains widely used, attracting over 750,000 annual sessions. CLEAN is a national leader in climate and energy education, offering an award-winning, scientist-reviewed collection of more than 1,000 free, classroom-ready resources, professional development opportunities, and a vibrant educator community of practice. The program supports K–16 educators with high-quality instructional materials, teaching guides, newsletters, and workshops that advance climate and energy literacy nationwide. CLEAN's resources align with NOAA's climate literacy principles and complement the U.S. Global Change Research Program's National Climate Assessment. With a network of over 700 members and strong outreach, CLEAN connects educators, scientists, and partners to strengthen climate education. CIRES, in collaboration with national climate educators and NOAA scientists, has expanded CLEAN into a leading platform for climate education and professional development. CLEAN also maintains visibility through sessions at major conferences, including the American Geophysical Union's Fall Meeting and Earth Educators' Rendezvous.

Science On a Sphere (SOS)®

This flagship outreach tool, developed by NOAA, is a room-sized, global display system that uses computers and video projectors to display NOAA planetary data onto a six-foot-diameter sphere, analogous to a giant animated globe. Animated images of atmospheric storms, climate change, and ocean temperature can be shown on the sphere to explain complex environmental processes in a way that is both intuitive and captivating. Engagement with SOS enhances scientific environmental literacy and improves understanding, value, and use of weather and water



NOAA's SOS Explorer® is an application that can be played right on your desktop or laptop computer in high resolution or projected onto a larger screen for wider viewing.

information as a public engagement platform, including for the K-12 education community.

The SOS sphere is installed in 157 museums and other outreach facilities around the world; there are 53 SOSx (flatscreen SOS version) installations and thousands of downloads of SOSx Mobile. Regular releases of new NOAA datasets make the tool easier to use and more engaging. Millions of learners around the world engage with NOAA and other Earth science datasets through these platforms every year. Supported primarily by CIESRDS and CIRES experts, the SOS data catalog has grown to over 600 datasets. A new curriculum series ("Data Lens") has been developed by the SOS and CEEE education team; these short data lessons equip teachers with tools to help their students engage with and understand complex NOAA data using SOS datasets. New lessons are released several times a month, and educator training webinars draw hundreds of teachers.

CEEE SOS staff organizes monthly SOS network meetings, the network's annual workshop, and regular public tours of the NOAA facilities in the David Skaggs Research Center. The team works in close consultation with the NOAA Office of Education, NOAA's Global Systems Laboratory (GSL), and the Cooperative Institute for Research of the Atmosphere (CIRA). The SOS Education Forum, facilitated by the CEEE SOS team, connects approximately 100 educators and content creators through regular webinars to share best practices, showcase new programming, and provide technical training. This sustained engagement, ongoing for 13 years, fosters strong collaboration between NOAA and external partners, featuring expert contributions from institutions such as The Lawrence Hall of Science, NASA, Clark Planetarium, and numerous universities.

Resilient Futures Teacher Workshop

Each summer, more than 50 middle and high school science teachers attend a full-day, in-person workshop at CIRES to explore classroom-ready lesson plans presented by experts from CEEE, Earth Force, the Colorado Department of Public Health and Environment, and CLEAN. The event features talks by CIRES/CIESRDS and NOAA scientists and includes a tour of NOAA's SOS. Sessions cover topics such as environmental hazards, water resources, climate mental health, and data literacy. Teachers receive training on engaging lessons and activities designed to reach the 5,000+ students they teach. The workshop is held annually and is scheduled again for July 2026.

Undergraduate Programs: Research Internship Programs

CIESRDS and NOAA researchers engage with undergraduate students as mentors in various research internships and career development programs, as listed below.

Global Systems Laboratory Research Internship Program

In 2022, CIRES/CIESRDS partnered with NOAA's Global Systems Laboratory to launch the Professional Research Experience Program: GSL/CIRES (PREP-GC), a summer internship designed for students. The program offers 10-week appointments for undergraduates and 12-week appointments for graduate students, including stipends and housing. Interns engage in weekly professional development sessions and networking events and conclude with a poster or oral presentation. Each year, nearly 100 students apply, with participants representing states from Vermont to California and territories such as Puerto Rico. PREP-GC continued successfully in 2023 and 2024, hosting 11 and 12 interns, respectively.

Hollings, EPP, and Lapenta Mentors

CIESRDS researchers actively support several student programs, including the Ernest F. Hollings Undergraduate Scholarship, the Educational Partnership Program (EPP), the William M. Lapenta Internship, and lab-based research internships with local universities. The prestigious Hollings Scholarship provides $9,500 annually for two years of full-time study, a 10-week paid summer internship at any NOAA facility nationwide, and funding to present research at two national scientific conferences. The William M. Lapenta Internship offers a full-time, 10-week experience between late May and early August, beginning with an orientation and icebreaker session. Interns work on projects that advance forecasting, operational model development, data analysis techniques, and visualization tools, as well as initiatives in air quality, ocean-atmosphere modeling, social science for integrated decision support systems (IDSS), and satellite data applications. Participants attend lectures and skill-building workshops and present their projects in written and oral formats. Benefits include a $6,000 stipend, furnished housing, travel allowance, conference abstract fees, transportation subsidies, and a certificate granting Direct Hiring Authority

upon completion. Interns collaborate with NOAA scientists across all line offices, including NWS, OAR, NESDIS, NOS, NMFS, and OMAO. Collectively, these programs hosted 38 student internships last year, providing hands-on research experience, professional development, and networking opportunities with NOAA and CIESRDS scientists.

Graduate Student Programs: Professional Development

Through the CIRES/CIESRDS Fellows, the institute funds graduate students across multiple departments, including Aerospace Engineering, Atmospheric and Oceanic Sciences, Chemistry, Civil, Environmental and Architectural Engineering, Ecology and Evolutionary Biology, Geological Sciences, Geography, Environmental Studies, and Molecular, Cellular and Developmental Biology. Some students complete research projects in NOAA-based labs, while others serve as research assistants in programs such as the Access and Cultural Innovation Program, CEEE, and Earth Lab.

CIRES also offers the Graduate Student Research Award, which provides support equivalent to two semesters, including salary, full tuition coverage, and a partial premium toward health insurance. This one-time award recognizes outstanding scholarship and merit among CIRES graduate students. Eligible applicants are current Ph.D. students formally supervised by and conducting funded research with a CIRES or CIESRDS Fellow or Researcher. Educational and professional development opportunities are available to all CIRES/CIESRDS graduate students through the organizations highlighted below.

CIRES Early Career Assembly (CECA)

All graduate and postdoctoral researchers advised or hosted by a CIESRDS researcher, or serving as research assistants within CIESRDS units, are invited to participate in CECA. The Assembly organizes academic and social activities designed to foster collaboration among early-career researchers, encourage interdisciplinary dialogue, and enhance science communication skills. CECA also administers the CIRES Travel Award (funding for conference attendance) and the Graduate Student Research Award Program (two semesters of support); maintains a Career Opportunities Board; and hosts events focused on career development, including conference preparation, networking, and community engagement. The Assembly is led by two member co-chairs who distribute regular newsletters to keep participants informed. CIRES/CIESRDS researchers have participated in CECA career panels and have offered workshops on mentoring, networking at conferences, technical skills, and community engagement.

Mentor Training

CEEE has developed and implemented a mentor training program designed for early-career scientists beginning their roles as research mentors. NOAA and CIESRDS graduate students and postdocs have participated in these sessions, which focus on effective mentoring practices. The program has been offered through in-person workshops and virtual formats and is currently being expanded into an asynchronous training module.

Student Salome Carrasco examines a grasshopper she caught for the research project she undertook through the Research Experience for Community College Students (RECCS).

Photo: Stephanie Maltarich/CIESRDS

Complementary Programs

The CEEE team continually pursues opportunities from other sources that support or complement NOAA's overall goals and mission. These include:

- **Data Puzzles** translates NOAA datasets and CIRES research into classroom-ready lessons, helping students analyze real climate and hazard data to build evidence-based reasoning skills. This work advances NOAA's education mission by making agency science accessible to teachers and students across the country.
- **Hazard Education, Awareness, and Resilience Task Force (HEART Force)** is an award-winning program that engages rural Colorado students and communities in building resilience to drought, wildfire, and flooding. Using NOAA's Resilience Toolkit as a framework, the program connects students directly with NOAA scientists from the National Weather Service, National Integrated Drought Information System, and Western Water Assessment. Funded by NOAA's Environmental Literacy Program, HEART Force translates agency science into locally relevant resilience strategies — and its scenario-based role-playing games have expanded beyond classrooms into community planning efforts statewide.
- **Research Experience for Community College Students (RECCS)** provides paid summer research opportunities for students from Colorado and surrounding rural areas, pairing them with CIRES/CIESRDS and NOAA scientist mentors for nine weeks of independent research. Over 11 cohorts, 125 students have completed the program — 43% first-generation and 16% from rural communities — with many advancing to four-year degrees and graduate studies. The program strengthens NOAA's future workforce pipeline while building connections between agency scientists and emerging talent from underrepresented communities.
- **GeoREU Network** leveraged NSF funding to support Research Experience for Undergraduates (REU) programs across the geosciences, with CEEE co-leading the effort and delivering evaluation training for program leaders nationwide. NOAA and CIRES/CIESRDS scientists participated actively, connecting agency workforce development efforts to a broader national community of practice.
- **Polar Science Early Career Community Office (PSECCO)**, funded by NSF, leverages national partnerships to support the next generation of polar scientists. CIRES/CIESRDS researchers contribute through mentorship, speaking engagements, and participation in the 2025 International Polar Early Career World Summit, which gathered input from 178 researchers to shape priorities for the 5th International Polar Year. The initiative extends NOAA's reach into the early-career polar science community and strengthens the agency's future workforce.
- **ADVANCEing Field Safety** leverages NSF ADVANCE funding to improve safety and inclusion in scientific fieldwork through online courses, workshops, and toolkits. CIRES/CIESRDS and NOAA scientists have completed the training, extending the program's impact to NOAA field operations and supporting the agency's goals for safe, welcoming research environments.

These activities and programs are examples of how CIESRDS effectively works to substantially leverage NOAA's investment in education and outreach.

i. Are these activities coordinated with other NOAA education/outreach programs in the area?

Leaders of CEEE and NOAA student internship programs meet quarterly through the CIRES/CIESRDS Student Program Network to collaborate and share best practices. This group exchanges materials and ideas on topics such as application processes, holistic review rubrics, mentor training, scientific identity development, and professional development for student participants.

The NOAA Education and Outreach Director and the CEEE Director have partnered on collaborative service projects, including the NOAA Western Regional Team annual meeting in Boulder. During this event, 40 team members engaged with CEEE leaders to learn about outreach initiatives—notably the We Are Water program (see Public Outreach in section 3.b. (https://ceee.colorado.edu/resources).

NOAA Educational Communities of Practice

CEEE has been a sought-after partner for NOAA's Office of Education in advancing NOAA's Environmental Literacy Program (ELP) Community of Practice. In 2023, CIESRDS/CEEE hosted and co-organized the NOAA ELP grantee workshop in Boulder, featuring opening remarks by the CIRES/CIESRDS Associate Director for Science, presentations from NOAA and CIESRDS experts, a tour of NOAA facilities, and a demonstration of Science On a Sphere. In 2024, CEEE co-organized the annual ELP workshop at the Wild Center in New York, bringing together the ELP and SOS communities of practice. These workshops foster collaboration, knowledge exchange, and capacity building among funded projects. CEEE supported planning, participant engagement, and session design. Both events featured keynotes, presentations, grantee profiles, interactive "Share-a-Thon" sessions showcasing educational resources, and breakout discussions that strengthened cross-project learning.

Colorado Science Conference

Through their strong partnership, NOAA and CEEE outreach staff have co-hosted an outreach booth at the Colorado Science Conference. Together, the teams presented hands-on educational activities, shared NOAA-supported resources, and presented current program work to hundreds of Colorado educators. This collaboration has expanded the visibility of NOAA's education initiatives, strengthened connections with the K–12 teaching community, and supported teachers in integrating high-quality environmental and climate literacy materials into their classrooms.

NOAA and CIRES education leaders also collaborate at national conferences held by organizations such as AGU, Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS), Advancing Indigenous People in STEM (AISES), and National Science Teaching Association (NSTA). Additionally, researchers actively participate in the national "Letters to a Pre-Scientist" program, writing to middle school students through a locally coordinated effort, and contribute to NOAA Planet Stewards book club discussions.

ii. How does the university make curricula, study guides, guest speakers, and teaching materials available to support these activities?

CEEE provides an extensive online resource library featuring hundreds of peer-reviewed lesson plans and activities, Earth science videos, professional learning opportunities, community climate stories, and virtual workshops. Science Show & Share webinars connect CIRES/CIESRDS and NOAA scientists worldwide with students and learners of all ages. Additional resources include game-based learning tools such as NOAA-funded hazard resilience roleplay games, virtual field trips, storytelling guides, climate mental health strategies, video-making workshops, and materials on geomagnetism and space weather.

Asynchronous online materials include courses such as:

- **"ADVANCEing Field Safety"** — A Massive Open Online Course (MOOC) hosted on the Coursera platform that provides field research team leaders and participants with the skills and tools to build a welcoming and supportive field culture. This course features a CIESRDS scientist's field campaigns.
- **"Frozen in the Ice: Exploring the Arctic"** — A self-paced, free Coursera MOOC highlighting the extraordinary MOSAiC Arctic research mission, which involved freezing an icebreaker into the Arctic Ocean for 13 months. The course features multiple NOAA and CIESRDS scientists.
- **"Water in the Western US"** — A self-paced, free Coursera MOOC allowing learners to explore water and climate topics in the Western United States and gain insight into the major legal, political, and cultural issues that make water so complex in the region. Co-developed with Western Water Assessment, this course features multiple NOAA and CIESRDS scientists.
- **CLEAN portal training** — Explores the free teaching resources offered on the NOAA-funded Climate Literacy and Energy Awareness Network climate education portal.
- **"Science Show and Share" videos** — Feature CIESRDS scientists leading short lessons involving their research.
- **"Strategies for Effective Mentorship"** — A new MOOC launching in spring 2026. Thousands of learners take advantage of these freely available courses on the Coursera platform.

CEEE publishes multiple monthly newsletters—one for educators and another for scientists and education-focused audiences—and shares weekly resource updates on Facebook and LinkedIn. It has also partnered with NOAA's Office of Education on "back-to-school" social media campaigns to highlight high-quality climate education resources.

Guest Speakers

CEEE provides several avenues for guest speakers at educational events. Many CIESRDS researchers give classroom talks across Colorado and present at CU Boulder department seminars. The NOAA Education and Outreach Director coordinates speaker requests. The Science Pathways Program offers free science and career talks at local institutions to build connections, reduce barriers to working at CIESRDS, and expand the reach of its science. Currently, five of the nine trained speakers are NOAA-based CIESRDS researchers.

b. What are current and planned outreach efforts?

