U.S. DEPARTMENT OF COMMERCE
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2020 NOAA Science Report

Emma Kelley, Gina Digiantonio, Isha Renta, Laura Newcomb, Gary Matlock, Eric Bayler, Neil Christerson, Monica Grasso, Michelle Harmon, Michael Liddel, Anthony Marshak, John McDonough, Peter Roohr, Stephan Smith, Jeffrey Wielgus

NOAA
Silver Spring, Maryland

April 2021

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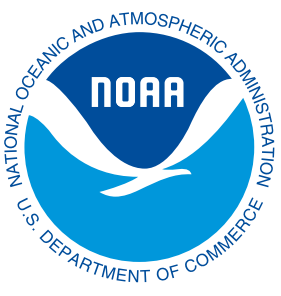

NOTICE

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PHOTO DISCLAIMER

Some images appearing in this report depict activities that occurred before CDC COVID-19 mask guidelines and travel restrictions were put in place.

COVER PHOTO
Underwater gliders ready for deployment in Puerto Rico for the 2020 hurricane season.
Credit: NOAA (July 2020)

FOREWORD

The year 2020 marked the 50th anniversary of NOAA. Since our establishment, NOAA has served as the Nation's premier ocean, weather, atmospheric, and climate science agency, enhancing the lives and livelihoods of the American People through cutting-edge science and engineering that extends from the bottom of the ocean to the surface of the sun.

Any examination of global science in oceans and the atmosphere have handprints and contributions from NOAA. While this Report is not retrospective, I invite you to examine the technical achievements and discoveries from this year, and imagine their foundational impact over the next 50 years. The technical achievements stand on their own merit, but with gratitude, we must applaud the dedicated people, scientists, engineers, managers, budget, lawyers, and administrative specialists who each contributed to this work. I thank you.

In the face of challenges from the COVID-19 pandemic, NOAA scientists have continued - with appropriate precautions - to perform research and development and have leveraged uncrewed systems, partnerships, and other technologies to gather data on earth system processes during this period of reduced traditional activity, but through determination and ambition, kept nearly all of our science on course.

Many of NOAA's scientific accomplishments represent transformative advancements for priority research and development topics. In 2020 NOAA established a new approach for achieving better coordination and organization for emerging technologies, and did so for five focus areas which are presented in this report. This defines a best practice for the application of new technologies and methods. But the foundation of this and other progress is NOAA's highly skilled and dedicated workforce. This report highlights new and continued efforts to promote a more welcoming, diverse, and inclusive environment through the NOAA Diversity and Inclusion Strategy and Action Plan.

The 2020 NOAA Science Report represents NOAA's world-class scientific accomplishments and showcases its vibrant workforce. NOAA is determined to continue to provide loyal service to the American People through innovative research and development to meet the needs of our Nation now and in the upcoming decades.

Craig N. McLean
Acting NOAA Chief Scientist

Lisa Kriederman, an Incident Meteorologist (IMET) with NOAA's National Weather Service, surveys smoke from a wildfire in East Fork, CO. Credit: NOAA National Weather Service (September 2020)

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INTRODUCTION

ENRICHING LIFE THROUGH SCIENCE

Extending from the surface of the sun to the depths of the oceans, the National Oceanic and Atmospheric Administration (NOAA) mission depends on a strong foundation of research and development (R&D) for observing and understanding the complex environmental systems that define our planet. This understanding ultimately provides users with the information and knowledge needed to protect lives and property, support livelihoods, enhance life, and sustain critical ecosystems.

WHY DOES NOAA INVEST IN RESEARCH?

Continually improving the quality of NOAA's products and services for the Nation requires NOAA investments in research and development. Products and services, developed through dynamic engagement between the agency and its users, result from stakeholders communicating their needs to NOAA. This generates development and new research initiatives, resulting in improved NOAA products and services to meet the needs of the people who depend on them.

By integrating research that is conducted internally with the efforts of partners, including Cooperative Institutes, universities, other government agencies, and the private sector, NOAA can transform concepts into the data, tools, and information upon which stakeholders rely.

NOAA balances a broad research portfolio to further the NOAA mission and serve a wide spectrum of end users.

NOAA'S MISSION: SCIENCE, SERVICE, AND STEWARDSHIP

To understand and predict changes in climate, weather, oceans, and coasts;

To share that knowledge and information with others; and

To conserve and manage coastal and marine ecosystems and resources.

NOAA'S PRIORITY OBJECTIVES

NOAA is supporting the Department of Commerce's Strategic Plan through two priority objectives [NOAA, 2018]:

1. Minimize the impacts of extreme weather and water events by implementing the Weather Research and Forecasting Innovation Act, with the underlying goal to regain world leadership in weather modeling.
2. Accelerating the American Blue Economy, with specific focus on reducing the nation's seafood trade deficit through expanded marine aquaculture.

The NOAA Research and Development Vision Areas: 2020-2026 sets priority foci for NOAA R&D. NOAA also is pursuing strategically focused research and development in the following areas:

1. harnessing 'omics approaches, from DNA sequencing to small molecule analysis;
2. uncrewed systems;
3. data;
4. citizen science;
5. artificial intelligence; and
6. adoption and use of information technology cloud services.

WHAT KINDS OF RESEARCH DOES NOAA SUPPORT?

NOAA's R&D addresses the needs of the user community while advancing fundamental scientific understanding. Our R&D portfolio allows the flexibility to consider contributions to the scientific knowledge base separately from (albeit related to) enhancing applicability.

In the context of the classical treatment by Donald Stokes [Stokes, 1997], we strive to position our investment primarily in "Pasteur's Quadrant," (Figure 1) while including critical investments aimed primarily at either advancing fundamental understanding or enhancing applications.

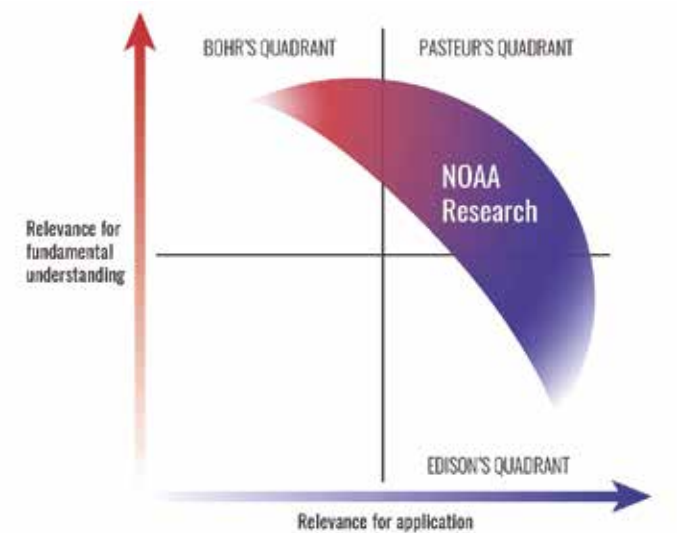


Figure 1. Donald Stokes proposed the above chart in his 1997 book *Pasteur's Quadrant: Basic Science and Technological Innovation*. This chart portrays that, while some research largely focuses on fundamental understanding (Bohr's quadrant upper left) or application (Edison's quadrant, lower right), it is possible for research to be highly relevant for both fundamental understanding and real-life applications (Pasteur's quadrant, upper right). The majority of NOAA research strives for this dual relevance as reflected in Pasteur's quadrant.

WHAT PRINCIPLES GUIDE NOAA RESEARCH?

NOAA strives to employ the following eight principles from NOAA Administrative Order (NAO) 216-115A [NOAA, 2016a] when formulating, directing, and evaluating all agency research:

- mission alignment
- transition readiness (NAO 216-105B, [NOAA, 2016b])
- research balance
- optimized partnerships
- sustained facilities and infrastructure
- workforce excellence
- scientific integrity
- accountability

These principles, grounded in communication within the agency and between our partners, work together to establish and maintain NOAA's high-quality research, development, services, and products.

NOAA maintains both intramural and extramural research investments, with some programs investing the majority of their R&D funding internally (intramural), at labs and science centers with federal employees, and other programs investing the majority of their funding with external (extramural) R&D partners at universities, industry, and other research institutions. In many cases, programs distribute their R&D investments across both intramural and extramural efforts. NOAA partnerships, vital to the agency's R&D efforts, enable NOAA to leverage the expertise, equipment, and facilities of leading universities, federal agencies, private companies, NGOs, and other science innovators. Key mechanisms for partnerships include Cooperative Institute and Cooperative Science Center agreements with universities; the network of university-based Sea Grant programs; extramural grant programs; contracts; and Cooperative Research and Development Agreements with the private sector.

SCIENTIFIC INTEGRITY

NOAA's priority for scientific integrity aims to foster a culture of scientific excellence and confidence in the quality, validity, and reliability of NOAA science. Scientific integrity ensures science products and services are free from bias, fabrication, falsification, plagiarism, political interference, censorship, and inadequate procedural and information security.