CIESRDS devotes considerable effort to scientific outreach as part of the institute's core mission and as key to supporting research and education excellence. CEEE has a team focused on community engagement work. CIESRDS also explicitly includes public outreach as an annual performance measure. Examples below are categorized as public outreach, professional training of scientists, and communication products.

Public Outreach

We are Water

Focused on drought and water scarcity in the desert Southwest, CEEE's award-winning We are Water program brings a traveling exhibit and interactive programs to rural communities across the Four Corners Region, engaging community members in conversations about their personal and community connections to local water topics. Libraries in rural areas, which often function as the local science center, host the exhibit, programs, and STEM experiences in their communities. The project won the 2023 CO-LABS Governor's Award for High-Impact Research, and the community engagement award from the Association of Tribal Archives, Libraries, and Museums.

Science On a Sphere (SOS)®

Beyond its educational applications described in section 3.a., SOS serves as a flagship NOAA public outreach platform, widely used in museums, planetarium theaters, and informal science centers to engage the public with Earth system sci-

Postdoctorate researcher Cassie Buhler gives a Science Pathways talk to a wetlands class at the Metropolitan State University of Denver.
Credit: Lauren Lipuma/CIESRDS

ence. Its intuitive visualization of complex NOAA datasets—including weather, climate change, and ocean processes—reaches millions of public visitors worldwide.

Science Pathways Program

Described in section 3.a.ii., this program also serves as public outreach by inviting Colorado institutions to host free science and career talks, building connections and expanding the reach of CIESRDS' science.

Winter Storm Severity Index

The Winter Storm Severity Index (WSSI) is designed to help National Weather Service partners and the public understand the potential severity of winter precipitation and its societal impacts. By translating complex forecast data into an easy-to-understand format, WSSI supports informed decision-making and community preparedness. While it is not an official warning tool, WSSI complements NWS forecasts and warnings, serving as an outreach resource to raise awareness and promote proactive responses to winter weather hazards.

NIDIS & WWA Webinars and Workshops

These units leverage emerging technologies to engage the public, decision-makers, and elected officials in building drought awareness and planning strategies. The drought.gov website serves as a highly accessible, user-friendly portal offering real-time drought conditions for every U.S. zip code. CIESRDS researchers working with NIDIS and WWA extend this outreach by organizing webinars and workshops that connect communities with actionable information and resources.

CU Wizards

For over four decades, this CU Boulder program has engaged and informed children about the wonders of science. Once each month, from September through June, CU Wizards presents a Saturday morning interactive outreach show on teh Boulder campus. NOAA and CIESRDS researchers present regularly, such as at the recent event titled "There's Something in the Air!"

High School Mentoring

CIESRDS researchers often work with high school students as judges of science and engineering fairs, panelists, research project supervisors, and science talk presenters. CEEE regularly matches CIESRDS and NOAA scientists with student research support, science fairs, and other engagement requests.

Professional Training of Scientists

NWS Training of Forecasters

Numerous training sessions have been conducted to equip NWS forecasters with skills to use new situational awareness tools, including the WPC Ensemble Clustering and Ensemble Sensitivity products. A training module on clustering was developed and made available through the University Corporation for Atmospheric Research (UCAR) Cooperative Program for Operational Meteorology, Education, and Training (COMET), complemented by in-person demonstrations at the NWS Boulder forecast office and WPC, as well as webinars for other offices upon request. These efforts ensure forecasters gain practical experience with advanced tools, adding valuable capabilities to their forecasting "toolbox." Regular engagement between CIESRDS research staff and operational NWS forecasters strengthens collaboration and fosters partnerships that enhance forecast accuracy and decision support.

CIRES/CIESRDS Mentoring Program

The CIRES/CIESRDS Mentoring Program is designed to foster professional growth and career development for both mentees and mentors. Through the exchange of knowledge, skills, and experience, mentors help mentees set career goals, navigate challenges, and balance work and life. The program offers mentees access to mentors within CIESRDS who provide practical insight into the CIESRDS–NOAA ecosystem, while mentors benefit by gaining leadership experience, expanding their networks, and engaging in self-reflection. By including federal researchers as mentors, the program strengthens connections between NOAA and CIESRDS. Annual evaluations show that participants report an increased sense of belonging and overwhelmingly recommend the program to others.

Braided River Trainings

The braided river professional development framework promotes varied pathways into and within STEM careers and supports opportunities for lifelong continuing education. CIRES and CEEE use the framework to offer a variety of professional development opportunities to CIESRDS and NOAA scientists. Examples include "Building a Meaningful Support Network" with Christine Wiedinmyer (CIRES and CIESRDS' former Associate Director for Science), "Effective Mentoring" with Anne Gold (former CEEE Director), and "Developing Feedback Skills" with Becca Edwards (CIRES Director for Access and Innovation) and Emily Hinga (CIRES Senior HR Generalist).

Dialogic Skills Program

The CIRES Access and Cultural Innovation Director partners with the Masters of the Environment Program (MENV) and the Laboratory for Atmospheric and Space Physics (LASP) to offer a series of four workshops focused on developing dialogic skills for graduate students, postdocs, and early-career scientists. This program is open to any MENV, CIRES, or LASP employee, allowing for cross-disciplinary conversations during interactive workshops.

Communication Products

The CIRES Communications team shares CIRES and CIESRDS science with the broader world, enhancing the impact, accessibility, and reach of institute research. Through writing, video and audio production, animation, illustration, graphic design, and social media, the team promotes research to journalists, partners, and the public. They manage CIRES social media channels, connect reporters with CIRES/CIESRDS scientists, and maintain CIRES and CIESRDS branding and style guidelines.

Partnership with NOAA

Communications staff embed with NOAA communications leads to develop story ideas, support NOAA communications priorities, and amplify NOAA news and research through CIRES channels. CIRES communicators and scientists produce or have substantial involvement in producing about one-third of stories on NOAA Research News. CIRES/CIESRDS experts also write NOAA Hot Items to convey important news to internal NOAA colleagues, including agency leadership. This close collaboration ensures alignment between institutional and agency messaging while extending the reach of NOAA science to broader audiences.

Content for Diverse Audiences

CIRES Communications delivers content in various forms tailored to specific audiences, including written stories, animations and videos, illustrations, audio stories, e-newsletters, and engaging Story Maps. *Spheres* Magazine, our flagship publication, highlights the wide-ranging research conducted at CIRES and CIESRDS, reaching scientists, partners, stakeholders, and the public. The team's newsroom features news stories, videos, and press coverage.

Media Relations

CIRES Communications engages regularly with science and other journalists, pitch stories to outlets, and connect reporters with CIRES experts across topics including fire, air quality, climate, weather, and polar science.

Science Communication Training

CIRES Communications works with NOAA colleagues to run communications training. Additional resources help CIRES and NOAA scientists communicate their work effectively, including video workshops and tip sheets covering topics such as crafting conference presentations, introduction to video and animation, visual communication, data visualization, photography, media interview preparation, and message construction.

Internal Communications

Connecting scientists and administrative staff with the information they need to succeed is a core function. The team supports internal communications across CIRES and CIESRDS to ensure staff are aware of resources, opportunities, and important developments. Working with the director, they hold regular town halls to keep staff informed and engaged.

Events and Outreach

In-person events serve as opportunities for information exchange with partners, stakeholders, and the public. We attend conferences and host booths to represent CIESRDS research. We also connect CIRES and NOAA scientists with community engagement opportunities, such as giving a talk at a Rotary Club meeting, public lecture series at a local brewery, presenting as part of the CU Wizards Program, or writing a syndicated essay for The Conversation, which may appear in newspapers around the world.

A vibrant social media presence is maintained by CIRES/CIESRDS, CEEE, WWA, and NSIDC, regularly crafting social media campaigns and amplifying research findings to diverse audiences.

i. Does the CI conduct joint outreach with other NOAA-funded or supported university activities (e.g., Sea Grant, CSCs)?

CIESRDS researchers work closely with NOAA's Director of Outreach, participating in a wide range of activities that engage the public and educational communities. These include public and school tours featuring the Science On a Sphere exhibit, classroom visits, local speaking engagements, congressional and VIP tours, and weather balloon demonstrations. Recently, researchers have supported University of Colorado Boulder undergraduates in earning a climate literacy seal on their diplomas.

HEART Force (described in section 3.a.) exemplifies joint outreach: funded since 2018 by NOAA's Environmental Literacy Program, its partnerships with statewide water education and resilience stakeholders highlight the broad impact of CIESRDS/CEEE outreach across Colorado. As a NOAA Environmental Literacy Program grantee, CEEE leverages NOAA's scientific investments to strengthen connections among institutions, educators, and communities.

ii. What are the current or planned efforts with non-academic partners (i.e., nonprofits or private sector engagement)?

CIESRDS researchers engage in numerous collaborative efforts with industry, education, and outreach partners. Companies such as Lockheed Martin regularly visit the NOAA David Skaggs Research Center (DSRC) for tours and engagement opportunities. The SWPC testbed project fosters collaboration with private sector partners, including the FAA and USAF. Through CO-LABS (Colorado Labs), researchers help connect companies, entrepreneurs, scientists, and technologists with more than 30 federally funded research labs and institutes across Colorado to support innovation.

Community engagement includes monthly science talks at local venues, where CIESRDS postdoctoral researchers share their expertise. NOAA's Education and Outreach Director and the CEEE Director have also partnered on service projects with the NOAA Western Regional Team, including outreach packet preparation for the We Are Water program (see Public Outreach in section 3.b.).

iii. What are the current or planned efforts for community outreach, where appropriate? Underserved and frontline communities?

CIESRDS researchers lead and participate in numerous outreach and engagement initiatives targeting underserved and frontline communities:

- **Community college connections:** Programs such as RECCS and Science Pathways focus on building connections with local community colleges. During field missions, researchers engage students, educators, and community partners through site visits and virtual briefings, incorporating their questions and perspectives into project planning.
- **Environmental justice research:** Western Water Assessment has launched a new social science study on air quality and heat impacts in mobile home communities in southern Colorado.
- **Tribal collaboration:** CIESRDS experts with NOAA's National Integrated Drought Information System (NIDIS) collaborate with Tribes to integrate Tribal Ecological Knowledge, enhance drought early warning capacity, and expand reservation-specific resources through the U.S. Drought Portal.
- **Wildfire recovery:** Researchers provide public talks on air quality and wildfire recovery practices, including a recent event at a local brewery following a devastating mountain town fire.
- **Youth STEM education:** A new partnership with the Gordon Family Giving Foundation supports STEM education for underrepresented youth, including DSRC tours led by CIESRDS researchers.
- **Frontline community resilience:** CIESRDS/CEEE offers regular community outreach using HEART Force engagement materials (see section 3.a.), often focusing on frontline communities likely to be impacted by natural hazards. By elevating the importance of authentic partnership with at-risk communities within the curriculum and through collaboration with educators and community leaders, CEEE is strengthening best-practice principles across all project activities related to natural hazards resilience. The program supports community-responsive engagement while building pathways for sustained community-school collaboration around hazard education and resilience.

4. SCIENCE MANAGEMENT PLAN

a. How does the institute identify new intellectual opportunities?

CIESRDS identifies new intellectual opportunities through several complementary mechanisms that encourage creativity, cross-disciplinary collaboration, and engagement with the broader scientific community.

Innovative Research Program (IRP)

The internally funded IRP supports agile, exploratory research efforts that foster intellectual risk-taking across the institute. The program enables investigators to rapidly assess the viability of novel ideas, seed future proposals, and build new capabilities. IRP awards also provide workforce development benefits through hands-on training for students and early-career researchers. (See Section 4.f.i for program details.)

Workshops and Convenings

CIRES and CIESRDS regularly convene workshops focused on emerging scientific themes identified by the director or proposed by employees. These workshops emphasize facilitated discussion, idea exchange, and collective problem-solving rather than traditional presentation formats.

By creating space for open dialogue, these convenings strengthen internal networks, surface new research directions, and support future collaborations across CIESRDS, CIRES, NOAA, and the broader research community. The CIRES/CIESRDS Science Summit is one example; the spring 2025 summit brought together 83 participants representing a broad range of career stages and institutional affiliations for a structured day of engagement.
(See Section 2.b.v for additional context on cross-disciplinary collaboration.)

Conference Participation

CIESRDS strongly encourages employees to participate in national and international conferences and to serve on relevant committees and boards. These activities enable researchers to present their work, learn from others, contribute to broader scientific dialogue, and identify emerging thematic areas. The majority of CIESRDS employees attend at least one conference annually, with travel typically supported through Task II, Task III, or external proposal funds.

The goal of the Science Summit, an in-person science-focused meeting, is to strengthen internal networks, foster collaborations, and amplify existing research, outreach, and engagement efforts. Photo: Kathy Bogan/CIESRDS

Visiting Fellow Matt Mendoza, a geophysicist studying earthquakes, lays fiber cable in Utah at a geothermal project site. He uses distributed fiber optic sensing for his research, a new technique that allows spatially continuous measurements of ground motion over large distances.
Credit: Matt Mendoza

Proposal Development

CIESRDS maintains a structured pathway for scientists to respond to emerging NOAA solicitations and programmatic needs. While core Task II activities support NOAA Lab and Center missions through established work plans, scientists may also explore new ideas with NOAA partners when opportunities arise. Discussions with NOAA partners help determine whether a concept aligns with CIESRDS themes and the relevant NOAA Lab's mission—guiding whether it should advance as Task II work, be developed into a Task III proposal for submission through grants.gov, or be pursued as a standalone University of Colorado Boulder proposal outside the cooperative agreement. This process surfaces novel research directions, strengthens engagement with NOAA program offices, and enables CIESRDS to expand its intellectual landscape in response to evolving scientific priorities. Section 4.f describes additional support offered to researchers to develop proposals via a Proposal Writing Clinic.

Visiting Fellows Program

The CIRES/CIESRDS Visiting Fellows Program brings external scientists to Boulder to collaborate with CIRES researchers on campus and CIESRDS researchers in NOAA laboratories, stimulating interdisciplinary research and introducing fresh perspectives across the institute. Two-year fellowships are available for postdoctoral researchers, with terms of up to 12 months for senior scientists on leave or sabbatical. Each Visiting Fellow is sponsored by a current CIRES/CIESRDS Fellow or Senior Research Scientist, ensuring strong mentorship and integration into ongoing research. Over the past 50 years, the program has attracted more than 350 scientists from around the world — many of whom have gone on to lasting careers in CIRES and NOAA. The program encourages applications from members of groups underrepresented in the environmental sciences and is funded primarily through the Cooperative Agreement.

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

The University of Colorado Boulder's Office of Contracts and Grants (OCG) approaches sponsored project agreements as collaborative partnerships that align with both the university's academic mission and the sponsor's goals, including commercialization.

U.S. patent and copyright laws govern intellectual property (IP) created during these projects. Generally, University of Colorado Boulder retains ownership of IP developed solely by its employees, while sponsors retain ownership of IP exclusively developed by them. If both parties contribute, the IP is jointly owned. CU Boulder often provides sponsors with the opportunity to obtain an exclusive license to project-related IP, and agreements may also include nonexclusive licenses to both background and foreground IP, depending on the project's scope and existing intellectual assets. While there are standard terms, CU Boulder emphasizes flexibility and is committed to customizing IP arrangements to meet the specific needs of each project and sponsor.

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

Patenting costs present a major barrier to commercialization. Filing in the U.S. typically ranges from $15,000 to $50,000 depending on complexity, and international filings increase costs exponentially. University of Colorado Boulder operates under a limited budget, which means not every disclosed invention can be patented or maintained for its full term.

For CIESRDS, many disclosures involve software, which is generally unpatentable. While software can be protected

by copyright, enforcement is difficult, making it less commercially valuable than patents. As a result, software-based companies often appear less attractive to investors compared to those built around patented technology.

Another challenge is that most CU Boulder and CIESRDS patents originate from research rather than finished products. Commercialization requires transforming research into a product, which involves years of development, additional intellectual property, and significant investment. It can take five to seven years—and sometimes up to ten—for a startup to create a marketable product. Larger companies typically avoid this risk, preferring startups that first develop a minimum viable product and validate the market before acquisition.

Although software can be developed faster than other technologies, it also becomes obsolete quickly. Creating a startup to advance early-stage research requires a founder who is both willing and capable. While some faculty pursue this path, many prefer to remain focused on academic research. When a principal investigator is not interested, CU Boulder must identify entrepreneurs who understand deep tech and can craft a viable business plan. CU Boulder has had success matching entrepreneurs to unlicensed technologies, but this remains a complex matchmaking process.

Finally, market demand is critical. Some technologies face limited opportunities because existing solutions suffice, the market is too niche, or the innovation is so advanced that the market does not yet exist. Building a market for cutting-edge technology adds time and complexity to already lengthy development cycles.

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

The University of Colorado Boulder manages intellectual property (IP) records primarily through the Sophia portal, where researchers submit disclosure forms for discoveries*, including inventions and software. Disclosing discoveries created by university personnel during sponsored research is required by university policy and ensures compliance with grants and contracts that funded the work. Once submitted through Sophia, the Venture Partners office at CU Boulder—the university's technology transfer office—reviews the disclosure. Venture Partners assigns a case number and case manager, who then meets with the scientists to discuss the discovery, available resources, and potential commercialization strategies. The Sophia portal also allows researchers to track their inventions and IP status.

**Under current IP policies, "discovery" refers to any inventive idea and/or its reduction to practice, including but not limited to: new processes or methods producing useful industrial results; compositions of matter such as chemical or biological compounds; new devices; new plant varieties; new designs for manufacturing; computer hardware or software programs; supporting know-how; and any new use or improvement of existing systems, devices, compositions, programs, or processes.*

CIRES administration coordinates IP matters for CIESRDS scientists. The CIRES Export and Unfunded External Research Agreements Team assists with logistics by tracking IP concerns in the CIRES Export and Research Agreement Ticketing system, guiding researchers through the Sophia portal, liaising with University of Colorado Boulder central offices, and providing support throughout the entire process.

iv. How and when does the institute share environmental data collected/ created by PIs? NOAA policy is that data likely to be useful for numerous applications should be visible, accessible, and independently understandable to users, except where limited by law, regulation, policy, or by security requirements.

Although CIESRDS employees collaborate with federal partners in collecting and generating data, ownership typically resides with the federal partners, who are therefore responsible for ensuring the management and sharing of that data. Some examples of data sharing are outlined in section 4.b. below.

b. What are some recent examples of data sharing?

CIESRDS employees work closely with their federal counterparts in associated laboratories, where federal colleagues often take responsibility for making data publicly available in compliance with laboratory regulations. This collaboration ensures that critical scientific information is accessible to stakeholders and the public. Several projects highlight how CIESRDS researchers collect, create, and share data in partnership with federal agencies. CIESRDS researchers are fundamental to the development of these products.

Real-Time Solar Wind (RTSW) – SWFO-L1

Managed by the Space Weather Prediction Center (SWPC), RTSW data comes from spacecraft positioned at the L1 Lagrange point, providing near-instantaneous solar wind measurements essential for space weather forecasting. SWPC maintains the ability to switch between spacecraft, such as DSCOVR and NASA's ACE, to ensure continuous data flow. This resource averages 3,000 page views daily and can spike to over 112,000 during solar storms. The data is pub-

licly available at https://www.swpc.noaa.gov/products/real-time-solar-wind, serving space weather forecasters, satellite operators, and international agencies.

Paleoclimatology Data

Hosted by NOAA's National Centers for Environmental Information (NCEI), this archive is the world's largest collection of climate and paleoclimatology data, derived from natural sources such as tree rings, ice cores, corals, and sediment records. These proxy datasets extend climate records by hundreds to millions of years, enabling scientists to model environmental variability and predict future climate change. The data, which includes geophysical and biological time series as well as reconstructed climate variables, is available at https://www.ncei.noaa.gov/products/paleoclimatology. It is widely used by climate scientists, drought.gov users, and resource managers.

Greenhouse Gas Measurement Network

Operated by NOAA's Global Monitoring Laboratory (GML), this network measures atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and carbon monoxide (CO), which are key indicators of climate change and air quality. The data undergoes rigorous quality control before publication and informs global climate models and policy decisions. Public access to this dataset is provided at https://gml.noaa.gov/ccgg/arc/?id=132, supporting WMO collaborators, climate scientists, educators, and policymakers.

Science On a Sphere® (SOS)

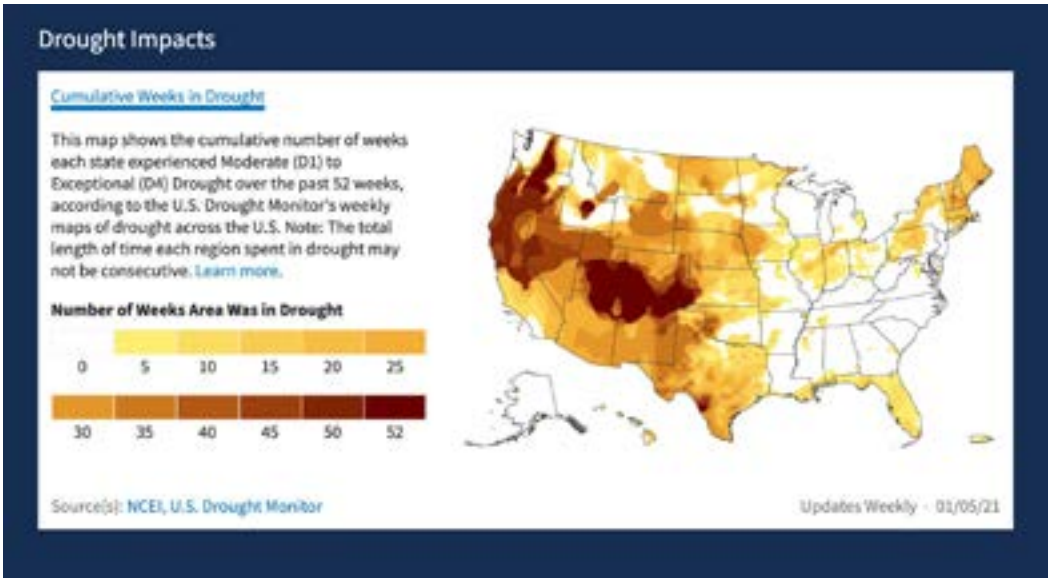
CIESRDS also contributes to public science education through this innovative visualization system that projects planetary data onto a six-foot sphere, creating an immersive educational experience. The SOS catalog includes diverse Earth system datasets and is complemented by SOS Explorer®, a flat-screen version available for PCs and mobile devices. This program is one of NOAA's premier outreach tools, making complex scientific data accessible and engaging for the general public, teachers, and students. The catalog can be explored at https://sos.noaa.gov/catalog.

U.S. Drought Portal – Drought.gov

This platform serves as the federal government's official source for drought-related information. Managed by NOAA's National Integrated Drought Information System (NIDIS), it provides interactive maps, real-time monitoring, historical trends, and sector-specific impact analyses. By aggregating data from multiple agencies, including NOAA, USDA, and USGS, Drought.gov supports proactive drought preparedness and resilience planning across all governance levels. This vital resource is available at https://www.drought.gov/ and is widely used by state and local governments, water managers, policymakers, and agricultural stakeholders.

World Magnetic Model (WMM)

CIESRDS researchers play a key role in developing the WMM, the global standard for navigation, attitude, and heading reference systems that rely on Earth's geomagnetic field. WMM supports critical applications in aviation and defense, as well as civilian navigation systems, and even powers a mobile app for easy access. Building on this foundation, the team is developing ChatGeo-Magi, an AI-driven conversational assistant designed to deliver interactive NOAA/CIRES geomagnetic data and resources, making magnetic field information more accessible to users. The WMM data can be accessed at https://www.ncei.noaa.gov/products/world-magnetic-model, serving navigation systems, defense, aviation, and citizen scientists.



Drought.gov brings together drought information and analysis from a wide variety of official sources, and provides new ways of understanding drought impacts.
Credit: drought.gov

c. How does the institute monitor and encourage compliance with public access policies and plans?

CIESRDS, CIRES, and the University of Colorado Boulder are engaged in fundamental research in science and engineering. Our research is intended to be, and is, widely and openly published and made available to the scientific and academic community. Unless specifically restricted by the sponsor or a controlled project, we are committed to the understanding that the work to be performed and the results generated are considered to be fundamental research, intended to be published and shared broadly within the scientific community. This is an expectation for all researchers that factors into performance evaluations.

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

In addition to complying with all applicable public access policies and plans, CIESRDS is committed to ensuring that the data, software, and documentation supporting published research are as open and accessible as possible, following the FAIR principles (Findable, Accessible, Interoperable, and Reusable; Wilkinson et al., 2016). Because many CIESRDS papers are published in American Meteorological Society journals, CIESRDS scientists adhere to AMS data and software policy guidelines for all submissions (https://www.ametsoc.org/index.cfm/ams/publications/ethical-guidelines-and-ams-policies/data-and-software-policy-guidelines-for-ams-publications); other publications have similar policies.. Even when there is no requirement, unless there is a compelling reason otherwise, all data used in a publication must be made publicly available before the paper's publication.

e. What are some recent examples of intellectual opportunities?

In this section, only a few of CIESRDS' most recent intellectual opportunities are summarized. There are many more.

SABRE (Stratospheric Aerosol Processes, Budget, and Radiative Effects)

SABRE is a NOAA airborne science mission focused on understanding stratospheric aerosols—tiny particles in the upper atmosphere that influence Earth's energy balance, ozone chemistry, and climate. Using the NASA WB-57 high-altitude aircraft, SABRE collects detailed measurements of aerosol size, composition, and radiative properties, along with related trace gases like ozone and water vapor. Its objectives include characterizing the baseline state of stratospheric aerosols, studying processes that control their formation and transport, and assessing responses to natural events (such as volcanic eruptions and wildfires) and human activities. Recent campaigns, like "Cold SABRE" in Alaska, have provided unprecedented data on polar stratospheric aerosols, improving our understanding of climate and atmospheric dynamics.

Verification of the Origins of Rotation in Tornadoes Experiment – Southeast (VORTEX-SE)

This project focuses on improving understanding of how environmental factors influence the formation, intensity, structure, and path of tornadoes in the southeastern United States. CIESRDS scientists contribute ground-based observations and model evaluation to improve forecasts of severe weather in the region. This research supports NOAA's goal of enhancing predictions of severe weather processes. The project is ongoing, with continued research and synthesis, and aligns with CIESRDS themes in Weather Research and Forecasting and Regional Science and Applications. Tangible outcomes include two journal articles, three conference presentations, and 17 datasets, contributing to better forecasting and risk assessment for extreme weather events.

NOAA's Space Weather Follow On – Lagrange 1 (SWFO-L1)

Launched on September 24, 2025, aboard a SpaceX Falcon 9, this satellite is the agency's first mission fully dedicated to continuous space weather monitoring from the L1 point—approximately one million miles from Earth—providing an uninterrupted view of the Sun. Equipped with a solar telescope and an instrument suite (Solar Wind Plasma Sensor, SupraThermal Ion Sensor, magnetometer, and Compact Coronagraph), SWFO-L1 captures real-time solar wind and charged particle data, as well as early detection of coronal mass ejections. These observations are critical for timely forecasting, watches, and warnings issued by NOAA's Space Weather Prediction

Sam Taylor, Ming Lyu, Tegan Brown, and Chuck Brock (left to right) inspect the new NMASS-NG after a successful test flight as part of the SABRE 2025 deployment. In this ongoing project, scientists and collaborators are characterizing the formation and properties of radiatively important aerosols in the atmosphere through airborne, ship-based, and ground-based field experiments. Credit: NOAA CSL

Center, helping protect navigation systems, satellite and radio communications, power grids, and astronaut safety. CIESRDS plays a critical role in the SWFO-L1 mission through leadership and technical expertise.

Geomag Team at NOAA NCEI

Supported by CIRES through CIESRDS, this team is dedicated to predicting Earth's magnetic field and advancing geomagnetic science for navigation, research, and public benefit. Their mission includes conducting research, developing data-based models, improving magnetic navigation, and curating global geomagnetic datasets. They maintain and enhance reference models such as the World Magnetic Model (WMM), which serves as the U.S. standard for navigation and is widely used globally. WMM2025 was recently released with software tools, error models, and online resources, achieving significant usage with thousands of downloads and millions of calculator hits.

The team also develops the High-Definition Geomagnetic Model (HDGM), specialized for directional drilling in oil, gas, and geothermal industries, combining core, crustal, and external fields in user-friendly software updated annually. In addition, they are advancing magnetic navigation as an alternative to GPS by creating accurate magnetic maps and exploring Very Low Earth Orbit satellite data for high-resolution modeling.

The team has embraced AI and machine learning through initiatives like the MagNet challenge, which improved space weather forecasting, and ChatGeo-Magi, an AI-powered assistant for interactive geomagnetic data access. They also lead a citizen science project funded by the Department of Energy to help locate undocumented orphaned oil and gas wells using magnetic data.

Since September 2022, the team has published 20 journal articles, released nine new models, delivered over 45 conference presentations, and secured more than $5 million in external funding. Looking ahead, their goals include improving forecasts using AI, enhancing crustal and external field models, and expanding machine learning applications to further support navigation and space weather prediction.

Weather Informatics and Decision Support (WIDS)

Supported by CIESRDS, this division develops tools to improve hazardous weather prediction and impact-based decision support for the National Weather Service (NWS).

Hazard Services is a comprehensive forecaster application that consolidates legacy systems (WarnGen, Graphical Hazards Generator, and RiverPro) into a single platform for generating watches, warnings, and advisories. Its latest version (Version 4) introduces major architecture and interface improvements, enabling flexible workflows for various hazards such as hydrology, convective storms, winter weather, fire weather, and aviation. Since 2024, Version 4 has been deployed in multiple Weather Forecast Offices for operational use, supporting NWS priorities for streamlined hazard communication.