NOAA's Scientific Integrity Policy (NAO 202-735D-2 [NOAA, 2021]), along with its accompany-ing Procedural Handbook, establishes a Code of Scientific Conduct and a Code of Ethics for Science Supervision and Management, setting the respon-sibilities for scientists, their managers, and those who use scientific results to set policy. The Scientific Integrity Office processes allegations of scientific misconduct with respect to these codes. NOAA pro-duces an annual scientific and research misconduct report that summarizes allegations that are being investigated and those that have been closed.

NOAA employees have access to a Scientific Integrity training module. Additionally, the NOAA Scientific Integrity Officer and Line Office Scientific Integrity Officers are available to NOAA staff for training, with the NOAA Scientific Integrity Commons website containing a list of relevant resources and documents. Through NOAA's comprehensive scientific integrity policy, training oppor-tunities, and culture of excellence, NOAA scien-tists continue to conduct exemplary research and development.

DIVERSITY AND INCLUSION: WHAT IS NOAA'S VISION AND PLAN FOR DIVERSITY AND INCLUSION ACROSS ITS WORKFORCE? HOW WILL IT ACHIEVE THIS VISION?

NOAA's vision for Diversity and Inclusion (D&I) is *an inclusive environment in which NOAA leverages diversity to achieve mission goals and business objectives and maximizes the potential of individuals and the organization*. NOAA's Diversity and Inclusion Strategic Plan (2020 - 2024) describes how NOAA envisions, defines, assesses, values, and commits to D&I. The plan outlines three goals: 1) workforce diversity, 2) workplace inclusion, and 3) sustainability. For each of these overarching goals, objectives, actions, and metrics are identified, as well as the responsible bodies for ensuring these goals and objectives are met.

> NOAA is fully committed to advancing diversity and inclusion at all levels to achieve our mission goals and business objectives, and maximize the potential of our workforce and the organization as a whole. In making this commitment, NOAA recognizes that all employees, contractors, supervisors, and leaders at all levels play a critical role in realizing this vision. All team members support a diverse workforce and an inclusive environment by demonstrating respect and integrity with and for each other in every aspect of daily work. (from the FY2020-2024 D&I Strategic Plan).

DIVERSITY AND INCLUSION: WHAT ARE NOAA'S DIVERSITY STATISTICS? HOW IS NOAA WORKING TOWARDS BETTER DIVERSITY AND INCLUSION ACROSS ITS WORKFORCE?

In 2019, the representation of Hispanics, White Females, African Americans, American Indian or Alaska Natives and two or more races in NOAA's workforce was below their representation in the civilian labor force for the last five fiscal years (data from the Office of Inclusion and Civil Rights Management Directive 715). In 2020, NOAA made a number of important improvements to create a more diverse and inclusive work environment. For example, ten new Employee Resource Groups representing minorities, women, and people with disabilities were developed.

In 2020, NOAA was recognized in the top 20 government or nonprofit supporters of Historically Black Colleges and Universities for the third year in a row. NOAA was also recognized in the top 50 STEM supporters for the American Indian Science and Engineering Society.

NOAA worked to identify important next steps to promote diversity and inclusion in 2020 and beyond, including marketing the Leadership Competencies Development Program to encourage Hispanics to apply and striving to increase representation of women in senior leadership positions. NOAA is also planning regular assessments of Line and Staff Offices for possible deficiencies and to develop strategies to remove identified barriers.

Dr. Catalina Martinez (NOAA Research) and the NOAA Office of Inclusion and Civil Rights hosted a virtual screening of *Can We Talk? Difficult Conversations with Underrepresented People of Color: Sense of Belonging and Obstacles to STEM Fields,* a documentary film by Dr. Kendall Moore, an award-winning documentary filmmaker and Professor at the University of Rhode Island. 117 Individuals viewed the film through this virtual screening. Dr. Moore moderated a virtual panel discussion in April with 161 attendees. Panelists included Dr. Martinez; RDML Timothy Gallaudet, Deputy NOAA Administrator; Dr. Brandon Jones, National Science Foundation; Dr. Vernon Morris, former Director of Howard University's NCAR Center; Dr. Wendy Smythe, University of Minnesota Duluth; and Dr. Aradhna Tripati, UCLA Center for Diverse Leadership in Science. Later in the year, a second panel discussion was held with NOAA senior leadership. The panelists for this second event included Dr. Catalina Martinez, Dr. Jamese Sims, Dr. Hernan Garcia, and Makeda Okolo.

Screenshot from Dr. Kendall Moore's panel discussion *"Can We Talk? Difficult Conversations with Underrepresented People of Color: Sense of Belonging and Obstacles to STEM Fields"* The virtual panel discussion featured speakers representing NOAA leadership and leaders in the field of diversity and inclusion. (April 2020)

DIVERSITY AND INCLUSION: WHAT IS THE NEW NOAA D&I ACTION PLAN AND D&I NOAA EXECUTIVE PANEL WORKGROUP?

In 2020, NOAA leadership created the NOAA Diversity, Inclusion, and Racial Equality Suggestion Box, which allowed for NOAA employees and team members to anonymously provide suggestions to improve in these areas. In response, NOAA then developed a D&I NOAA Executive Panel Workgroup who developed the NOAA-wide D&I Action Plan, which describes actions NOAA may implement immediately, such as: hiring an independent contractor to conduct a NOAA-wide assessment and review of current policies/procedures; ensuring that hiring panels within NOAA are diverse in race, gender, and age; increasing leadership's engagement with the newly established Employee Resource Groups; and, developing new ways to increase the number of new hires from the Educational Partnership Program (EPP).

NOAA DIVERSITY AND INCLUSION SUMMIT

NOAA hosted its 4th Annual Diversity and Inclusion Summit on September 1, 2020. The theme for this year's summit was "Our Differences are Our Strengths." The annual summit is designed to provide members of the workforce an opportunity to embrace the value proposition of advancing diversity

and creating an inclusive culture at NOAA. With the assistance of leading experts, from both government and the corporate world, the summit provided attendees with valuable insight and best practices as the agency continues the journey of advancing diversity and inclusion. Attendees were provided a unique platform to discuss, learn, and expand their knowledge of diversity and inclusion and explore ways these initiatives can be used to benefit not only NOAA as a whole, but within their individual work spaces. Michael Bush (Great Places to Work) provided the keynote.

DIVERSITY AND INCLUSION: HOW DOES NOAA INVEST IN THE DEVELOPMENT OF THE NEXT GENERATION OF SCIENTISTS TO HELP PROMOTE D&I?

The NOAA Office of Education supports education from pre-kindergarten through doctoral level students and collaborates in NOAA-mission fields with universities to prepare exceptional talent, including from diverse backgrounds, playing an important role in contributing to NOAA's Diversity and Inclusion goals.

The Educational Partnership Program with Minority-Serving Institutions (EPP/MSI) supports the education, professional development, and graduation of students at NOAA-supported minority serving institutions who are from traditionally underrepresented minority communities. EPP/MSI develops eligible candidates in support of a diverse future NOAA-mission workforce and focuses on post-secondary education and research capacity development in STEM, social science, and policy fields at MSIs that are aligned with NOAA mission fields. Since 2001, EPP/MSI funding has supported 2,405 degrees: 1,459 Bachelors, 594 Masters, and 318 PhDs, and 34 other (i.e., Associates and Professional degrees). More than 300 EPP/MSI alumni have entered federal service as employees or contractors. Of those, 56 are currently full time employees in the NOAA workforce. EPP/MSI supports four Cooperative Science Center (CSC) awards aligned to core NOAA mission areas. Established through national competition, the CSCs collaborate in the training of post-secondary students in fields that directly support NOAA's mission. Students are required to participate in meaningful science, technology, engineering, mathematics, policy, natural resource management, and social science research at NOAA facilities under the guidance of their academic advisor and NOAA mentor. While each CSC is aligned with a primary line office, the centers partner and collaborate across NOAA in education, training, and research towards the development of candidates for the future NOAA workforce. From 2005-2018, EPP/MSI CSCs graduated more than 50 percent of African-Americans receiving PhDs in atmospheric sciences and meteorology and environmental sciences and nearly 40 percent of African-Americans receiving PhDs in marine sciences.

> "NOAA's leadership and I remain committed to continuing our efforts in the development of a multicultural workforce that is both diverse and inclusive and an environment that creates a sense of belonging. We understand that diversity adds to our ability to be innovative, creative, and betters our ability to serve the public."
> **Kenneth M. Bailey, Director of the NOAA Office of Inclusion and Civil Rights.**

ALL SIX NOAA LINE OFFICES PROVIDE UNIQUE CONTRIBUTIONS TO NOAA R&D

The **National Ocean Service (NOS)** is the nation's premier science agency for oceans and coasts. NOS delivers the applied science, modeling, tools, and services needed to understand, predict, and respond to the challenges we face along America's 95,000 miles of shoreline and 3.5 million square nautical miles of coastal, Great Lakes, and deep-ocean waters. Additionally, NOS oversees the definition, maintenance, and access to the National Spatial Reference System for all federal geospatial activities. This enables NOS to better manage the sea/shore boundary for coastal resilience and planning.