The Impact-Based Decision Support Services (IDSS) Engine is a web-based tool designed to shift meteorology from forecasting weather to forecasting its impacts. It provides

tailored, impact-focused guidance to decision-makers—such as emergency managers and event planners—by visualizing when and where weather conditions may meet user-defined thresholds (e.g., heat, wind, freezing rain), along with their likelihood, duration, and intensity. This personalization makes forecasts more actionable and enhances real-time decision-making for weather-sensitive operations. For example, the IDSS Engine recently supported incident meteorologists at the 2025 U.S. Open, helping assess risks from thunderstorms and high winds.

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

CIESRDS supports new starts through coordinated mechanisms for idea generation, collaboration, proposal development, and administrative support.

The Innovative Research Program provides seed funding to assess concept viability before pursuing larger investments (see Section 4.f.i). Workshops and convenings such as the Science Summit and Visiting Fellows Program foster cross-disciplinary collaboration and surface new research directions (see Section 4.a). Regular institute-wide town halls and lab- and center-level town halls provide forums for researchers to highlight opportunities, discuss strategies, and share techniques. The Proposal Writing Clinic and associated resources help researchers develop competitive proposals for external funding. CIRES facilitates collaboration across its centers, labs, and programs through forums such as the Council of Fellows, CIRES Members Council, and CIRES Early Career Assembly.

Administrative infrastructure supports the exchange of information and the launch of new projects. Internal communication channels—including institute-wide emails and internal websites—keep researchers informed of funding opportunities, emerging initiatives, and available resources. Additional support includes coordination with the Office of Contracts and Grants, export control assistance, and liaison with NOAA program offices to help researchers navigate the requirements associated with new awards. (See Administrative Briefing Book for additional detail on administrative support functions.)

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

Innovative Research Program

CIRES offers the Innovative Research Program, designed to stimulate a creative research environment within CIRES and to encourage synergy between disciplines and research colleagues. The intent is to support small research efforts that can quickly provide concept viability or rule out further consideration. The program encourages novel, unconventional, or fundamental research that might otherwise be difficult to fund. Funded projects are inventive, sometimes opportunistic, and do not necessarily have an immediate practical application or guarantee of success.

This program supports pilot or exploratory studies, which may provide rapid results. Activities are not tightly restricted and can range from instrument development, lab testing, and field observations to model development, evaluation, and application. CIESRDS researchers can submit proposals with a $30,000 budget request. Depending on available funds, there are typically nine awarded proposals each year. All research and spending must be completed within the 18-month project period. Awardees present at an annual poster session, allowing researchers to share new results with the community.

Science Summit

Aligned with our strategic plan, CIRES is working to connect CIESRDS researchers and CU Boulder-based social scientists through an annual CIRES-wide interactive workshop. This workshop, titled "The Science Summit," intends to strengthen our internal networks, foster collaborations, and amplify existing research, outreach, and engagement efforts. Additionally, this collaborative event supports the CIRES community by identifying colleagues working in shared and new research areas while encouraging innovative thinking beyond traditional approaches.

Proposal Writing Clinic

CIESRDS offers a Proposal Writing Clinic to support researchers in developing competitive proposals. Participants can submit a form to request feedback on identifying funding opportunities or crafting proposals for specific calls. Each participant is paired with an experienced proposal writer for two meetings, and a review rubric is provided to guide improvements. In addition to the clinic, CIESRDS maintains a resources page featuring workshops led by CIRES and University of Colorado Boulder experts on topics such as securing external funding, tailoring proposals to specific audiences, and pitching new research ideas.

CU Boulder supports robust administrative infrastructure to allow CIESRDS researchers to focus on science.

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

Funding for these activities comes from multiple sources. The Innovative Research Program, along with initiatives stemming from the strategic plan—such as the Science Summit—is supported by returns from indirect costs at CU Boulder. Other activities, including the Proposal Writing Clinic, are funded and managed by staff whose salaries are covered under Task I of the cooperative agreement.

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

Recruitment

All positions are publicly advertised and competitively filled through Jobs at University of Colorado Boulder (https://jobs.colorado.edu/). Most postings remain open for approximately three weeks to ensure broad visibility and attract a diverse pool of candidates. CU Boulder also promotes openings beyond its own site, posting to platforms such as HigherEdJobs, LinkedIn, Chronicle of Higher Education, Indeed, relevant discipline-specific job boards, and a jobs clearinghouse to maximize reach. Additionally, job announcements are crafted to be as inclusive as possible—within the requirements of the position—to encourage a wide range of applicants.

Rewards

CIESRDS offers several types of awards to recognize exceptional contributions:

Bronze, Silver, Gold, and Technology Transfer Awards

CIESRDS employees often collaborate with NOAA teams whose federal members receive NOAA or Department of Commerce Bronze, Silver, or Gold Medals, or a NOAA Technology Transfer Award. CIRES strives to provide comparable recognition to its members of these teams.

Cash-in-a-Flash Award

This program provides cash awards to employees who demonstrate exceptional achievement beyond normal job expectations, based on successful nominations.

Outstanding Performance Awards

Managed by the CIRES Members' Council (CMC), these annual awards honor individuals or teams for outstanding contributions during the previous year. Science and Engineering Awards recognize excellence in research or engineering, while Service Awards highlight exceptional work in administration, IT, project management, outreach, or other non-research roles. More details are available on the CIRES website at https://cires.colorado.edu/award-programs/outstanding-performance-awards.

NOAA Research Outstanding Scientific Paper Awards

When CIESRDS collaborators co-author papers recognized by NOAA Research, CIRES provides reciprocal awards to all CIESRDS contributors.

CIESRDS researchers celebrate a NOAA Bronze medal "for significantly increasing awareness of NOAA's mission through outreach, education, and service" at the 2025 CIRES Rendezvous at the University of Colorado Boulder.
Photo: Lauren Lipuma/CIESRDS

Training and Professional Development

CIRES supports ongoing professional development through a dedicated fund that employees can access with supervisor approval. These funds can be used for training opportunities that enhance job performance and career growth. CU Boulder complements this by offering a wide range of training for all employees, covering general professional development, leadership, and organizational skills. In addition, the university provides access to numerous free or deeply discounted online learning resources through platforms such as LinkedIn Learning, Coursera, and Percipio.

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

CI employees receive HR training during their initial university onboarding and throughout their employment via University of Colorado Boulder HR and CIRES HR programs. For example, new employees learn about benefits and retirement during QuickStart orientation sessions conducted by CU Boulder HR. CIESRDS embedded staff also attend a CIRES-at-NOAA onboarding session covering leave reporting, performance reviews, and site-specific information relevant to NOAA.

Employees participate in annual benefits open enrollment periods, with updates provided online and through benefits fairs where they can meet representatives from companies administering university benefits. Retirement options are introduced during onboarding and remain accessible online. Additionally, retirement plan administrators visit NOAA sites monthly to provide one-on-one counseling and periodic training on investment strategies and best practices.

Throughout the year, University of Colorado Boulder HR and CIRES HR offer updated training on topics such as the Annual Summary of Accomplishments (a document used for annual performance evaluation for CIRES research faculty and university staff), CIRES performance review processes, professional development, supervisor best practices, and career advancement. They also provide specialized training based on staff needs—for example, during the COVID-19 lockdown period, CU Boulder offered sessions on building remote work skills and effective team collaboration.

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

Yes, CI employees participate in general NOAA HR training when appropriate. Examples include Sexual Assault and Sexual Harassment Training, General Security Awareness Course, Department of Commerce Cybersecurity Awareness Training, Annual Records Management Training, and Foreign Travel Training.

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

While CIRES and CU Boulder provide extensive professional development opportunities through university HR and CIRES administrative teams, programs specifically designed for early-career researchers are also available.

Graduate Students

CIRES hires and supports Graduate Research Assistant (GRA) appointments, giving graduate students hands-on research experience alongside faculty mentors. Some of these students work at NOAA alongside CIESRDS colleagues. These roles help students build strong technical skills and knowledge essential for future careers and are a key component of their education. The CU Graduate School further supports junior researchers through frequent training sessions and workshops.

Postdoctoral Researchers

The university's Office of Postdoctoral Affairs (OPA) offers targeted training for CIESRDS postdoctoral employees, including sessions on public speaking, proposal writing, interviewing, communication skills, and resume and cover letter preparation. OPA also provides a peer mentoring program to foster professional growth.

Mentoring

The CIRES Mentoring Program pairs volunteer mentors—both CI and federal employees—with mentees at all career stages from research and administrative backgrounds. Modeled after AGU's Mentoring365 program, it promotes career development and offers insight into the CIRES-NOAA ecosystem.

Professional Development Resources

CIRES maintains a professional development fund that employees can access, with supervisor approval, to support training aligned with their roles and career goals. CU Boulder complements these efforts with a wide range of professional development courses covering communication, emotional intelligence, leadership, project management, and more. Employees also have access to free or low-cost online learning platforms such as LinkedIn Learning, Coursera, and Percipio.

Conference Participation

CIRES encourages participation in regional, national, and international conferences, providing opportunities for employees to engage with cutting-edge research in their fields. Major conferences, such as those hosted by the American Geophysical Union and the American Meteorological Society, also offer career development workshops that many CIESRDS employees attend.

h. What is the state of the financial health of the institute? (Provide a budget summary and identify imbalances or needed adjustments.)

As of the end of October 2025, CIESRDS has received $216 million in award funding through the NOAA cooperative agreement. Of this:

- **95.6 percent ($206 million)** supports Task II research activities involving ongoing collaboration with NOAA scientists.
- **2.2 percent ($5 million)** supports Task III research activities by CIRES personnel outside Task I and II, with little or no NOAA collaboration.
- **2.2 percent ($5 million)** supports Task I activities, including salaries and operating expenses for CI management, Education and Outreach, Postdoctoral and Sabbatical Visiting Fellows, and Graduate Research Award programs.

The award ceiling is $565.8 million, and our average monthly expenditures are $4 million.

In addition, CIESRDS has received $42 million in supplemental appropriations from Congress under the Disaster Relief Supplemental Appropriations Act (DRSA), the Bipartisan Infrastructure Law (BIL, formerly the Infrastructure Investment and Jobs Act), and the Inflation Reduction Act (IRA).

CIRES applies a reduced indirect cost rate for Task I and Task II, as outlined in an internal MOU with the university. For Task II, the indirect rate is 22%, compared to the university's standard rate of 56.5% for on-campus work and 26% for off-campus research. Furthermore, for Task II, the campus returns more than double the standard indirect cost recovery (ICR) to CIRES to support the administrative infrastructure necessary for the successful execution of the cooperative agreement.

Overall, CIRES maintains a strong financial position supported by a diversified funding portfolio. The Cooperative Agreement accounts for approximately 50% of annual award funding, with an average yearly award funding total of $119 million. Other major sponsors include NSF, NASA, and USGS.

i. How does the institute intend to work towards accomplishing its financial goals?

CIESRDS maintains a strong financial position. To further strengthen resilience and reduce reliance on a single funding stream, we will continue to actively pursue a more diversified funding portfolio—including other federal agencies (NSF, NASA, USGS), industry partnerships, and philanthropic sources. At the same time, we will ensure that all proposal budgets fully account for the true cost of completing the scope of work, including personnel, fringe benefits, indirect costs, compliance requirements, and administrative support.

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

Federal and CI Employee Interactions

From the HR perspective, it will be important for NOAA and CIRES to continue working toward shared employee relations protocols. These protocols are necessary in guiding challenging interactions that can arise between federal and CI employees. Currently, each organization follows its own protocols, and those do not always align. A shared understanding of how to manage related challenges would benefit both organizations and their respective employees. CIESRDS, along with its federal partners from the Global Monitoring Lab, co-created an interaction guide to help in this effort; however, protocols to support these interactions were previously identified as a goal of the Cooperative Institutes Administrative Office (CIAO), and CIESRDS looks forward to its completion.

Funding and Priority Transparency

In working with NOAA partners on the annual science plan, CIESRDS faced challenges obtaining clear and timely information about NOAA's scientific priorities and available funding. These challenges are compounded by delays in finalizing the federal budget, which often prevents NOAA from confirming available resources early in the planning cycle. Additionally, new Department of Commerce approval requirements for contracts and grants have slowed the release of funds once budgets are finalized. This uncertainty makes it difficult to scope projects, allocate staff, and ensure the timely execution of mission-critical tasks.

eRA Commons System Limitations

Since the implementation of eRA Commons, both research and administrative staff have faced increased challenges and administrative burden. For example, RPPR reports for the cooperative agreement and all supplemental awards are due annually, but system limitations require semi-annual submissions. This means the PI and support staff must submit a blank report for the first six months, followed by a comprehensive annual report in the next period. Additionally, RPPR

requires financial expenditures to be entered, duplicating effort since the SF-425 financial report is also required. Another limitation is the submission of a first no-cost extension: while first no-cost extensions are grantee-approved, system constraints require NOAA Grants Management approval in eRA to officially extend the award end date.

Ambiguity in Award Language

Inconsistent language and interpretation in Notices of Award regarding budget periods and allowable spending timelines create confusion and increase the risk of non-compliance. This ambiguity often requires additional clarification and administrative effort, further slowing down processes.

These issues collectively create inefficiencies, divert time from research activities, and increase administrative workload, which can delay project progress.

NOFO Clarity

One area that creates challenges for the CIESRDS administrative team is when NOAA Notices of Funding Opportunities (NOFOs) lack precision and clarity in their requirements. Ambiguity in proposal instructions—such as unclear or inconsistent formatting expectations, or vague guidance on requirements—can lead to several issues:

- *Increased Administrative Burden:* The team spends considerable time seeking clarification, which delays proposal preparation and reduces efficiency.
- *Risk of Non-Compliance:* Unclear requirements increase the likelihood of missing critical elements, which can jeopardize the competitiveness of proposals.
- *Compressed Timelines:* When clarifications arrive late in the process, it forces last-minute adjustments, creating stress for both administrative and scientific teams.
- *Resource Inefficiency:* Time and effort that could be devoted to strengthening the scientific content are instead spent interpreting ambiguous instructions.

CIRES recommends that future NOFOs include explicit, detailed guidance on proposal structure, required components, and necessary formatting. This clarity will enable the institute to submit higher-quality proposals that fully align with NOAA's expectations and better serve both NOAA and university interests.

Impact of Government Shutdowns

When unexpected disruptions occur, such as a government shutdown, it can be challenging to coordinate with partners who provide critical support for proposal submissions, such as resource commitments or letters of collaboration. These disruptions impact both new and experienced researchers—newer staff may struggle to navigate procedures and identify the right contacts, while seasoned staff may face delays in securing necessary documentation. Such challenges can slow an otherwise smooth proposal process. Establishing a designated point of contact in advance for these situations would help ensure continuity and minimize delays.

University of Colorado Boulder main campus

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

CIRES has identified several areas where enhanced coordination with the University of Colorado Boulder could reduce administrative burden on research scientists and administrative staff and improve research efficiency.

Procurement Processes

Recent changes to university procurement policies — particularly for information technology goods and services — have added steps that can slow time-sensitive research

purchases. Streamlining mandatory pre-checks, Information and Communication Technology (ICT) reviews, and security compliance processes while maintaining necessary safeguards would help ensure research progress keeps pace with project timelines.