The **National Marine Fisheries Service (NMFS)**, also known as NOAA Fisheries, is responsible for the stewardship of the nation's living marine resources and their habitats. NOAA Fisheries provides vital services for the nation to support productive and sustainable fisheries, safe sources of seafood, the recovery and conservation of protected resources, and healthy ecosystems—all backed by sound science and an ecosystem-based approach to management. Using the Magnuson-Stevens Act as the guide, NOAA Fisheries works in partnership with Regional Fishery Management Councils to assess and predict the status of fish stocks, set catch limits, ensure compliance with fisheries regulations, and reduce bycatch.

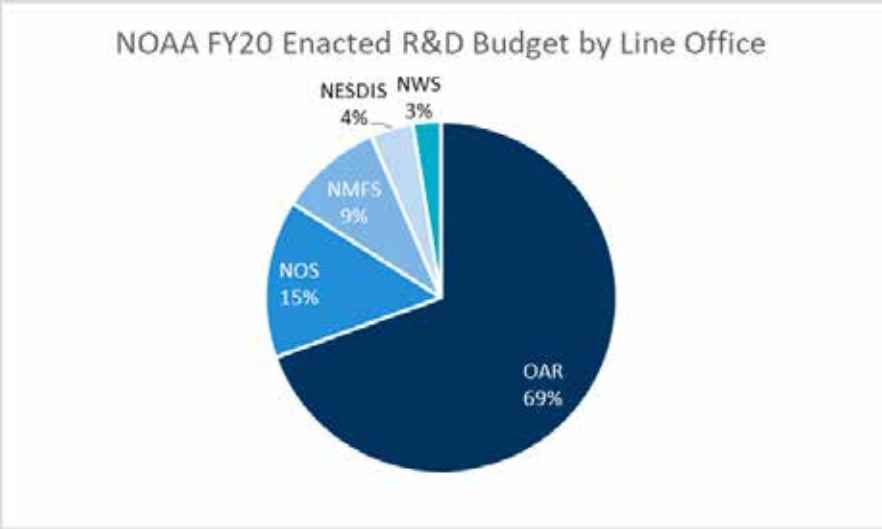
The **National Environmental Satellite, Data, and Information Service (NESDIS)** provides timely access to global environmental data from satellites and other sources to promote, protect, and enhance the Nation's economy, security, environment, and quality of life. NESDIS supports science through the Center for Satellite Applications and Research (STAR) and National Centers for Environmental Information (NCEI). Through these programs, NESDIS researches, formulates, develops, maintains, and sustains environmental measurements from satellites, as well as associated applications of satellite environmental observations, and maintains the quality of NOAA's operational satellite measurements, directly enabling and supporting NOAA's environmental analysis and prediction capabilities. NESDIS hosts and provides public access to one of Earth's most comprehensive archives for atmospheric, oceanic, and geophysical data, with research and development focusing on preserving, stewarding, and providing the best possible long-term environmental data records; thereby, maximizing the data's utility and enabling the Nation's environmental science efforts.

The **Office of Marine and Aviation Operations (OMAO)** operates a wide variety of specialized aircraft and ships to complete NOAA's environmental and scientific missions. OMAO is also responsible for the administration and implementation of the Aviation Safety Program, Small Boat Program and NOAA Diving Program to ensure safe and efficient operations in NOAA-sponsored aviation, small boat and underwater activities.

Oceanic and Atmospheric Research (OAR), also known as NOAA Research, provides the research foundation for understanding the complex earth systems that support our planet. NOAA Research's role is to provide unbiased science to better manage the environment nationally and globally. The science and technology that NOAA Research produces and transfers to partners (in NOAA's service lines and beyond) is instrumental to preventing the loss of human life, managing natural resources, and maintaining a strong economy. NOAA Research has partnerships and platforms around the world and offices located across the country, including ten laboratories and six program offices that support research and provide information used from the international to the local level.

The **National Weather Service (NWS)** provides weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy. NWS data and products form a national information database and infrastructure which can be used by other governmental agencies, the private sector, the public, and the global community. NWS sustains and improves its observing system infrastructure with new technologies while leveraging more observations through innovative public and private partnerships; additionally, next generation weather and Earth system models are developed using a community-based approach, along with advances in high-performance computing. NWS also improves its tools, systems, and policies for virtualization, analytics, data management, and dissemination to maximize the societal benefits of state-of-the art science, data sources, and technologies. Collaboration with partners across NOAA, other federal agencies, and the weather enterprise are critical to enable effective research to operations and operations to research activities for impact-based decision support services.

WHAT IS THE BUDGET FOR NOAA RESEARCH?

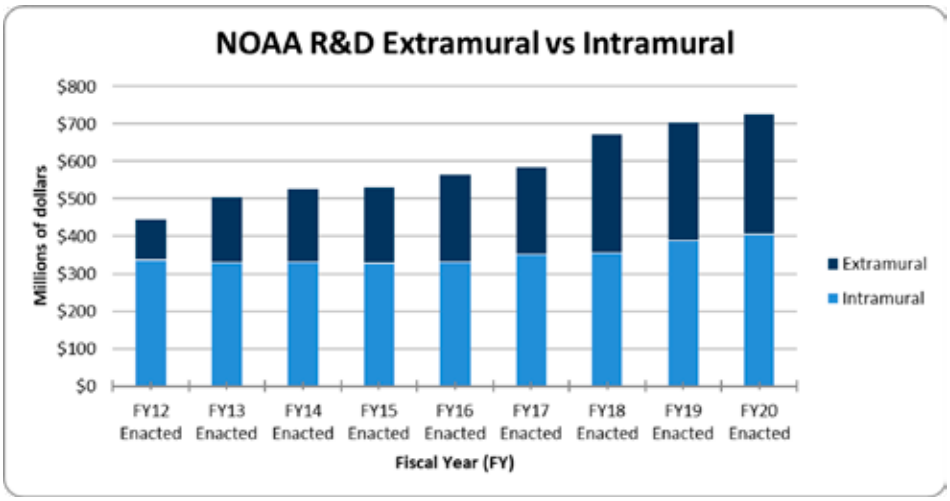


NOAA dedicated $725 million, approximately 14 percent of the agency's total budget, to R&D in fiscal year 2020 (FY20), with R&D defined as all research and development activities excluding R&D-related facilities and equipment purchases. This continues an eight-year trend of increased R&D expenditures, highlighting NOAA's efforts to address increased stakeholder needs for environmental intelligence and services in the face of a changing planet.

Note: OMAO tracks management and operation of aircraft and vessels in support of Line Office R&D as Equipment; therefore, it is not included here. NOAA satellite development to support operations and research is also not included.

WHERE DOES IT GO?

Approximately 55 percent of NOAA's FY20 R&D budget went to internal R&D efforts, with the remaining 45 percent set aside for extramural research, enabling partnerships and collaborations with non-NOAA entities. Note: All graphs exclude facilities and equipment from R&D budget calculations.



SCIENTIFIC INFRASTRUCTURE

The science described in this report is not possible without investments in enabling research infrastructure, including the acquisition and maintenance of "hard" infrastructure, such as extensive observing systems, satellites, ships, aircraft, laboratories, and high-performance computing systems. These critical assets provide the data and tools for NOAA scientists to increase the understanding of our Earth systems, provide better forecasts, and inform decisions.

NOAA TRANSITIONS RESEARCH INTO OPERATIONS, APPLICATIONS, COMMERCIALIZATION, AND OTHER USES (R2X)

NOAA and the Nation extract benefits from NOAA's research when the research results transition into use; consequently, research and development transitions are essential to addressing NOAA's missions. NOAA uses a system of nine readiness levels (NAO 216-105B) to characterize and track the maturity of NOAA scientific projects through research, development, demonstration, and deployment.

Transition plans describe and facilitate the transition of R&D to potential end use, and help ensure agreement between researchers and planned transition adopter with regard to content, format, schedule, and resources. Additionally, NOAA's 12 testbeds and proving grounds enable pre-deployment testing of NOAA's research and development, facilitating the transition into forecasts, warnings, products, services, and decision support.

NOAA's testbeds and proving grounds are:

1. Arctic Testbed
2. Aviation Weather Testbed
3. Climate Testbed
4. Coastal and Ocean Modeling Testbed
5. Developmental Testbed
6. Satellite Proving Ground
7. Hazardous Weather Testbed
8. Hydrometeorology Testbed
9. Joint Center for Satellite Data Assimilation
10. Joint Hurricane Testbed
11. Operations Proving Ground
12. Space Weather Prediction Testbed

EXAMPLES OF RESEARCH TRANSITION

NOAA TRANSITION TO OPERATIONS PROVIDES COST SAVINGS AND IMPROVES SPACE WEATHER PREDICTION

NOAA transitioned the first major element of the Satellite Product Analysis and Distribution Enterprise System (SPADES) application to operations, which processes and provides Geostationary Operational Environmental Satellite-16 (GOES-16) space weather products for NOAA operations and the United States Air Force. This transition established the first hardened operational instance of the SPADES software application, which processes GOES-16 space weather data, and includes information on impactful phenomena such as solar storms. Space weather forecasting is critical for commercial aviation and other sectors. SPADES feeds mission-critical products to NOAA NWS on a very-near-real-time basis.

UNCREWED SYSTEM REDUCES COST AND RISK FOR MARINE MAMMAL MONITORING

NOAA, with collaborators (Mystic Aquarium, GeoThinkTank, and Aerial Imaging Solutions), developed an uncrewed aerial system- (UAS) based approach that was tested for surveying northern fur seal pup production on the Pribilof Islands, Alaska. The traditional method of manual surveys by crews of people is costly, labor intensive, poses potential risk to personnel (inherent when working with wild animals), and causes disturbance to northern fur seals. This UAS method could virtually eliminate risk to personnel and disturbance to animals, as well as reduce survey costs by up to 75 percent. NOAA worked with industry to develop an observation system for surveying northern fur seals with the APH-28 hexacopter system integrated with a thermal and visual sensor. While this system has some limitations for counting northern fur seals, the system is now operational and online should others want to pursue it for their applications. In addition, NOAA has transitioned the APH-28 (with standard visual sensor) for annual surveys of endangered Steller sea lions. Future enhancements to this system are ongoing via NOAA Research funding to include new sensors, machine learning, and artificial intelligence to develop an approach to automate image processing and analysis to produce counts.

ESTIMATING THE ECONOMIC BENEFITS OF HURRICANE FORECAST IMPROVEMENTS

The Weather Research and Forecasting Innovation Act of 2017 requires NOAA to prioritize research that improves forecasts and warnings for the protection of life, property, and the enhancement of the national economy. NOAA-funded researchers - focusing on areas recently hit by hurricanes Florence and Michael - merged atmospheric modeling and econometrics to determine the public willingness to pay for more accurate hurricane forecasts and establish the value of improvements in storm track, wind speed, and precipitation forecast precision. Preliminary results based on this sample suggest that the public values these dimensions of forecast improvement at an estimated total of $260 million per year across regions that are vulnerable to hurricanes.

NOAA EXPANDS THE EXTRATROPICAL SURGE AND TIDE OPERATIONAL FORECAST SYSTEMS

NOAA NOS transitioned a global version of the Extratropical Surge and Tide Operational Forecast System (ESTOFS) into operations in November 2020. Global ESTOFS replaced the existing regional ESTOFS-Atlantic, ESTOFS-Pacific, and ESTOFS-Micronesia systems and add enhancements to ESTOFS capabilities. Benefits include extending the system to cover all OCONUS (outside contiguous United States) territories, providing boundary and initial conditions for nearshore wave models, and improving spatial resolution for the U.S. coastal regions. Global ESTOFS will improve NOAA

capabilities in coastal inundation prediction and open the doors for new applications, including precision navigation, risk assessment analysis, and on-demand coastal inundation prediction systems on a global scale.

INFORMATION TRANSFER ABOUT SHELLFISH HATCHERY OPERATIONS: AN EXTENSION PROJECT TARGETING SMALL FAMILY-BASED HATCHERY FARMS IN FLORIDA

NOAA funded a Florida Sea Grant research and extension program that addressed challenges facing a growing aquaculture industry in southwest Florida. Research supported efforts to diversify species that are better suited to warming temperatures, understand removal rates of red tide toxins in clams, and identified a better method for clam seed production. In addition, the effort transferred knowledge about the shellfish hatchery operation and management to local shellfish hatchery farmers for better practice to increase seed production. The researchers held two workshops attended by 56 shellfish growers to share knowledge in order to instill best practices leading to increased seed production, which helped boost the profitability of their clam-growing operations. Information about shellfish triploid-tetraploid technology was also transferred during the workshops and site visits, and an online product detailing "shellfish reproduction and broodstock management" was developed for free and long-term access. Research and outreach efforts helped update national regulations related to closing shell-fishing areas due to red tide events. Regulations are now based more on precise, targeted meat-sample analyses rather than a water sample.

EXAMPLES OF COVID-19 PANDEMIC R&D

NOAA researchers continued to produce products and services for the nation while taking appropriate precautions during the novel coronavirus (COVID-19) pandemic. In the face of challenges such as mass telework and fewer ship days at sea, NOAA took advantage of novel research opportunities. NOAA research aided a broad community of stakeholders through epidemiology and social and behavioral science studies and captured changes to environmental conditions due to reduced economic activity.

NOAA studies conducted in 2020 in response to the coronavirus pandemic included:

NOAA data supports epidemiological studies of COVID-19: NOAA NESDIS is working with scientists from the National Biodefense Analysis and Countermeasures Center (NBACC) to meet their environmental data needs for modeling the transmission of COVID-19. NBACC has requested retrospective data on ultraviolet radiation and relative humidity, along with temperature data, and NOAA is working to provide the data at appropriate temporal and spatial resolutions to meet that need. NBACC is using the information specifically to design in-laboratory tests that vary environmental parameters and determine the effect on the coronavirus' ability to replicate and spread.

Enhanced sampling of atmospheric composition changes during COVID-19: Frequency of Ozonesonde launches was increased in Boulder, CO, and Trinidad Head, CA, in spring 2020 to capture changes in vertical distribution of ozone, temperatures, and relative humidity due to COVID19-related changes in the production of pollution events in Asia. These additional high resolution measurements of the atmosphere will help to improve evaluation of the baseline levels of ozone in the air masses entering the western U.S. coast and transported inland. With this information, U.S. air quality models will be able to improve the evaluation of the U.S.-originated sources of pollution in the western U.S.

Image of NOAA Chemical Sciences Laboratory (CSL) instruments measuring during COVID-19 "safer-at-home" orders. Credit: Dr. Jessica Gilman, NOAA CSL (November 2020)

NOAA exploring impact of COVID-19 response on emissions: In Boulder, CO, scientists are observing changes in the amount, composition and timing of emissions as the result of changes in human activities during COVID-19. Reduced local traffic resulted in fewer vehicle emissions that occurred during a later "rush hour" while consumer product usage (paints, solvents, coating) was largely unchanged. NOAA manages state-of-the-art instruments that measure dozens of different gases in real-time, around the clock. These measurements will be important in understanding how the chemical composition of the air has changed from reduced human activities and the related impacts on local air quality.

COVID-19 Climate.gov webpage: What environmental data are relevant to the study of infectious diseases like COVID-19? The COVID-19 Climate.gov webpage has been developed to facilitate access to environmental data commonly used in infectious disease modeling. The COVID-19 pandemic has triggered an increase in infectious disease modeling studies, some of which incorporate environmental parameters. These studies are driven by questions about the potential seasonality of disease transmission, potential comorbidities associated with other environmentally-linked respiratory diseases, and a desire to improve predictions to inform future national and local policies to control transmission. The webpage includes a comprehensive table of information designed to help users quickly locate environmental datasets for a given variable and timescale.

NOAA data analyses and modeling aim to understand COVID-19 impact on air quality: NOAA Research scientists in College Park, MD, are using surface and satellite observations to update current emission inventories to better represent the impacts that the economic slowdown resulting from COVID-19

has had on the amount of ground level ozone pollution (or "smog") in the U.S. Ground-level ozone is formed by chemical reactions of volatile organic compounds and nitrogen oxides in the presence of sunlight. Using the updated emission inventories to drive the NWS National Air Quality Forecasting Capability (NAQFC), significant changes in ozone concentrations across the U.S. were found during the period from March to July 2020. Future work includes the study of COVID-19 impacts on atmospheric composition and deposition in the urban coastline of the Long Island Sound, as well as the impacts of COVID-19 related ozone changes on crop yields across the U.S. Results of this work have implications for the effect of emissions controls used to curb ground level ozone pollution across the U.S. and can also be used to improve NOAA's operational forecast models for air quality and sub-seasonal to seasonal weather.

Improving weather and climate modeling by studying the impact of the COVID-19 related decline in emissions of air pollutants: The lockdown measures instituted to control the spread of COVID-19 caused unprecedented disruptions to many economic sectors, among which manufacturing and transportation were particularly hard hit, and led to a significant decline in emissions of air pollutants. Using NASA satellite observations and NOAA Research climate model simulations, NOAA and partners were able to attribute about one-third of the observed large, precipitous decreases in solar clear-sky reflection (7 percent) and aerosol optical depth (32 percent) over the East Asian Marginal Seas in March 2020 to pandemic-related emission reductions, and the rest to weather variability and long-term emission trends. This work validates the representation of aerosols, clouds, radiation, and other fast atmospheric physical processes in global weather and climate models, which constitute one of the biggest sources of model biases. This will help enhance NOAA's modeling capability, advance the scientific understanding of the Earth System, improve predictions, and provide useful information for planning and decision-making.

Rapid response to incorporate new data into operational data assimilation system: Weather model outputs depend heavily on input observations. Computer models for weather prediction, including NOAA's Global Forecast System (GFS), are constrained with observed data from satellites and other weather instruments to provide more accurate weather forecasts. The number of aircraft flights, and weather observations from aircrafts, declined during the COVID-19 pandemic, meaning that the critical observational inputs for NOAA weather models were not available. In April 2020, NOAA NWS responded by including additional aircraft datasets that were not yet being used operationally to constrain GFS. Additionally, in collaboration with the Joint Center for Satellite Data Assimilation, NOAA began using Global Positioning System (GPS) radio occultation observations from the COSMIC-2 network of microsatellites to constrain GFS beginning in May 2020. NOAA NWS's rapid response to add constraints from new data strengthened operational GFS weather predictions during the unprecedented COVID-19 pandemic.