Export Control Reviews

The CU Central Export Controls Office manages reviews that are often prerequisites for initiating research activities, hiring personnel, or procuring equipment. Delays in these reviews can impact activities under the Cooperative Agreement. Faster turnaround times would help CIESRDS:

- *Expedite Timelines:* Export control reviews are often prerequisites for initiating research activities, hiring personnel, or procuring equipment. When reviews take weeks or months, it stalls project progress and jeopardizes our ability to meet NOAA deliverables on schedule.
- *Mitigate Funding and Compliance Risks:* Delays can lead to situations where funds are obligated but cannot be spent efficiently, increasing the risk of lapses in compliance and underutilization of resources.
- *Reduce Collaboration Barriers:* NOAA projects frequently involve international partners and data sharing. Extended review times hinder timely collaboration and can strain relationships with our scientists and external collaborators.
- *Enhance Operational Clarity:* Without predictable turnaround times, it is difficult to plan project milestones, allocate staff, and manage expectations with NOAA program managers.

CIRES recommends evaluating process improvements or adding staffing resources within the CU Export Controls Office to shorten review times and enhance workflow transparency. Current bottlenecks not only slow research progress but also place significant strain on administrative teams.

University Centralization of CI HR Roles

The university has announced potential plans to centralize campus-wide HR functions in 2026–27. Under this restructuring, the CI's current in-house HR team would no longer report to the CI Director but instead become embedded employees within the institute. Their titles, job descriptions, duties, and salaries would be determined by the university rather than the CI. Additionally, the university may reassign current CI HR staff to other campus units as part of this transition.

Many transactional HR functions currently handled in-house would shift to a centralized processing team known as the HR Service Center. It is possible this change could lead to interruptions or delays in business operations during the transition. Furthermore, the scope of these changes may negatively impact the existing HR team, which was specifically hired by CIRES to support the institute's needs and has developed specialized knowledge and structures to serve CIESRDS initiatives and employees, and effectively navigate the unique complexities of the cooperative agreement. While CIRES goal is to retain the current HR team's internal reporting structure and continue managing transactional functions in-house for sake of control and efficiency, CIRES will work with the university to minimize impacts to CIRES and CSIERDS HR operations if this centralization moves forward.

Additionally, layoff protocols now require heightened scrutiny and detailed justification for terminations due to lack of funding,which requires significant coordination across the CI's in-house HR team.

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

Section 1.c.i. listed the criteria that the CIs agreed upon in 2018 to measure progress in accomplishing CI goals. In this section, those metrics that apply to CIESRDS are quantified to the best extent possible.

Science Dissemination

Number of papers in peer-reviewed journals per year

This information is included in the CI annual reports. Since the beginning of the current agreement period in September 2022, CIESRDS has produced an impressive 1,551 peer-reviewed publications, including journal articles and technical reports. This output reflects the broad and collaborative design of CIESRDS, which spans three NOAA line offices and eight labs and centers. These entities not only conduct cutting-edge research but also focus on transitioning research into operational applications and supporting strictly operational activities. This structure enables CIESRDS to contribute across the full spectrum—from fundamental science to practical implementation—ensuring that innovations have broad impact.

Number of conference presentations generated per year

This information is included in the CI annual reports. Although ideally these documents would have a DOI for easy traceability, this is often not the case, as many presentations at annual meetings of the American Meteorological Society, the American Geophysical Union, topical meetings, and workshops are not assigned DOIs. CIESRDS has delivered 1,780 conference presentations across domestic and international venues, averaging roughly 500 presentations

per year. These presentations play a critical role in showcasing the scientific leadership of NOAA and the cooperative institute, reinforcing their impact and visibility within the research community.

Number of testbeds conducted

CIESRDS leverages testbeds as a critical mechanism for evaluating and refining new models, techniques, and tools, while ensuring research aligns with established practices and operational applications across NOAA offices. These testbeds also help expand the reach of CIESRDS research to broader audiences, bridging the gap between innovation and implementation. In total, 51 testbeds have been conducted, demonstrating a strong commitment to advancing science and accelerating the transition from research to operations.

Research Impact

Number of products transitioned into operations

Many areas of CIESRDS span the full spectrum of activity—from foundational research to research-to-operations and fully operational applications. However, translating these efforts into clearly defined products can be challenging due to ambiguity in how products are categorized. To address this, we have included both products currently in operation and those awaiting transition into operational settings, totaling 103. This approach reflects the institute's commitment to advancing science while ensuring practical impact across NOAA's mission areas.

Leveraged Resources

Funding Leveraging

To date, CIESRDS has received $216 million in award funding supporting Task I, Task II, and Task III activities. Additionally, CIESRDS has secured $42 million in supplemental appropriations from Congress through the Disaster Relief Supplemental Appropriations Act (DRSA), the Bipartisan Infrastructure Law (BIL, formerly the Infrastructure Investment and Jobs Act), and the Inflation Reduction Act (IRA).

CIESRDS researchers have also obtained significant funding from NOAA through competitive proposals, including the Weather Program Office (WPO) and Climate Program Office (CPO) programs, totaling $14 million. Beyond NOAA, our researchers consistently secure funding from other major sponsors such as NASA, the National Science Foundation, and USGS, representing approximately 50% of total award funding at CIESRDS/CIRES.

Career Development and Training

Number of CI-supported students/postdocs/research scientists/research associates who have obtained employment in positions related to the fulfillment of NOAA's objectives. A clear description of how it is determined that an individual is employed in a position related to NOAA's objectives needs to accompany this number.

Between September 2022 and December 2025, 38 CI employees transitioned into NOAA federal positions. CIESRDS tracks these moves through outgoing employee input, where departing staff confirm if they are joining NOAA. This information is further validated through collaboration with federal partners and documented in annual technical reports submitted to NOAA.

CU Boulder offers robust career development opportunities for staff through Human Resources Organization and Employee Development (OED), which provides training and workshops on leadership, professional skills, and more. The Staff Career Development Program (SCDP) supports career advising and planning, helping employees explore paths and set goals. Additional resources like LinkedIn Learning and Skillsoft enable continuous skills growth. Staff can leverage tools such as career advising sessions, training catalogs, and development plans to build competencies and advance within the university.

Appendices

Appendix A: Acronyms

AAG	American Association of Geographers
ACE	Advanced Composition Explorer (NASA spacecraft)
AGU	American Geophysical Union
AI	Artificial Intelligence
AISES	Advancing Indigenous Science and Engineering Society
AMS	American Meteorological Society
APECS	Association of Polar Early Career Scientists
BIL	Bipartisan Infrastructure Law (formerly Infrastructure Investment and Jobs Act)
CAP	Climate Adaptation Partnerships
CECA	CIRES Early Career Assembly
CEEE	Center for Education, Engagement, and Evaluation
CI	Cooperative Institute
CIAO	Cooperative Institutes Administratione Office
CIESRDS	Cooperative Institute for Earth System Research and Data Science
CIRA	Cooperative Institute for Research in the Atmosphere
CIRES	Cooperative Institute for Research in Environmental Sciences
CLEAN	Climate Literacy and Energy Awareness Network
CMC	CIRES Members Council
CO	carbon monoxide
CO_2	carbon dioxide
CPO	Climate Program Office (NOAA)
CSB	Crowdsourced Bathymetry
CSC	Cooperative Science Centers
CSL	Chemical Sciences Laboratory
CU	University of Colorado
CH_4	methane
DOC	Department of Commerce
DOE	Department of Energy
DOI	Department of the Interior
DSCOVR	Deep Space Climate Observatory
DRSA	Disaster Relief Supplemental Appropriations Act
DSRC	David Skaggs Research Center

ELP	Environmental Literacy Program
EPP	Educational Partnership Program
eRA	Electronic Research Administration
FAIR	Findable, Accessible, Interoperable, and Reusable
FAA	Federal Aviation Administration
FPO	Federal Program Officer
GML	Global Monitoring Laboratory
GPRA	Government Performance and Results Act
GPS	Global Positioning System
GRA	Graduate Research Assistant
GSL	Global Systems Laboratory
HDGM	High Definition Geomagnetic Model
HEART Force	Hazard Education, Awareness, and Resilience Task Force
HR	Human Resources
ICR	Indirect Cost Recovery
ICT	Information and Communications Technology
IDSS	Impact-Based Decision Support Services
IHO	International Hydrographic Organization
IP	Intellectual Property
IRA	Inflation Reduction Act
IT	Information Technology
LASP	Laboratory for Atmospheric and Space Physics
MENV	Masters of the Environment Graduate Program
MOOC	Massive Open Online Course
MOSAiC	Multidisciplinary drifting Observatory for the Study of Arctic Climate
MOU	Memorandum of Understanding
N_2O	Nitrous oxide
NASA	National Aeronautics and Space Administration
NCCASC	North Central Climate Adaptation Science Center
NCEI	National Centers for Environmental Information
NESDIS	National Environmental Satellite, Data, and Information Service
NIDIS	National Integrated Drought Information System
NMFS	National Marine Fisheries Service

NOAA	National Oceanic and Atmospheric Administration
NOFO	Notice of Funding Opportunity
NOS	National Ocean Service
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSTA	National Science Teaching Association
NWS	National Weather Service
OAR	Oceanic and Atmospheric Research
OCG	Office of Contracts and Grants
OED	Organization and Employee Development
OMAO	Office of Marine and Aviation Operations
OPA	Office of Postdoctoral Affairs
PI	Principal Investigator
PREP-GC	Professional Research Experience Program – GSL/CIRES
PSECCO	Polar Science Early Career Community Office
PSL	Physical Sciences Laboratory
RECCS	Research Experience for Community College Students
REU	Research Experiences for Undergraduates
RISA	Regional Integrated Sciences and Assessments
RPPR	Research Performance Progress Report
RTSW	Real-time solar wind
SABRE	Stratospheric Aerosol Processes, Budget, and Radiative Effects
SACNAS	Society for Advancement of Chicanos/ Hispanics and Native Americans in Science
SCDP	Staff Career Development Program
SERC	Science Education Resource Center
SF-425	Federal Financial Report (Standard Form 425)
SOS	Science On a Sphere
SOSx	Science On a Sphere Explorer
STEM	Science, technology, engineering, and mathematics
SWFO-L1	Space Weather Follow On – Lagrange 1
SWPC	Space Weather Prediction Center
TPM	Technical Program Manager
UOW	Undocumented Orphan Well
USAF	United States Air Force
USDA	United States Department of Agriculture
USGCRP	U.S. Global Change Research Program
USGS	United States Geological Survey
VORTEX-SE	Verification of the Origins of Rotation in Tornadoes Experiment – Southeast
WIDS	Weather Informatics and Decision Support
WMM	World Magnetic Model
WMO	World Meteorological Organization
WPC	Weather Prediction Center
WPO	Weather Program Office (NOAA)
WSSI	Winter Storm Severity Index
WWA	Western Water Assessment

Appendix B: CIRES/CIESRDS Council of Fellows

The CIRES/CIESRDS Council of Fellows includes university faculty, researchers, and NOAA scientists who personify the institute's cooperative spirit and guide the development of cross-cutting research programs. Fellows are experts in cryospheric and polar processes, ecosystem science, environmental chemistry, environmental observations, modeling, and forecasting, solid Earth sciences, weather and climate dynamics, and policy. Through their research, they seek to better understand our changing planet, providing policymakers and the general public with science to benefit society.

Current Fellows

Dr. Waleed Abdalati, Director, Cooperative Institute for Research in Environmental Sciences (CIRES/CIESRDS)

Dr. Hazel Bain, Research Scientist, Space Weather Predication Center (SWPC), CIESRDS

Dr. Balaji Rajagopalan, Professor of Civil, Environmental and Architectural Engineering (CEAE)

Dr. Jennifer Balch, Professor of Geography and Director of Environmental Data Science Innovation & Impact Lab (ESII)

Dr. Roger Bilham, Emeritus Professor, Geological Sciences

Dr. Maxwell Boykoff, Professor of Environmental Studies and Faculty Executive Director of the SPIKE Center for Sustainability Education

Dr. Maria Capotondi, Senior Research Associate, Physical Sciences Laboratory (PSL), CIESRDS

Dr. John Cassano, Professor of Atmospheric and Oceanic Sciences (ATOC)

Dr. Xinzhao Chu, Professor of Aerospace Engineering

Dr. Arnaud Chulliat, Senior Research Associate, National Centers for Environmental Information (NCEI), CIESRDS

Dr. Ellen Considine, Assistant Professor of Geography

Dr. Shelley Copley, Professor of Molecular, Cellular & Developmental Biology (MCDB)

Dr. Joost de Gouw, Professor and Chair of Chemistry

Dr. G Farmer, Professor of Geological Sciences

Dr. Graham Feingold, Research Scientist, Chemical Sciences Laboratory (CSL), CIESRDS

Dr. Noah Fierer, Professor of Ecology and Evolutionary Biology

Dr. Khosro Ghobadi-Far, Assistant Professor, CIRES

Dr. Anne Gold, Research Associate, CIRES

Dr. Robert Hardesty, Research Associate, Director of Environmental Observations, Modeling and Forecasting Division (EOMF), CIRES

Dr. Eve-Lyn Hinckley, Associate Professor, Ecology and Evolutionary Biology

Dr. Jose Jimenez-Palacios, Distinguished Professor of Chemistry

Dr. Craig Jones, Professor of Geological Sciences

Dr. Kristopher Karnauskas, Associate Professor of Atmospheric and Oceanic Sciences (ATOC)

Dr. Jennifer Kay, Associate Professor of Atmospheric and Oceanic Sciences (ATOC)

Dr. Ben Livneh, Associate Professor of Civil, Environmental and Architectural Engineering (CEAE)

Dr. Kathryn Materna, Assistant Professor of Geological Sciences

Dr. Stephen Montzka, Senior Scientist, Global Monitoring Laboratory (GML), NOAA

Dr. Mark Serreze, Distinguished Professor of Geography

Dr. Anne Sheehan, Professor and Chair of Geological Sciences

Dr. Matthew Shupe, Research Associate, CIRES

Dr. Katherine Siegel, Assistant Professor affiliated with CIRES, Geography, and Environmental Data Science Innovation & Impact Lab

Dr. Kristy Tiampo, Professor of Geological Sciences

Dr. Margaret Tolbert, Distinguished Professor of Chemistry and Associate Director of CIRES

Dr. Gregory Tucker, Professor of Geological Sciences

Dr. Dave Turner, Senior Scientist, Global Systems Laboratory (GSL), NOAA

Dr. Paul Ziemann, Professor of Chemistry

Emeritus Fellows

Dr. Susan Avery, Past Director, CIRES

Dr. Stanley Benjamin, Past Senior Research Scientist, Global Systems Laboratory (GSL), CIRES

Dr. Fred Fehsenfeld, Past Senior Research Scientist, Chemical Sciences Laboratory (CSL), CIRES

Dr. William Lewis, Emeritus Professor of Ecology and Evolutionary Biology

Dr. William Neff, Past Senior Research Scientist, Physical Sciences Laboratory (PSL), CIRES

Dr. Douglas Robertson, Past Senior Research Scientist, Laboratory for Geosciences, CIRES