NOAA satellite data confirm COVID-19 impact on improved air quality in the U.S.: Signals in satellite data due to human mobility and economic activity changes associated with COVID-19 lockdown measures are being analyzed by scientists at NOAA NESDIS. NOAA scientists are using observations of nitrogen oxide (NOx) emissions changes from the ground and correlating those changes to satellite observations of aerosols and aerosol precursors such as nitrogen dioxide to benchmark the changes. Key findings are that power plants are no longer a major source for NOx emissions; instead cars and trucks are the major source for NOx emissions. Trends in mobility and unemployment since the onset of the complete or partial lockdown are the drivers for improved air quality.

NOAA Investigates Ocean Noise During COVID-19: NOAA has launched a wide-ranging research effort to investigate the impact of reduced vehicle traffic, air travel, shipping, manufacturing and other activities on Earth's atmosphere and oceans. NOAA and the National Park Service are collaborating to analyze data from hydrophones deployed around the United States coastal waters to measure changes and assess any impacts on fisheries and marine mammal activity due to reduced maritime transportation and other maritime activities.

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Southern Manhattan, Brooklyn Bridge taken during a flight over the East River on April 28, 2020. Credit: NOAA

Sandy Lucas discussing science goals of ATOMIC with (from the left): Dr. Bjorn Stevens, Max Planck Institute for Meteorology, RDML Tim Gallaudet, Assistant Secretary of Commerce for Oceans and Atmosphere, and David Farrell, Director, Caribbean Institute of Hydrology and Meteorology. (January 2020)

SCIENCE HIGHLIGHTS

The Jet High Performance Computing System is located at the David Skaggs Research Center (DSRC) in Boulder, Colorado. The Jet system totals 55,984 cores of 64-bit Intel CPU's, with a total capability of 1,795 trillion floating point operations per second – or 1.79 petaflops with a total scratch disk capacity of 6.6 Petabytes. (November 2020)

1. REDUCING SOCIETAL IMPACTS FROM HAZARDOUS WEATHER AND OTHER ENVIRONMENTAL PHENOMENA

NOAA research and development improves the forecasts and warnings that provide accurate and timely information to inform the public about hazardous weather and environmental events. Through a better understanding of weather and climate phenomena, as well as the human perception and behavior in response to risk communication, NOAA science helps to save lives and property.

In 2020, NOAA's scientific accomplishments for reducing societal impacts from hazardous weather and other environmental phenomena included the following:

- Unified Forecast System Innovations
- Public Release Of The Unified Forecast System Medium Range Weather Application To The Community
- National Water Model Version 2.0 Is Expanded To Improve NOAA's Ability To Provide Hydrologic Guidance To Underserved Locations
- Communicating Important Information About Hazardous Weather Events
- NOAA Conducts Atomic Field Campaign To Improve Weather And Climate Prediction
- Innovations With The Geostationary Lightning Mapper
- Improving Forecasts With Advances In Regional Models
- Calculating Carbon Dioxide (Co_2) Emissions From Fossil Fuels In The United States
- A New Public Release Of The State-Of-The-Art Wavewatch III Wave Model
- Optimize Use Of S2S Predictability Sources To Maximize Forecasts Of Opportunity
- Proving Ground And Operational Transitions To Improve Tropical Cyclone Forecasts
- Forecasting Hazardous Algal Blooms: Modeling And Molecular Tools

UNIFIED FORECAST SYSTEM INNOVATIONS

NOAA's Unified Forecast System (UFS) is a community-based modeling system being developed to provide a common framework for all NOAA NWS operational forecasting systems. One of the modeling applications within this framework is the coupled Subseasonal-to-Seasonal (UFS-S2S) forecasting system, aimed at delivering accurate predictions for weeks to months in the future. Predictability on weather time scales of several days in the future is largely driven by the atmospheric initial conditions. For longer timescales (from weeks to months), accurate simulations of the land surface, sea ice, and ocean states play increasingly important roles. The UFS-S2S combines these elements in a four-way coupled system, consisting of state-of-the-art community-developed atmospheric, land, oceanic, sea-ice, and ocean wave component models. Preliminary results show a substantial improvement in the prediction of tropical convection and sub-seasonal forecast outlooks for surface temperature over the continental United States. The target for these developments are future operational implementations of Global Forecast System (GFS) and Global Ensemble Forecast System (GEFS) in 2024.

Ensemble predictions inform forecasters of the range of possible weather scenarios and are increasingly being used for providing situational awareness of high-impact weather forecast events. Version 12 of the Global Ensemble Forecast System (GEFSv12), implemented into operations by NOAA NWS in 2020, brings significant improvements in the probabilistic forecast guidance for medium range and sub-seasonal weather forecasts. GEFSv12 is the first UFS coupled system to be implemented into operations for the sub-seasonal scale predictions, and utilizes the component models (atmosphere, waves, and aerosols) and common software infrastructure within the UFS framework. The update included an upgrade to the Finite-Volume Cubed-Sphere (FV3) dynamical core. In addition, for the first time, GEFSv12 extends the forecast length to weeks three and four (35 days). With higher resolution (~25 km) and increased number of ensemble members (31), GEFSv12 demonstrated much improved severe weather forecasts including hurricane track and intensity, precipitation, wave heights, and aerosols for all global regions.

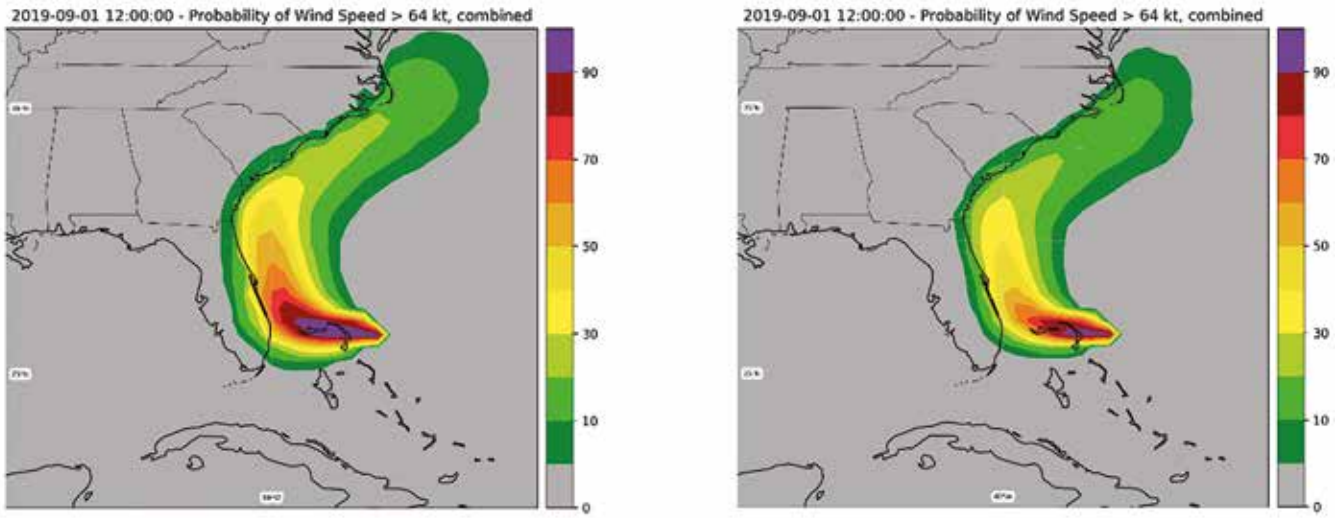
PUBLIC RELEASE OF THE UNIFIED FORECAST SYSTEM MEDIUM RANGE WEATHER APPLICATION TO THE COMMUNITY

NOAA is transitioning to the community based Unified Forecast System (UFS) as a source from which NOAA selects its operational prediction codes. NOAA began sharing the UFS with the community through public releases of the UFS. The medium range weather application (for prediction of weather for several days in the future) was the first major release of the UFS in March 2020. The aim was to provide a well documented and tested modeling system and infrastructure that could be set up on different computing platforms for the research community to use. A considerable amount of effort was placed in making the system easily portable to different computers. This initial release included the UFS in a global atmospheric configuration, the system of libraries and tools needed to run the model and visualize the results, and a workflow to allow the user to easily carry out simulations. Subsequent releases will introduce the community to more features of the UFS as they reach maturity.

NATIONAL WATER MODEL VERSION 2.0 IS EXPANDED TO IMPROVE NOAA'S ABILITY TO PROVIDE HYDROLOGIC GUIDANCE TO UNDERSERVED LOCATIONS

The growing risks from flooding and severe weather across the country drive the increasing demand to bring state-of-the-science water prediction to operations. In 2016, NOAA launched the National Water Model (NWM) to provide the Nation with more detailed, frequent, and expanded water information. Developed by NOAA scientists, in partnership with the National Center for Atmospheric Research, the NWM is a continental scale water prediction model that uses NOAA operational meteorological models as atmospheric inputs and observation data from more than 8,000 U.S. Geological Survey gauges to simulate conditions for nearly 3.5 million miles of rivers and streams in the contiguous United States. NWM version 2.0 was deployed in 2019 and expands the model's domain for hydrologic guidance to include the Hawaiian Islands, providing the first-ever operational water resource forecasts for the state of Hawai'i. This most recent upgrade to the model marks a notable extension of NOAA's water prediction capabilities to address water-related risks and facilitates more efficient and effective management of water resources.

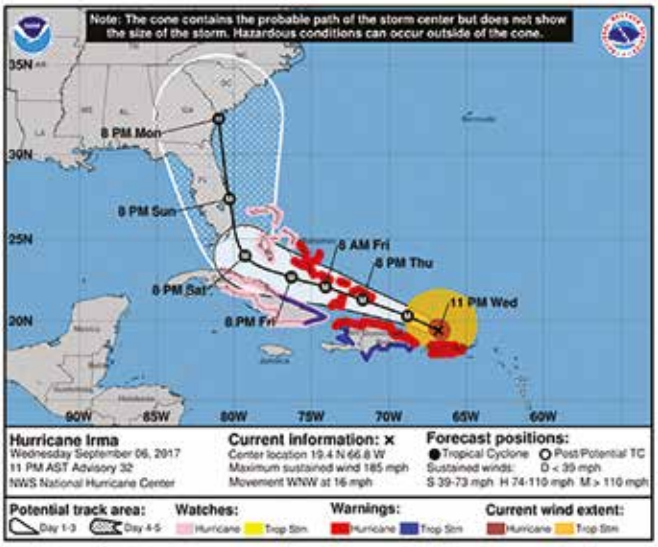
COMMUNICATING IMPORTANT INFORMATION ABOUT HAZARDOUS WEATHER EVENTS



The probability of hurricane force winds within 5 days after 01 Sept 2019 at 12 UTC from the 2019 operational wind speed probability model (left) and the 2020 updated model (right). Hurricane Dorian was a fairly small hurricane as it moved northward offshore from the Florida east coast, and hurricane force winds were never observed in Florida. Note how the updated model reduced the maximum probability of hurricane winds in Florida from more than 60% in the 2019 model to only about 30% in the 2020 model. The updated 2020 model would have much more accurately represented the wind threat from Hurricane Dorian in Florida and will be used for public-facing products if the 2020 internal evaluation is successful.

Protection of life and property from hazardous weather events is a core mission element for NOAA NWS. But what is the best way to deliver this information? NWS has harnessed the power of social science research to address this question, featuring extensive engagement with both NWS partners

A conceptual look at a proposal for simplifying the NWS Watch, Warning, and Advisory system. Image Credit: NOAA NWS Hazard Simplification Team.



The 5-day cone of uncertainty with black line toggled on. Credit: NOAA

and the public via surveys, focus groups, multi-day workshops, and a Hazardous Weather Testbed exercise. This research showed that users believe there are currently too many Watch, Warning, and Advisory (WWA) products, product formats are inconsistent, and the WWA terms themselves are confused (with "Advisories" the least understood term). Based on feedback from partners and the public, NWS has decided to simplify and optimize the NWS suite of alert products by replacing "Advisory" headlines with plain language headlines. This change will take place no sooner than 2024. The exact wording of the plain language headlines is yet to be determined but, as an example, the headline "The NWS has issued a Wind Advisory" could be replaced with "The NWS expects gusty winds." This change will improve the ability of partners and the public to take appropriate safety and preparedness actions, simplify NWS public education efforts, and better support NOAA's goal of building a Weather-Ready Nation that is more resilient to weather, water, and climate events.

NOAA NWS has a long history of providing probabilistic uncertainty estimates with its official hurricane forecasts. A major improvement in NWS's wind speed probability model was transitioned to operations for internal evaluation during the 2020 hurricane season, which leveraged research performed in the Joint Hurricane Testbed. The new version uses storm size information from the NWS official forecast to provide stakeholders with more accurate probabilities of hurricane force winds and related time of arrival of gale force wind information. The figure below shows an example of how the new version of the model would have improved the hurricane force (64 kt) wind probability estimates for Hurricane Dorian in 2019.

NOAA NWS's tropical cyclone forecast track graphic, commonly referred to as the Cone of Uncertainty (Cone Graphic), may be both the most viewed and the most misinterpreted product within the tropical cyclone product suite. Designed to convey the forecast uncertainty of the center of a tropical cyclone's track, the cone graphic's visual features have come under scrutiny with a number of studies and reports pointing to misunderstanding.

It is vital that partners understand the uncertainty in the forecast before they use the Cone Graphic

to make key decisions on distributing resources or ordering evacuations. The cone of uncertainty can also give people notice outside of the storm's center that they may need to prepare for tropical cyclone hazards, such as wind, storm surge, heavy rainfall, and tornadoes, but the cone graphic does not convey the specifics of each hazard associated with the tropical cyclone.

NOAA is working with social scientists to conduct a use study of the Cone Graphic. The use study includes 1) a qualitative literature review on interpretations and uses of the cone graphic by members of the public and emergency managers, along with its implications for decision-making; 2) in-depth interviews with international meteorologists to understand how integral the Cone Graphic is to their decision-making and whether the graphic serves their operational and stakeholder communication needs; and 3) a survey to gather feedback from a wider, less-studied user base - the energy and utility, tourism and recreation, transportation, and marine sectors. Results from this study may inform changes made to the Cone of Uncertainty to best suit the needs of NWS partners and stakeholders.

NOAA CONDUCTS ATOMIC FIELD CAMPAIGN TO IMPROVE WEATHER AND CLIMATE PREDICTION

Although known to influence temperature and weather conditions across the world, the interaction between the ocean and shallow convective clouds is poorly understood and not well represented in weather and climate models. To better understand these complex interactions and better represent these critical processes in forecast models, NOAA and its partners conducted a large, collaborative science field campaign called ATOMIC (Atlantic Tradewind Ocean-Atmosphere Mesoscale Interaction Campaign) in Barbados from January 6 to February 15, 2020. Funded by NOAA Research, ATOMIC is the U.S. component of a collaborative effort among the United States, Germany, France, United Kingdom, and Barbados called EUREC^{4}A (Elucidating the Role of Clouds-Circulation

Sandy Lucas discussing science goals of ATOMIC with (from the left): Dr. Bjorn Stevens, Max Planck Institute for Meteorology, RDML Tim Gallaudet, Assistant Secretary of Commerce for Oceans and Atmosphere, and Dr. David Farrell, Director, Caribbean Institute of Hydrology and Meteorology. (January 2020)

Scientists lower Conductivity, Temperature, Depth Rosette into the Atlantic Ocean off Barbados. Credit: Richard Marchbanks/CIRES NOAA (January 2020)

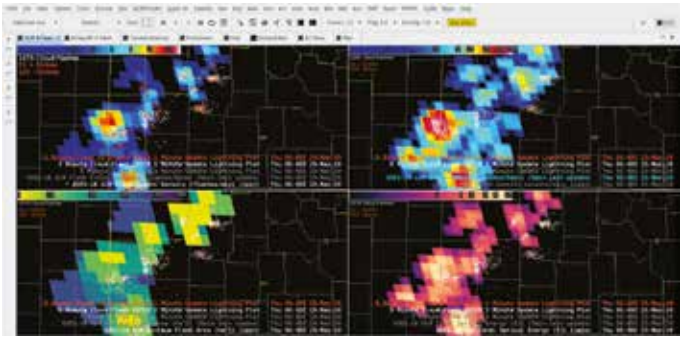
land-based observing sites from multiple nations operating on and around Barbados. NOAA's contribution to ATOMIC included the NOAA Ship Ronald H. Brown, the NOAA WP-3D Orion aircraft, uncrewed aircraft systems, wave gliders, and surface drifting buoys. Twice a week weather briefings during the campaign provided an opportunity to systematically compare in situ data and satellite observations to Global Forecast Systems (GFS) operational analysis/forecasts. Observations from ATOMIC were used to evaluate the GFS and identify systematic errors in vertical profiles of temperature and humidity. These findings have led the way for new research to better understand the source of these errors and determine how to eliminate or reduce these biases. Overall, data gathered during ATOMIC will advance scientific understanding of how the ocean and atmosphere work together to create weather, ultimately helping improve weather and climate prediction.

INNOVATIONS WITH THE GEOSTATIONARY LIGHTNING MAPPER

NOAA NESDIS is leveraging data from the Geostationary Lightning Mapper (GLM) onboard the Geostationary Operational Environmental Satellite -16 and -17 (GOES-16 and GOES-17) series of satellites to better predict storms.

NOAA incorporated data from the GLM instrument into the operational Hurricane Weather Research and Forecasting (HWRF) model for the first time in the 2020 hurricane season. Lightning detection in hurricanes can help forecasters identify rapid intensification of hurricanes, and the high resolution and frequency of the GLM imagery over open oceans represents an opportunity for potential improvement of NOAA operational HWRF forecasts.