Dr. Robert Sievers, Past Director, CIRES

Dr. Hartmut Spetzler, Emeritus Professor of Geological Sciences

Dr. Veronica Vaida, Professor Emeritus of Chemistry

Dr. Carol Wessman, Emeritus Professor of Ecology and Evolutionary Biology

Appendix C: Executive Board

The CIESRDS Executive Board provides high-level management, oversight, and strategic direction to ensure the continued advancement and welfare of the Cooperative Institute. Composed of leadership from CIESRDS, CIRES, and NOAA line offices, the board works collaboratively to align the Institute's activities with NOAA's mission, the cooperative agreement, and relevant CU Boulder policies. Through regular meetings and coordinated engagement with the Council of Fellows and Senior Management Team, the board guides long-term planning, policy development, and program execution to support the scientific, administrative, and operational success of CIESRDS. The current composition of the board is listed below:

CIESRDS Director (CI): Dr. Waleed Abdalati

CIESRDS Technical Program Manager (F): Dr. Roger Pulwarty

CIESRDS Federal Program Officer, ex officio (F): Holly Ohlhorst

CIESRDS Administrative and Scientific Program Manager (CI): Kari Bowen

CIESRDS Associate Director for Science (CI): Vacant, interviewing

CIESRDS Director of Finance (CI): Annie Fudale

CIESRDS Director of Human Resources (CI): Angela Knight

CIESRDS ACI Director (CI): Dr. Becca Edwards

Director of GML, ex officio (F): Dr. Vanda Grubisic

Director of GSL, ex officio (F): Acting is Dr. Melissa Petty

Director of CSL, ex officio (F): Dr. David Fahey

Director of PSL, ex officio (F): Acting is Dr. Roger Pulwarty

Director of SWPC, ex officio (F): Clinton Wallace

Director of NCEI, ex officio (F): Dr. Derek Arndt

Director of WPC, ex officio (F): Dr. David Novak

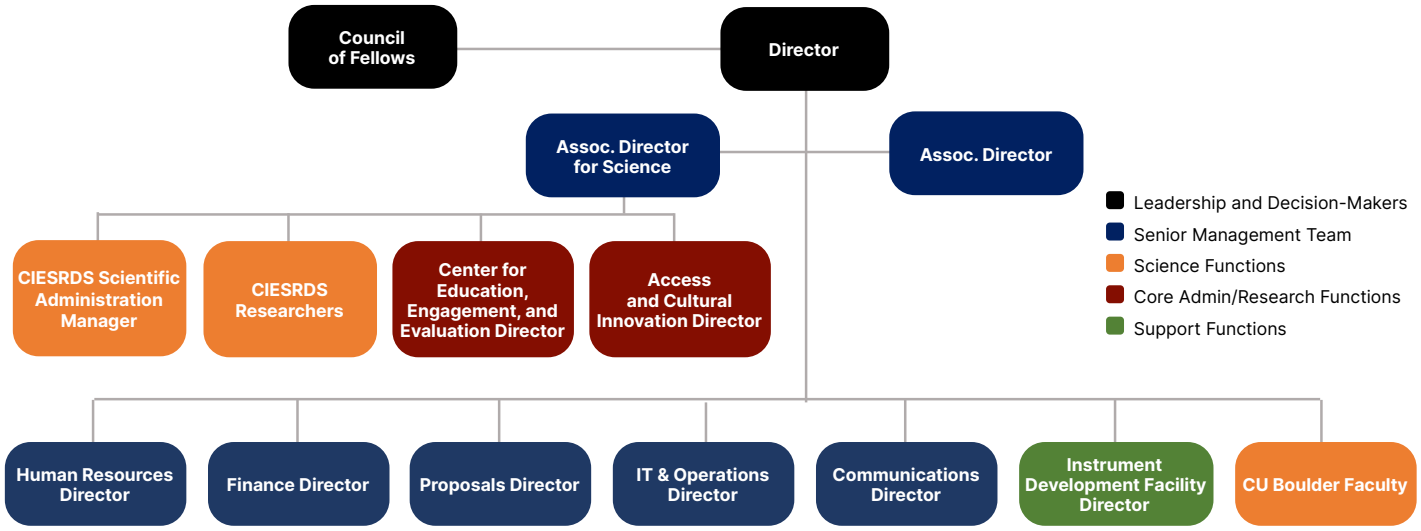
Director of Office of Education, ex officio (F): Louisa Koch

Appendix D: Organizational structure, personnel and graduate students

The CIRES/CIESRDS organizational structure is summarized in the organizational chart below. More than 900 students, staff, faculty, researchers, and others work at CIRES. We are roughly split between NOAA, where our people work embedded in several laboratories and centers at the David Skaggs Research Center in Boulder, Colorado, and CU Boulder campus, where we partner with 10 departments. A complete list of personnel is available at https://cires.colorado.edu/people.

CIRES* Administration Organization Chart

February 2026



*CIRES Administration supports the cooperative-agreement or CA-funded component of CIRES titled CIESRDS, the Cooperative Institute for Earth System Research and Data Science.

Appendix E: Awards

Awards by year

CIESRDS teams and individuals have received numerous awards recognizing research excellence, scientific innovation, and outstanding service. The following is a compilation of awards reported by teams for the period September 2022 through early 2026.

2025

NOAA OAR TEAM MEMBER OF THE YEAR

Daniel Abdi

"For exemplary leadership in spearheading the development of HRRR Cast, a groundbreaking machine learning framework that has redefined high-resolution weather forecasting"

AMERICAN METEOROLOGICAL SOCIETY HONORARY MEMBER

Stan Benjamin, CIRES Fellow

"The highest honor bestowed by the AMS, Honorary Members have shown preeminence in the atmospheric or related oceanic or hydrologic sciences, either through their own contributions to the sciences or their applications."

NESDIS OUTSTANDING SCIENCE AND RESEARCH TEAM AWARD

Dimitrios Vassiliadis, William Rowland, Christen Bethge, Tyler Gardner, Gabriel Dima, Elysia Lucas, Vicente Salinas, Andrew Wilson, Donald Schmit, Jeff Johnson, Nathan Miles, Michael Burek, Martin Aubrey, George Millward

"For demonstrated excellence in the areas of providing sensor-derived products and interpretive analyses; acquiring, processing, and storing environmental data and ground processing systems; and improving on existing environmental information products to enhance utility, clarity, or efficiency"

NESDIS SCIENCE TEAM AWARD

Space Weather Science Team

"For the Space Weather Follow-On Coronagraph" program"

NESDIS OUTSTANDING TEAM AWARD

Mission Operations Team

"For GOES-18 product validation"

CLARIVATE HIGHLY CITED RESEARCHERS

Noah Fierer, Jennifer Balch, José Jiménez

The annual list celebrates researchers with significant and broad influence.

AGU FELLOW

Jennifer Balch

"For her expertise on wildfire science, and advising government agencies and other organizations outside the sciences"

AGU ATMOSPHERIC SCIENCE ASCENT AWARD

Jennifer Kay

Recognizes mid-career excellence in research and leadership in the atmospheric and climate sciences

PAVEL S. MOLCHANOV CLIMATE COMMUNICATION PRIZE

Twila Moon

"For her work as a communications specialist to break down important concepts relating to climate change for those working in business, policy, finance, philanthropy, and media"

NOAA BRONZE MEDAL

Tim Newberger, Sonja Wolter, Steve Borenstein

"For developing a novel, low-cost, balloon-glider platform for deploying lightweight meteorological and atmospheric composition sampling and measurement systems to 90,000 feet and returning them to their original launch location"

NOAA BRONZE MEDAL

Adam Ahern, Alex Baron, Samantha DeLone, Colin Gurganus, Eric Jensen, Mike Lawler, Ming Lyu, Catherine Rasco, Eric Ray, Mike Robinson, Sam Taylor, Eleanor Waxman, Elizabeth Asher, Patrick Cullis, Geoff Dutton, Eric Hintsa, Fred Moore, David Nance

"For establishing a new paradigm for NOAA-directed stratospheric science with the successful execution of the Stratospheric Aerosol processes, Budget and Radiative Effects (SABRE) 2023 airborne science mission"

INNOVATIVE ENVIRONMENTAL EDUCATION AWARD

Chelsea Zaniboni, Anne Gold, Pacifica Sommers, Melisa Diaz

"For the Girls on Rock program, hosted by the CIRES Center for Education, Engagement, and Evaluation"

NOAA OUTSTANDING PAPER AWARD

Tatiana Smirnova, Jaymes Kenyon, Jeffrey Duda

"For the High-Resolution Rapid Refresh (HRRR): An hourly updating convection-allowing forecast model, published in Weather and Forecasting."

NOAA OUTSTANDING PAPER AWARD

Caroline Womack, Wyndom Chace, Siyuan Wang, Dorothy Fibiger, Alessandro Franchin, Colin Harkins, Erin McDuffie, Andrew Neuman

"For midlatitude ozone depletion and air quality impacts from

industrial halogen emissions in the Great Salt Lake Basin, published in Environmental Science & Technology."

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE SERVICE

Nathan Miles
"For near-real-time images of the Sun's corona"

CIRES OUTSTANDING PERFORMANCE AWARD: ADMINISTRATION

Rebecca Stossmeister, Laura Burfield
"For operational processes supporting NC CASC"

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE

Michael Gallagher
"For autonomous and renewable power systems that were deployed at remote locations on the Greenland Ice Sheet"

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE

Jeff Johnson
"For developing cutting-edge systems that are critical to safeguarding the nation's power grid, economic stability, and national security"

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE

Alex Fritz
"For the Sonde-Pi reception system, a small, portable hardware system that captures data from balloon-borne instruments"

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE

Prashant Sardeshmukh
"For transformational successes in climate science that have advanced our understanding of El Niño-Southern Oscillation dynamics"

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE SERVICE

Jeff Peischl, Anna McAuliffe, Sonja Wolter, Steve Borenstein, Eric Moglia, Kate Baugh, Monica Madronich, Tim Newberger, Molly Crotwell
"For a groundbreaking airborne survey that has significantly advanced greenhouse gas monitoring across the U.S."

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE SERVICE

Jimmy Neguse
"For dedication to CIRES science outreach and education"

ARMSTRONG MEMORIAL SCHOLARSHIP

Jesse Rush
"For passion, creativity, and dedication to leadership and mentoring"

REID MEMORIAL SCHOLARSHIP

Yingfei Chen
"For significant contributions to research at McMurdo Station, Antarctica using lidar to study the upper atmosphere"

2025 FULBRIGHT DISTINGUISHED ARCTIC SCHOLAR TO NORWAY

Mark Seefeldt
"To investigate temperature extremes in the Arctic and northern high latitudes and the atmospheric characteristics associated with the extremes"

STUDENT LEADERSHIP CAMPUS SUSTAINABILITY AWARD

Jonah Shaw (part of a team)
"For creating and now teaching a climate action planning course that empowers undergrads to reduce CU Boulder's emissions and shape climate policy through research and justice-centered engagement."

CIRES GRADUATE STUDENT RESEARCH AWARDS

Ashley Azadeh, Romulo Cruz-Simbron, Bri Dobson, Ash Gilbert, Joel Johnson, Kyle McMillan, Claire Winfrey

RIO FACULTY FELLOW

Ellie Browne

SPACE WEATHER PREDICTION CENTER DIRECTOR'S AWARDS

Hazel Bain, Ratina Dodani, Dominic Fuller-Rowell, Tim Fuller-Rowell, Adam Kubaryk, Jasmine Li, Scott Longmore, Charlotte Martinkus, Mark Miesch, Kim Moreland, Jaci Stickrod

2024

NOAA BRONZE MEDAL CIRES/NOAA OUTREACH AMBASSADORS

Astrid Maute, Bianca Baier, Christina Kumler, Christoph Senff, Chuck Anderson, Craig Hartsough, Eleanor Waxman, Eric Moglia, Hilary Peddicord, Jessica Knezha, Jessica Nation, James Negus, Karin Vergoth, Kimberly Moreland, Lucia Harrop, Monica Madronich, Peter Effertz, Sergio Ibarra-Espinosa, Shawn Murdzek, Vanessa Caicedo, Wyndom Chace
"For significantly increasing awareness of NOAA's mission through outreach, education, and service"

NOAA BRONZE MEDAL

Chuck Anderson, Veronica Martinez, Jessica Nation, Carrie Wall Bell
"For CruisePack, a tool that enables critical marine geophysical data to be archived and preserved for generations to come"

CLARIVATE HIGHLY CITED RESEARCHERS
Noah Fierer, José Luis Jiménez

2024 AGU SVERDRUP LECTURE
Antonietta Capotondi

2024 AGU TURCO LECTURE
Kris Karnauskas

AMS EDITOR'S AWARD
Jeffrey Duda
"For providing extremely thorough, constructive, and timely reviews of numerous manuscripts"

NASA GROUP ACHIEVEMENT AWARD
ACCLIP
"For stratospheric modeling and analysis"

DEVELOPMENTAL TESTBED CENTER "PROUD" AWARD
Evelyn Grell
For physics development

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE SERVICE
Elizabeth Payton
"For her role as NCA5 chapter lead required it all: scientific expertise, superb organizational skills, diplomacy, and the ability to engineer plain language to communicate complex ideas—not to mention navigating the ins and outs of the federal government**"**

CIRES OUTSTANDING PERFORMANCE AWARD: ADMINISTRATIVE SERVICE
Lucia Harrop
"For a pivotal role in fostering seamless collaboration between CIRES and NOAA, ensuring that employees receive unparalleled support and guidance throughout their tenure"

CIRES GRADUATE STUDENT RESEARCH AWARDS
Yingfei Chen, Laura Rea, Emmy Longnecker, Leah Bertrand, Daniel Hassell, Daniel Katz, Samba Siva Sai Prasad Thota, Ashley Dancer

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE SERVICE
Katya Schloesser, Alicia Christensen, Katie Boyd, Meg Littrell, Daniela Pennycook, Ami Nacu-Schmidt
"For an innovative, impactful, and award-winning education program to support rural Colorado youth and communities most impacted by natural hazards such as drought, flood, and wildfires"

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE SERVICE
Anne Gold
"For her astonishing work growing the Center for Education, Engagement, and Evaluation program into an internationally recognized powerhouse"

NSF GRADUATE RESEARCH FELLOWSHIP PROGRAM
Ethan Carr and Mobeen Zahid

RICHARD ARMSTRONG MEMORIAL
Naomi Ochwat
"For dedication to inspire and train the next generation of scientists"

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE
Barry Eakins, Rick Saltus, Erin LeFevre, Finn Dahl, Elliot Lim
"For establishing the outer limits of the U.S. Extended Continental Shelf (ECS), which added nearly one million square kilometers of seafloor to the United States to manage or conserve"

CIRES OUTSTANDING PERFORMANCE AWARD: ADMINISTRATIVE SERVICE
David Zakavec
"For exceptional IT responsiveness and support"

AGU OUTSTANDING STUDENT PRESENTATION AWARDS
Megan Thompson-Munson, Jonah Shaw
Megan spoke on "Characterizing the Response of Firn to Climate Change;" Jonah's talk was "Observational Uncertainty is Necessary for Assessing Time-of-Emergence."

BOULDER FACULTY ASSEMBLY EXCELLENCE AWARD
Joost de Gouw
Recognized in the category of Research, Scholarly, and Creative Work

INTERNATIONAL ARCTIC SCIENCE COMMITTEE AWARD FOR SERVICE
Matthew Shupe
"For outstanding achievements in planning and executing the unique international Arctic Ocean program Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) which is fundamental for our understanding of the Arctic and which will serve the international community with new data that was not previously possible to access"

2023

CLARIVATE HIGHLY CITED RESEARCHERS
Noah Fierer, José-Luis Jiménez, Julienne Stroeve

DEPARTMENT OF COMMERCE GOLD MEDAL

Stan Benjamin, Jeffrey Duda, Jason English, Guoquing Ge, Jeff Hamilton, Joan Hart, Craig Hartsough, Jaymes Kenyon, Ruifang Li, Laura Melling, William Moninger, Shawn Murdzek, Gopa Padmanabhan, Sijie Pan, Michael Rabellino, Julia Simonson, Molly Smith, Sam Trahan, Hongli Wang, Chunhua Zhou

"For scientific and engineering excellence in developing a revolutionary prediction tool that provides short-term probabilistic thunderstorm guidance"

DEPARTMENT OF COMMERCE SILVER MEDAL

Ravan Ahmadov, Sam Trahan, Eric James

"For the operational value of predictions of wildfire smoke transport and its impact on weather to support air quality alerts and visibility forecasts"

DEPARTMENT OF COMMERCE SILVER MEDAL

Gijs de Boer and Jonathan Hamilton

"For the first deployment of a fully autonomous system for the measurement of vertical profiles of aerosol, cloud, and meteorological properties"

DEPARTMENT OF COMMERCE SILVER MEDAL

Elizabeth Asher, Patrick Cullis, Emrys Hall, Dale Hurst, Allen Jordan, Yunqian Zhu

"For successfully executing a rapid response campaign to study the atmospheric impact of the unprecedented Hunga Tonga-Hunga Ha'apai volcano eruption"

NOAA BRONZE MEDAL

Ken Aikin, Matthew Coggon, Jeff Peischl, Chelsea Stockwell, Kristen Zuraski

"For exceptional service to communities affected by the Marshall Fire in providing timely air quality information to support recovery efforts"

NESDIS OUTSTANDING SCIENCE AND RESEARCH AWARD

Marine Geology and Geophysics Team

"For improving coastal modeling and resilience"

CO-LABS GOVERNORS AWARD: PATHFINDING PARTNERSHIPS

Brigitta Rongstad Strong, Anne Gold, Megan Littrell, Christine Okochi, Katie Boyd, Annamarie Schaecher, Ami Nacu-Schmidt, Daniela Pennycook, Benét Duncan, Ethan Knight, Claire Ratcliffe Adams

"For research that engaged four or more distinct research entities in Colorado (with at least two being federally-funded labs) whose results leveraged the resources and strengths among partnering organizations – and demonstrate the power of collaboration"

AMERICAN ASSOCIATION OF GEOGRAPHERS' ELEVATE THE DISCIPLINE PROGRAM

Katie Clifford

Katie Clifford, the social sciences lead at the Western Water Assessment, was named to the American Association of Geographers' inaugural 'Elevate the Discipline' cohort.

CIRES OUTSTANDING PERFORMANCE AWARD: SERVICE

Hazel Bain

"For leadership, expertise, and enthusiasm have helped shape the nation's understanding of space weather impacts on aviation and the strategies necessary to mitigate them"

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE

Elizabeth Asher

"For pioneering the deployment of Portable Optical Particle Spectrometers (POPS) at multiple locations and at critical times to measure key episodes, such as the Raikoke (2019) and Hunga-Tonga (2022) volcanic eruptions, as well as the 2022 Australian New Year's fires"

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE

Mike MacFerrin, Chris Amante, Matt Love, Kelly Carignan, Elliot Lim

"For releasing a new Earth TOPOgraphy (ETOPO) global relief model that includes significant improvements"

CIRES OUTSTANDING PERFORMANCE AWARD: SERVICE

Chris Bond, Lisa Booker, Daniel Crumly, Leslie Goldman, Jonathan Kovarik, Shannon Leslie, Matt Savoie, Amy Steiker

"For launching NASA's Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) data–an Earth observing mission which produces 1 TB of data a day–into the NASA Earthdata Cloud"

CIRES OUTSTANDING PERFORMANCE AWARD: SERVICE

Brigitta Rongstad, Annamarie Schaecher, Megan Littrell, Katie Boyd, Christine Okochi, Casey Marsh, Daniela Pennycook, Ami Nacu-Schmidt, Ethan Knight, Benét Duncan, Matt Price

This CIRES team developed and led the We are Water project, an ambitious public education program focused on water in the desert Southwest

OUTSTANDING PERFORMANCE AWARD: SCIENCE

Maxwell Holloway

"For using his impressive skills in hardware design, CAD, mechanical fabrication, assembly and modification, as well as his extensive knowledge and skill in electronics have propelled the group's instrument development and field campaign successes"

REID MEMORIAL SCHOLARSHIP

Zach Schiffman

"For outstanding scholarship and community service"

2023 CIRES GRADUATE STUDENT RESEARCH AWARDS

Alex Bradley, Matthew Gebert, Parthkumar Modi, Jessica Rush, Megan Thompson-Munson, Evan Tucker

RISING STAR IN ENVIRONMENTAL RESEARCH

Ellie Browne

Ellie Browne was one of six early career investigators selected from around the world, honored for her work to address important environmental research issues.

2022 Awards

CLARIVATE HIGHLY CITED RESEARCHERS

Jennifer Balch, Noah Fierer, Jose-Luis Jimenez, Julienne Stroeve

DEPARTMENT OF COMMERCE SILVER MEDAL

David Allured and Irina Djalalova

"For development and implementation of Air Quality Model v6 to significantly advance operational air quality predictions for the Nation"

NOAA BRONZE MEDAL

Christoph Senff, Brandi McCarty, Sunil Baidar, Ken Aikin, Jeff Peischl, Chelsea Stockwell, Mike Robinson

"For synthesis, critical evaluation, and communication to scientists and the public of the global air quality impacts of COVID-19 pandemic lockdowns"

NOAA BRONZE MEDAL

Adam Lang, Elizabeth Ossoswski, Kelsey Stalino, Britt Parker, Molly Woloszyn, Amanda Sheffeld, Joel Lisonbee, Sylvia Reeves

"For the new Drought.gov website, a cutting-edge implementation of the NIDIS public law, built on interagency and DOC partnerships"

NOAA BRONZE MEDAL

Beth Wehe, Shilpi Gupta, Alexander Kirst, Hilary Peddicord, Tony Liao

"For the Department's first research to education transition that secured NOAA's ability to deliver data products to a vast network with global reach"

NOAA Bronze Medal

Michael Gallagher, Amy Solomon, Matthew Shupe, Byron Blomquist, Ola Persson, Dave Costa, Ludovic Bariteau, Gijs de Boer, Jonathan Hamilton, Radiance Calmer, John Cassano, Gina Jozef, Anne Gold, Lianna Nixon, Erika Lynne Harden, Jonathan Griffith, Katya Schloesser, Katy Human, Katie Weeman, Amy Lauren, Laura Riihimaki, Sean Horvath, Julienne Stroeve, Sergey Matrosov, Anne Sledd

"For extraordinary contributions to the year-long Multidisciplinary Drifting Observatory for the Study of Arctic Climate (MOSAiC) polar expedition"

NOAA BRONZE MEDAL

Jan Kazil, Takanobu Yamaguchi, Ludovic Bariteau, Richard Marchbanks, Byron Blomquist, Gijs de Boer, Radiance Calmer, Jonathan Hamilton, Steve Borenstein, Michael Zucker, Sunil Baidar, Max Holloway

"For scientific achievement in the design and implementation of the complex Atlantic Tradewind Ocean-atmosphere Mesoscale Interaction Campaign"

AGU CHARLES A. WHITTEN MEDAL

Roger Bilham

"For excellence in scientific research, education, communication, and outreach"

CO-LABS GOVERNORS AWARD: TECHNOLOGY TRANSFER

Tzu-Wei Fang (NOAA SWPC), Tim Fuller-Rowell, Zhuxiao Li, Adam Kubaryk

"For research that resulted in a technological solution with widespread and/or significantly measurable societal utilization, with related impact on a global challenge or issue"

NESDIS VISION AND CREATIVITY AWARD

MagNet Team

AGU HYDROLOGIC SCIENCES EARLY CAREER AWARD

Ben Livneh

"For his tremendous personal sacrifices and selfless dedication to advancing Earth and space sciences"

NATIONAL ACADEMY OF SCIENCES BOARD ON ENVIRONMENTAL CHANGE AND SOCIETY

Lisa Dilling

Lisa Dilling was appointed to the National Academy's Board on Environmental Change and Society.

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE

Rochelle Worsnop

"For the scientific development, demonstration, and technology transfer of a one- to two-week forecast of fire weather potential—an agency first"

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE

Mike Hobbins

"For leadership and innovation in life- and property-saving drought research, including developing and operationalizing the Evaporative Demand Drought Index"

CIRES OUTSTANDING PERFORMANCE AWARD: SCIENCE

Zhe Peng

"For world-class excellence in atmospheric chemistry research including the airborne transmission of COVID-19"

CIRES OUTSTANDING PERFORMANCE AWARD: SERVICE

Kevin Beam, Michael Brandt, Daniel Crumly, Matt Fisher, Agnieszka Gautier, Jonathan Kovarik, Audrey Payne, Matt Savoie, Trey Stafford, Troy Williams

"For high-impact work communicating—with the scientific community and the general public—how the cryosphere is changing and why it matters"

CIRES OUTSTANDING PERFORMANCE AWARD: SERVICE

Veronica Martinez

"For a pivotal role in a NOAA data rescue project saving priceless environmental data collected by the agency's research ships"

CIRES OUTSTANDING PERFORMANCE AWARD

Katie Boyd, Gina Fiorile, Alicia Christensen, Naomi Elaine Ochwat, Casey Lea Marsh, Daniela Pennycook

"For promoting scientifically accurate educational materials around climate, making CLEAN the national go-to resource for teachers and educators"

CIRES GRADUATE STUDENT RESEARCH AWARDS

Sarah Becker, Corinne Walsh, Sarah Jaffe, Zachary Schiffman, Shane Zhang, Karl Alexander Widney, Ian Geraghty

NOAA OUTSTANDING PAPER AWARD

Eric James and Tanya Smirnova

"For a paper on improved snow and ice forecasts"

NOAA ADMINISTRATOR'S AWARD

Ravan Ahmadov, Hannah Barnes, Jeff Duda, Jason English, Guoqing Ge, Jeffrey Hamilton, Siwei He, Eric James, William Moniger, Tanya Smirnova, Molly Smith, Michael Toy, Samual Trahan, Hong Wang

"For completion of the High-Resolution Rapid Refresh weather model project that improves forecasts and warnings for high-impact weather events"

Appendix F: CIESRDS by the numbers

Aggregate Performance Metrics (September 2022 – Present)

The following table summarizes key performance metrics reported by CIESRDS research teams for the current cooperative agreement period. These figures represent self-reported data from 36 teams across all eight CIESRDS research themes.

Metric	Total	Teams Reporting
Peer-reviewed publications	1,553	33
Conference presentations	1,773	34
Datasets published	3,479	30
Testbeds conducted	51	11
Non-Task II proposals awarded	234	32
Patents filed	12	7
Students hosted	139	23

NOTES

- Metrics reflect the period from September 2022 through early 2026.
- Not all teams reported data for every metric category.
- Some teams conduct primarily operational or support activities and may not generate publications or datasets as primary outputs.

Appendix G: Challenges and opportunities

The following section summarizes challenges reported by CIESRDS teams during the current cooperative agreement period. These challenges have been organized thematically to identify common issues that may benefit from institutional attention.

Staffing and Personnel

- **The Space Weather Observations team** experienced significant staffing turnover and hiring difficulties during program-wide testing, requiring team members to go "above and beyond" to meet launch schedules.
- **The SWPC Modeling Project** reports a reduction in personnel due to budget cuts, retirements, and departures. The team is currently at its lowest staffing level in five years (nine individuals), requiring scaling back of key contributions including website support, commercial data programs, and several models.
- **The GML Ozone and Water Vapor Division team** reports loss of staff affecting operations.
- **The Global Monitoring Laboratory Global Greenhouse Gas Reference Network** notes that retirement of senior federal employees has stretched the CIESRDS team thin to maintain measurement operations and data publications.
- **The Geomag team** faces ongoing challenges filling research scientist positions due to the limited pool of trained geomagnetism specialists in the United States and constraints on hiring foreign nationals at NOAA.
- **The PSL/Data Instrumentation and Field Division team** reports difficulty hiring and retaining employees due to various hiring restrictions.
- **The NSIDC team** (fewer than 2 FTE from the Cooperative Agreement) cannot allocate enough hours to maintain data products fully. Without adequate funding and staffing, data set quality will decline over time.
- **The Weather Prediction Center HydroMeteorology Testbed team** (3-4 FTE) maintains three experiments, five websites, and extensive model/observational data with an internally written Python library—a situation described as "unsustainable to maintain and grow."
- **The CSL Tropospheric Chemistry Program** has reduced CIESRDS staffing, which limits the ability to field all available instrumentation and significantly reduces the scope of multidisciplinary field campaigns.

Computing and IT Infrastructure

GSL/AVID reports limited computing resources including computing hours and disk storage.

- **WPC Verification Development** has computing infrastructure with limited capabilities, impacting ability to transition tools from local workstations to operationally supported servers.
- **The Chemical Sciences Laboratory Atmospheric Composition Modeling team** notes that as NOAA moves computing to the cloud, local Linux machines will be phased out, requiring reliance on CU-Boulder computing resources.
- **The Marine Geology and Geophysics team** has navigated extensive federal IT hurdles associated with changing requirements and aging hardware and infrastructure.
- **NCEI Paleo** experiences significant delays (many months) in security review and software release due to lack of staff at NCEI, slowing operations substantially.
- **The Science On a Sphere team** spent close to a year transitioning infrastructure to the cloud and working with a new IT department after moving to the Office of Education.

Funding uncertainty

- **WPC Development and Training Branch** reports lack of funding availability and calls for proposals. One project was recommended for funding but ultimately not awarded.
- **PSL Hydrology Applications** saw efforts toward research goals put on hold when the FEWSNet program was impacted by changes to the USAID program earlier in 2025.
- **CSL Atmospheric Remote Sensing** notes that federally-driven limits on purchasing and funding beginning in early 2025 have greatly increased the risk of failure for field projects.
- **EPAD** reports funding uncertainties and impacts from government shutdowns (absence of federal employees).
- **Atmosphere-Ocean Processes and Predictability (PSL/AOPP)** notes budget and personnel constraints limiting project scope.