NOAA NESDIS co-developed spatially gridded imagery of GLM data with academic and federal partners to provide details on both the spatial coverage and density of the lightning activity as seen from space. Within the operational environment,



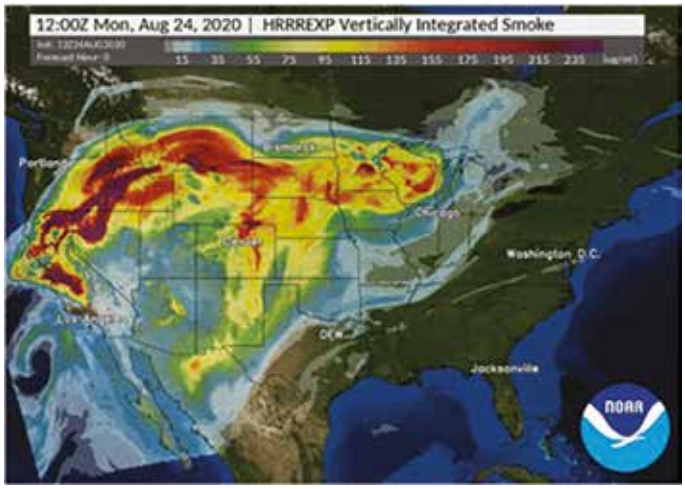
Screenshot of NOAA NWS forecaster display in the NOAA Hazardous Weather Testbed on 23 May 2019 of both GLM and Earth Networks' Total Lightning Network measured lightning activity. The panels of the display show different measures related to lightning such as the density, detection locations, flash area, and optical energy. Credit: NOAA National Severe Storms Laboratory

forecasters are then able to view the GLM data in conjunction with lightning location detections made by ground-based systems from industrial partners. Examinations by NOAA NWS forecasters in the NOAA Hazardous Weather Testbed have shown that viewing the data in combination provides a holistic view of the lightning activity associated with

storms providing both high temporal and increased spatial knowledge. NWS forecasters are now using this data to make severe weather warning decisions and to communicate risks of lightning hazards to Emergency Managers and other partners for decision support services.

IMPROVING FORECASTS WITH ADVANCES IN REGIONAL MODELS

NOAA's flagship high-resolution weather models —Rapid Refresh (RAP) and High-Resolution Rapid Refresh (HRRR)—work hand-in-hand to provide the foundation for many of the forecast products issued by NOAA NWS every day. The final research versions of RAP and HRRR went into NOAA operations in December 2020. This operational implementation is the culmination of more than 25 years of ground-breaking research to develop frequently-updated, short-range weather predictions of high-impact weather to support the NWS and the aviation, agriculture, water resource and energy sectors, among others. These final versions include upgrades that improve model forecasts of clouds, precipitation, wildfire smoke, thunderstorms, and other weather at all levels of the atmosphere. For example, HRRR-Smoke was utilized extensively for wildfire operations and planning. NWS meteorologists used this model to adjust forecast temperatures, provide fire crew briefings, and forecast for aviation operations during the 2020 fires. Using satellite observations of fire location and intensity, HRRR-Smoke predicts the movement of smoke in three dimensions across the country over 48 hours, simulating how the weather will impact smoke movement and how smoke will affect visibility, temperature, and wind. This information provides guidance on how smoke from western wildfires might impact life from coast to coast.



The experimental NOAA Global Systems Laboratory's High-Resolution Rapid Refresh-Smoke (HRRR-Smoke) model simulates the emissions and transport of smoke from wildfires and the impact of smoke on the weather. Credit: NOAA Global Systems Laboratory

> "The Global Systems Laboratory's development of foundational and pragmatic state-of-the-science technologies to improve predictions of weather and its impacts on society has been one of the nation's true success stories that is significantly under-appreciated given the enormous value it returns to the nation."—The Weather Company

CALCULATING CARBON DIOXIDE (CO_2) EMISSIONS FROM FOSSIL FUELS IN THE UNITED STATES

Cooperative Institute for Research in Environmental Studies (CIRES) scientist Duane Kitzis approaches the air sampling station on Niwot Ridge, Colorado, part of NOAA's Global Greenhouse Gas Reference Network, in this 2017 photo. The first air sample analyzed for carbon-14 as part of research into a new method of estimating fossil fuel emissions from ambient air was collected here in 2003. Photo credit: James Murnan, NOAA National Severe Storms Laboratory (2017)

For the first time ever, national carbon dioxide (CO_2) emissions from fossil fuel sources have been calculated using atmospheric data. NOAA Research scientists used measurements of atmospheric CO_2 and its radiocarbon content (Carbon-14, or ^{14}C, the best known proxy for fossil fuel emissions) from NOAA's Global Greenhouse Gas Reference Network in combination with an atmospheric data assimilation model to estimate fossil emissions for 2010 at a monthly time scale, with a further regional breakdown to the western, central, and eastern United States. The emissions estimates are slightly higher than those reported by the U.S. Environmental Protection Agency and other commonly used emissions "inventories," and the new method demonstrates the ability of atmospheric data to provide independent evaluation of inventory-based estimates.

A NEW PUBLIC RELEASE OF THE STATE-OF-THE-ART WAVEWATCH III WAVE MODEL

The Consumer Option for an Alternative System to Allocate Losses (COASTAL) Act requires an accurate modeling of flooding due to hurricanes. The wave model chosen as part of developing this modeling system is the WAVEWATCH III wave model—a state-of-the-art community wave modeling system whose development is managed by NOAA. NOAA released a new version of the global wave model with two major updates. The first major update improves performance on modern high-performance computing architectures allowing for higher resolutions traditionally needed for better predictions in coastal applications. The second major update is the inclusion of software that interfaces with the Earth System Modeling Framework, allowing the model to be used in community coupled modeling systems. With this release, WAVEWATCH III has moved to open-development on GitHub to facilitate increased

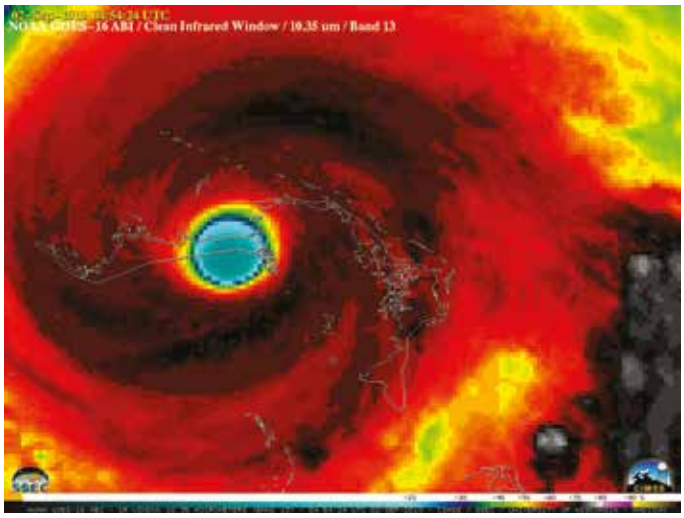
engagement with the wave modeling community. This latest version of the WAVEWATCH III is coupled to the NOAA NWS operational Global Ensemble Forecast System (GEFSv12) implemented in 2020 and will be coupled to the deterministic Global Forecast System (GFSv16) planned for implementation in 2021.

OPTIMIZE USE OF S2S PREDICTABILITY SOURCES TO MAXIMIZE FORECASTS OF OPPORTUNITY

Subseasonal to seasonal (S2S) forecasting sits between short-term weather prediction and long-term climate outlooks. It's the ability to forecast conditions (average, probability of occurrence) during the week two to seasonal period from the initial condition, and it has become an area of emerging need in various economic sectors, and therefore an area of robust and innovative scientific research and development. Subseasonal-to-seasonal (S2S) climate is closely connected to changes in short (weather) and longer (inter-annual to multi-decadal) time scales. As such, operational S2S predictions over the Pacific-North America are influenced by signals ranging from multi-day evolution of convective bursts to long-term trends. Variation among the way models represent physical processes, cross-scale interactions, and chaotic natural variabilities can lead to difficulties in estimating and forecasting clear signals from among the noise. NOAA is developing machine learning applications to assist in model predictions of S2S climate. This work gives promising improvement in operational S2S climate prediction products and services.