Research Direction

The MDAD Physics Development Team observes an ongoing challenge within NOAA PSL (driven largely by NOAA OAR) regarding a transition from a focus on basic research in favor of applied research that can be more rapidly transferred to operations.

Appendix H: Technology Transfer and Products in Transition

CIESRDS teams develop innovative tools, models, algorithms, and data products that transition from research to operations. The following summarizes products that have been transitioned or are awaiting transition to operational settings.

Operational Algorithms and Models

Space Weather

The NCEI Space Weather Team provides 43 operational algorithms to the NOAA Space Weather Prediction Center for operational forecasting.

CIRES/SWPC Modeling Project products:

- Python/javascript CME Analysis Tool (pyCAT)
- Local CME Ensemble Application
- Geoelectric Climatological forecast model
- Global Total Electron Content (GloTEC) model
- Updated Solar Cycle Prediction model
- WSA Dashboard
- H3lioViz (3D visualization platform for Enlil)
- Air Force Data Assimilative Photospheric flux Transport (ADAPT) model
- Solar Indices Forecasting Tool (SIFT)
- Mercury application and ICAO Space Weather Advisories
- CARI-7 (radiation exposure for airlines)
- GOES SUVI flare location product
- GOES SGPS Alpha Particle product
- Cloud migration of SWPC services

Geomag Team:

High-Definition Geomagnetic Model (research-grade models transitioned to operational setting)

Weather and Atmospheric Models

GSL/AVID

- Rapid Refresh Forecast System version 1
- Three-dimensional Real-Time Mesoscale Analysis version 1

EPAD (Environmental Prediction, Aerosols, and Development)

- RRFS v1 (Rapid Refresh Forecast System with smoke and dust) – 2024 for 2026 implementation
- UFS SRW App (Unified Forecast System Short-Range Weather App) – 2021-2025
- GEFS-Aerosol v12.3 (Global Ensemble Forecast System with Aerosols) – January 2023
- HRRRCast – 2025
- GCAFS (Global Chemistry and Aerosol Forecast System) – 2025 for 2026 implementation
- NARA v1 and 1.1 (NOAA Aerosol Reanalysis)
- Common Community Physics Package (CCPP) v7 – June 2025
- Unified Workflow Tools (UWTools)
- Pollen experimental real-time forecasts
- Domestic Aviation Forecast System (DAFS) v1

Reanalysis and Data Assimilation Team

- New snow depth data assimilation algorithm incorporated into Joint Effort for Data Integration repository
- Snow depth data assimilation operational in NCEP Global Forecast System version 17
- Standalone interpolation from cube-spheric grid to Gaussian grid
- Six additional improvements to ensemble data assimilation system merged to JEDI GitHub repository
- Downscaled 20th Century Reanalysis v3 precipitation used by States of Colorado and New Mexico for updated dam safety requirements

MDAD Physics Development Team

- Novel test case for evaluating shallow convection regimes using single-column modeling
- Coupled Arctic Forecast System (CAFS) for high-resolution Arctic weather forecasts
- Parameterization for large-scale gravity wave dynamics in single-column-model version of NOAA UFS

Weather Prediction Center Products

- WPC Development and Training Branch
- WSSI for Alaska
- Hourly WSSI
- WPC Ensemble Clustering Product
- WPC Ensemble Sensitivity Analysis Product

WPC Verification Development

- Automated Low Cluster
- Tracking of Heavy Precipitation Objects
- Snowband Probability Tracker
- Analog Forecasting of Precipitation Objects
- Mesoscale Precipitation Discussion Verification

- Excessive Rainfall Outlook Verification

WPC HydroMeteorology Testbed

- Freezing Rain Analysis (NSSL to WPC)
- Machine Learned ERO 1st guess (CSU to WPC)
- Snow to liquid ratio (University of Utah to WPC)

Decision Support Systems

GSL Weather Informatics and Decision Support (WIDS)

- Hazard Services Convective workflow to NWS Weather Forecasting Offices
- ATOMS (Tsunami) workflow to Tsunami Warning Centers
- IDSS Engine code repository to NWS Meteorological Development Laboratory

NIDIS

Updated social science designed operational NWS Climate Prediction Center Drought Outlooks

Instrumentation and Technology

NOAA CSL (Atmospheric Composition & Chemical Processes)

- IBIS (In-situ Balloon-borne Ice Spectrometer)
- OPUS (Ozone Photometer for UAS/Balloon Studies)
- NO-LIF (Laser Induced Fluorescence Instrumentation for Nitric Oxide)
- NightFOX (Nighttime Fire Observations eXperiment)

NOAA GML Technology Transfer, Engineering and Applications Division

- HORUS2

Appendix I: CIESRDS Partnerships

Overview

CIESRDS maintains extensive partnerships with federal agencies, academic institutions, state and local governments, international organizations, and private sector entities. These collaborations extend the reach and impact of CIESRDS research while leveraging complementary expertise and resources.

- 34 teams reported domestic partnerships
- 25 teams reported international partnerships

B.1 Domestic Partnerships

Federal Agencies

NOAA (Internal Collaboration)

Air Resources Laboratory (ARL)

Atlantic Oceanographic and Meteorological Laboratory (AOML)

Climate Prediction Center (CPC)

Climate Program Office (CPO)

Environmental Modeling Center (EMC)

Geophysical Fluid Dynamics Laboratory (GFDL)

Global Monitoring Laboratory (GML)

Global Systems Laboratory (GSL)

National Centers for Environmental Information (NCEI)

National Centers for Environmental Prediction (NCEP)

National Environmental Satellite, Data, and Information Service (NESDIS)

National Severe Storms Laboratory (NSSL)

National Weather Service (NWS)

Office of Education (OEd)

Office of Ocean Exploration and Research

Pacific Marine Environmental Laboratory (PMEL)

Physical Sciences Laboratory (PSL)

Space Weather Prediction Center (SWPC)

Weather Program Office (WPO)

Other Federal Agencies

Department of Defense (DoD)

Department of Energy (DOE)

Department of the Interior (DOI)

Department of State

Environmental Protection Agency (EPA)

Federal Aviation Administration (FAA)

Federal Emergency Management Agency (FEMA)

National Aeronautics and Space Administration (NASA)

National Institute of Standards and Technology (NIST)

National Science Foundation (NSF)

U.S. Air Force / U.S. Space Force

U.S. Army Corps of Engineers

U.S. Bureau of Land Management (BLM)

U.S. Bureau of Ocean Energy Management (BOEM)

U.S. Bureau of Reclamation

U.S. Centers for Disease Control and Prevention (CDC)

U.S. Coast Guard

U.S. Fish and Wildlife Service

U.S. Forest Service

U.S. Geological Survey (USGS)

U.S. Navy / Naval Research Laboratory (NRL)

National Laboratories

Argonne National Laboratory

Lawrence Berkeley National Laboratory

Lawrence Livermore National Laboratory

Los Alamos National Laboratory

National Center for Atmospheric Research (NCAR)

National Renewable Energy Laboratory (NREL)

Pacific Northwest National Laboratory

Academic Institutions

University of Colorado System

CU Boulder Department of Atmospheric and Oceanic Sciences

CU Boulder Laboratory for Atmospheric and Space Physics (LASP)

CU Boulder Institute of Arctic and Alpine Research (INSTAAR)

CU Denver

Other Universities (Partial List)

Boston University

California Institute of Technology
Colorado State University
Columbia University
Cornell University
Harvard University
Johns Hopkins University
Massachusetts Institute of Technology
Oregon State University
Pennsylvania State University
Princeton University
Purdue University
Scripps Institution of Oceanography (UC San Diego)
Stanford University
Texas A&M University
University of California (Berkeley, Davis, Los Angeles, Santa Barbara, Santa Cruz)
University of Maryland
University of Miami
University of Michigan
University of Minnesota
University of Oklahoma
University of Washington
University of Wisconsin–Madison
Woods Hole Oceanographic Institution
Yale University

State and Local Agencies

California Air Resources Board (CARB)
California Department of Forestry and Fire Protection (CalFire)
Colorado Department of Public Health and Environment (CDPHE)
Maryland Department of the Environment
Pennsylvania Department of Environmental Protection
Texas Commission on Environmental Quality
Utah Division of Air Quality

Private Sector and Non-Governmental Organizations

Aerodyne Research Inc.
AERIS Technologies
BWC Visual Technology
Chevron
Earth Networks
Equinor
National Drought Mitigation Center
Nikira Labs, Inc.
NVIDIA
Orsted
Raytheon (EPIC partnership)
The Nature Conservancy
Vineyard Wind

Tribal Nations

CIESRDS partners with Tribal Nations on drought resilience, ecosystem management, and natural hazard preparedness, including the Confederated Salish & Kootenai Tribes of the Flathead Reservation and other Tribal partners through NIDIS.

B.2 International Partnerships

By Country/Region

Australia: Bureau of Meteorology, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Monash University

Austria: Globoccess, University of Vienna

Belgium: Royal Belgian Institute for Space Aeronomy (BIRA), Vlaams Instituut voor de Zee

Canada: Environment and Climate Change Canada (ECCC), Natural Resources Canada (NRCan), Sander Geophysics, University of Calgary, University of Manitoba, University of Toronto, University of Victoria, University of Waterloo

China: Beijing Normal University, First Institute of Oceanography, Ocean University of China, Polar Research Institute of China, Shanghai Jiao Tong University, Zhejiang University

Denmark: Danish Meteorological Institute (DMI), Danish Technical University

France: Centre National de la Recherche Scientifique (CNRS), Laboratoire des Sciences du Climat et de l'Environnement (LSCE), Meteo-France, University of Réunion Island, University of Toulouse

Germany: Alfred Wegener Institute (AWI), Deutscher Wetterdienst (DWD), Forschungszentrum Jülich, Karlsruhe Institute of Technology, Leibniz Institute for Tropospheric Research (TROPOS), Max Planck Institute for Biogeochemistry, University of Cologne, University of Hohenheim, University of Leipzig, University of Mainz

Japan: Hokkaido University, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), National Institute for Environmental Studies (NIES)

Netherlands: Koninklijk Nederlands Meteorologisch Instituut (KNMI), Technical University Delft, Wageningen University

New Zealand: Earth Sciences New Zealand, NIWA Atmospheric Research

Norway: Norwegian Institute for Air Research (NILU), Norwegian Technical University

South Korea: Yonsei University

Spain: Observatorio del Teide, Universitat Politècnica de Catalunya

Sweden: University of Stockholm

Switzerland: ETH Zurich, MeteoSwiss, World Meteorological Organization (WMO)

United Kingdom: Imperial College London, Lancaster University, Oxford University, UK Centre for Ecology and Hydrology, UK Met Office, University of Exeter, University of Leeds, University of Manchester, University of York

Multi-National Organizations

Baseline Surface Radiation Network (BSRN)

Climate and Ocean: Variability, Predictability, and Change (CLIVAR)

European Centre for Medium-Range Weather Forecasts (ECMWF)

European Space Agency (ESA)

EUMETSAT

General Bathymetric Chart of the Oceans (GEBCO)

Global Atmospheric Watch (GAW)

Global Climate Observing System (GCOS)

Global Ocean Observing System (GOOS)

Integrated Carbon Observation System (ICOS)

International Association of Geomagnetism and Aeronomy (IAGA)

International Civil Aviation Organization (ICAO)

Network for Detection of Atmospheric Composition Change (NDACC)

North Pacific Marine Science Organization (PICES)

World Climate Research Program (WCRP)

World Meteorological Organization (WMO)

Appendix J: CIESRDS Strategic Plan

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CIESRDS Strategic Plan

NA22OAR4320151 funds the CIESRDS grant, managed by CIRES at CU Boulder, and supports research and collaboration with NOAA.

Given the structure of CIESRDS, the strategic plan is a living document that will be revised continually to incorporate any new guidance or directives with each new award period. Below are the current strategic imperatives developed out of the current cooperative agreement.

1. **Conduct high-quality Earth system research and data science in collaboration with and service to NOAA to support society's resilience to environmental change.**
    a. Support a comprehensive series of integrated research programs to produce world-class Earth system research and data science that is in service to society, and close collaboration with NOAA.
    b. Collaborate with NOAA to develop annual science plans that ensure our research agenda remains ambitious, innovative, and achievable, and that it aligns with the current priorities of our NOAA partners.
    c. Be flexible as Earth system research and data science needs evolve, CIESRDS will respond, both through our collaboration with NOAA and through other sources of external funding that complement our NOAA portfolio.
    d. Be highly connected to Colorado's collaborative Earth system research and data science community; this research network enables quick response to needs and efficient use of federal and other resources.
2. **Train and inspire a diverse and skilled future Earth system and data science workforce for NOAA and beyond.**
    a. Support robust workforce development programs to promote excellence while inspiring engagement, innovation, collaboration, and leadership at all levels.
    b. Work to ensure a positive and healthy culture at CIRES and incorporate CU Boulder's Inclusive Excellence elements into our systems and practices across the organization.
    c. Support the professional development of Graduate Students and Post-docs with training, fellowships, travel and meeting support, mentoring, networking, and other programs.

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   d. Improve the current and future research enterprise through postdoctoral and visiting scientist programs.
   e. Employ and mentor undergraduate students through multiple programs and initiatives.

3. **Grow Earth system research and data science literacy in learners of all ages.**
   a. Connect NOAA and CIRES/CIESRDS-funded science with educators, learners, communities, and future scientists.
      i. Work closely with NOAA to provide content for various outward-facing sites and resources.
      ii. Promote and strengthen scientific and environmental literacy by engaging communities.
   b. Encourage media coverage of our science.
      i. Work with NOAA, CU Boulder, and other partners to assist the media, policymakers, scientific colleagues, and funders in understanding the value of earth system research and data science carried out by NOAA and CIESRDS.
   c. Improve public understanding of science.
      i. Enhancing scientific and environmental literacy utilizing Science On a Sphere and improving understanding, value, and weather and water information through services to the public and the K-12 education community.
      ii. Support external communication to enhance public education.
4. **Provide the robust scientific and administrative infrastructure to run a cooperative institute cost-effectively, to successfully fulfill NOAA's needs and objectives.**
   a. Hire and retain a robust administrative support network that serves CIESRDS scientists and NOAA partners at NOAA facilities.
      i. Provide professional development opportunities, onboarding, town halls, and access to CU campus community groups and wellness resources.
      ii. Provide mentoring programs that further connect CIESRDS/CIRES scientists and NOAA partners.
   b. Enhance communication between CIESRDS, CIRES, and NOAA
      i. Participate in the NOAA CI Directors Executive Committee and CI Directors and Administrators annual meetings.
      ii. Lead the formation and organization of a CIESRDS Executive Board made up of both CIESRDS and NOAA representatives.
   c. Provide high-quality pre-and post-award administration support services.
      i. Work in partnership with CU Boulder's Office of Contracts and others to ensure compliance with all applicable federal, state, and funding agency regulations, and university policies, as well as award terms and

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conditions.

ii. Monitor all expenditures to ensure they are compliant, reasonable, allowable, and allocable to the project.

iii. Effectively manage the pursuit of funding opportunities that further serve the interests of NOAA and the cooperative agreement.