PROVING GROUND AND OPERATIONAL TRANSITIONS TO IMPROVE TROPICAL CYCLONE FORECASTS

Tropical cyclones are a major threat to growing global coastal populations. NOAA research and development uses observations and models to improve hurricane forecasts, with the goal of saving lives and reducing property damage. In 2020, NOAA-funded University of Wisconsin researchers addressed variation in tropical cyclone intensity estimates from new-generation satellite platforms (GOES-16 and JPSS) by developing and demonstrating an innovative satellite-based consensus approach (called SATCON) that analyzes the various tropical cyclone intensity estimates. This approach reduces uncertainty and provides better estimates of how intense a tropical cyclone will be by taking into account known strengths in each of the estimation methodologies. The SATCON information is

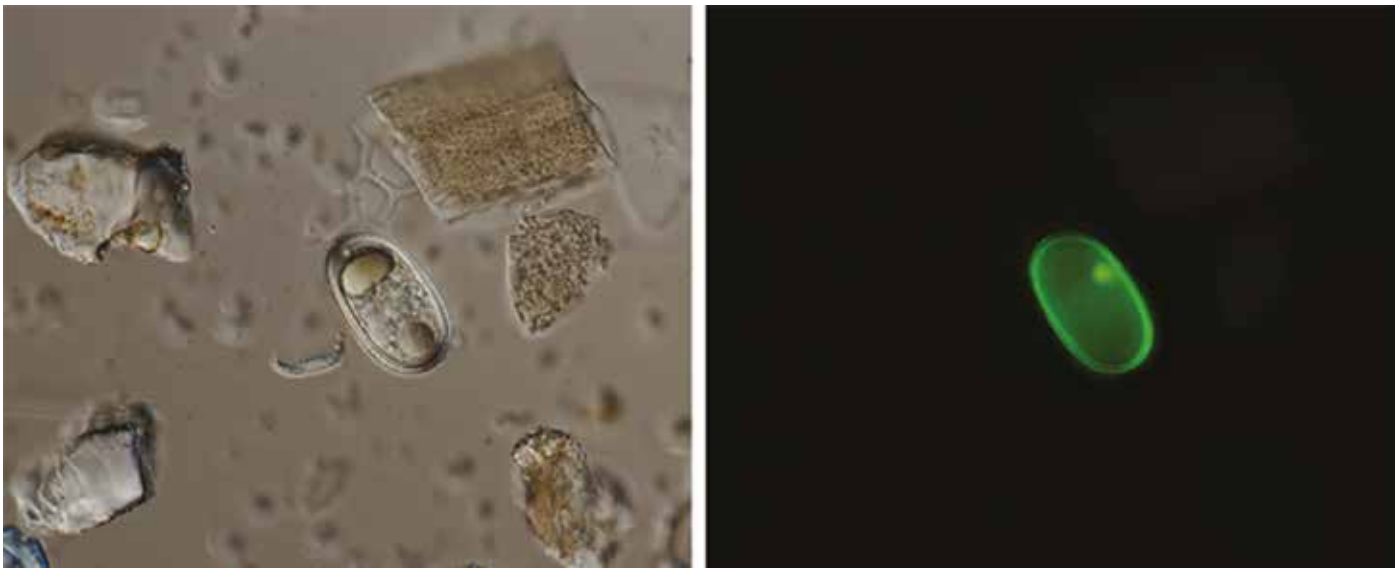


Color-enhanced GOES-16 infrared image during Hurricane Dorian's peak intensity over the Bahamas on September 2, 2019

available in near real-time to tropical cyclone operational and research communities through NESDIS

Satellite Proving Ground activities. In addition, NOAA NWS approved five NOAA Joint Hurricane Testbed projects for operations. Two examples of JHT projects recently approved for transition are the Tropical Cyclone Genesis Index, which predicts the likelihood of an area of distrubed weather developing into a cyclone, and Tropical Cyclone Logistical Guidance for Genesis, which provides forecast and observation data as guidance to predict tropical cyclone formation out to seven days. The transitioned projects will help NWS assess tropical disturbances, which are likely to develop into tropical cyclones. They will also aid in NWS's prediction of the intensity and evolution of existing tropical cyclones, as well as storm surge and other impacts.

FORECASTING HAZARDOUS ALGAL BLOOMS: MODELING AND MOLECULAR TOOLS



Light micrograph (left) of an *Alexandrium* resting cyst in the sediment. The same cyst (right) stained with a fluorescent stain for counting. Credit: S. Kibler, NOAA

The August 2014 shutdown of Toledo, Ohio's drinking water treatment facility caused by a Harmful Algal Bloom (HAB) had an economic impact estimated at $65 million[1], making HAB forecasts very important in Lake Erie. NOAA and the Cooperative Institute for Great Lakes Research developed a new model that allows forecasters to see in three dimensions how extensively the bloom has spread from the lake's surface to its floor. The Lake Erie cyanobacteria colonies (*Microcystis*) float to the surface under calm conditions, and mix through the water column under windy conditions. The new model provides more accurate predictions of both the horizontal movement and vertical position of the bloom within the water column. This information is especially valuable to water treatment plant operators because intake structures are usually located beneath the surface and the risk of toxin in the water supply can be greater when the colonies are mixed to the bottom. Along with the model upgrade, the Lake Erie

1 M. Bingham, S. K. Sinha, and F. Lupi. "Economic Benefits of Reducing Harmful Algal Blooms in Lake Erie." Environmental Consulting & Technology, Inc., Report, 66 pp, October 2015. https://legacyfiles.ijc.org/tinymce/uploaded/Publications/Economic-Benefits-Due-to-Reduction-in-HABs-October-2015.pdf

Aerial photo of harmful algal bloom in western Lake Erie, taken during a remote sensing flight on July 20, 2020, to support the NOAA HAB forecast. This airborne campaign is part of weekly Lake Erie HAB monitoring. Credit: Zachary Haslick, Aerial Associates Photography Inc, Inset: Screenshot of the cyanobacterial density animation from the Lake Erie HAB Forecast on July 21, 2020. The Forecast, which is issued twice weekly throughout the bloom season, depicts the HAB's current location and forecasted movement along with predicted winds, currents, and water temperature. The animation is a new feature that was incorporated into the forecast in 2020. Credit: NOAA

HAB Forecast website has been redesigned to help users more easily and quickly understand HAB data.

NOAA is also developing new methods to better forecast blooms of *Alexandrium catenella,* a marine alga that causes paralytic shellfish poisoning (PSP) along the Pacific and Atlantic coastlines of the U.S. and Canada. PSP is a potentially fatal illness that results from eating shellfish that have ingested *Alexandrium* cells. NOAA forecasting scientists are working with the University of Washington Tacoma, the University of Alaska, and the Woods Hole Oceanographic Institution to map the distribution of *Alexandrium* resting cysts in the sediment of Gulf of Maine, Puget Sound, and Alaska. Cyst distribution and abundance are used to forecast blooms of *Alexandrium* cells in the water column. New methods employing molecular-level analytical procedures known as quantitative polymerase chain reaction (qPCR) and fluorescent *in situ* hybridization (FISH) were developed to reduce the time and effort required for cyst identification and counting. These molecular tools are being tested to better characterize cyst distribution speed up the forecasting process for *Alexandrium* blooms.

2. SUSTAINABLE USE AND STEWARDSHIP OF OCEAN AND COASTAL RESOURCES

Our ocean, coasts, and Great Lakes are home to diverse ecosystems, support fisheries and aquaculture, and provide tourism and recreation opportunities. NOAA science seeks a better understanding of the biogeochemical and human processes that impact these resources and informs their conservation, restoration, and sustainable use.

In 2020, NOAA's scientific accomplishments for enhancing the sustainable use and stewardship of ocean and coastal resources included the following:

PROOF-OF-CONCEPT FOR METHODS TO INDUCE REPRODUCTIVE STERILITY IN CULTURED SABLEFISH

NOAA Northwest Fisheries Science Center and University of Maryland Baltimore County researchers collect ovulated eggs from female sablefish broodstock for sterility induction experiments. Sablefish broodstock are handled under red light to reduce stress and avoid disruption of their reproductive cycle. Photo by Edward Hayman, NOAA (July 2019)

Reliable methods for reproductive sterilization are broadly needed by the marine aquaculture industry to reduce ecological concerns associated with escapement of farmed fish and to safeguard against unauthorized propagation of proprietary aquaculture strains. In collaboration with research partners from the University of Maryland Baltimore County, scientists at NOAA Fisheries have achieved effective sterility in sablefish (*Anoplopoma fimbria*) using two approaches that do not involve gene editing. Researchers successfully induced sterility in sablefish using either a new bath immersion technique that entails soaking batches of sablefish eggs, prior to fertilization, in a solution that temporarily silences a specific reproductive-related gene known as "dead end," or by briefly applying cold or pressure just after fertilization to induce triploidy (the retention of a third set of chromosomes normally extruded after fertilization). More research is needed to determine potential effects (positive or negative) of these treatments on fish performance, such as survival and growth, and to optimize each method to achieve higher rates of sterility. This provides proof-of-concept that these approaches may be applied on a large scale in aquaculture to induce sterility in sablefish and potentially other marine species, reducing the potential for environmental impacts.

EDUCATION SPOTLIGHT: ELYSE BONNER

A 2019 EPP/MSI Undergraduate Scholar, Elyse is a senior environmental science major at Tuskegee University. In 2019, she conducted her first summer internship research with NOAA NOS titled "Assessment and Characterization of Legacy and Current-use Pesticides (CUPs) in the Maumee and Ottawa Riverine Systems". Also in 2019, Elyse had the opportunity to participate in a HABs cyst research cruise aboard the NOAA Ship *Gordon Gunter.* In 2020, she conducted a virtual internship with the NOAA Fisheries and created a large data set of 60,000 independent samples of 11 environmental variables to improve managerial decisions for sustainable fisheries. Elyse plans to attend graduate school to study ecotoxicology and hopes to one day work for NOAA.

Elyse Bonner, EPP/MSI Undergraduate Scholar aboard the NOAA *Ship Gordon Gunter.* Credit: Elyse Bonner (October 2020)

INCREASING THE SUSTAINABILITY OF AQUACULTURE FEEDS

Diet pellets with mealworm. Credit: Bernadita Anulacion, NOAA

Aquaculture is currently the fastest-growing food-producing sector in the world and demand for feed ingredients, especially fishmeal and fish oil, has increased dramatically in recent years. With many global fisheries at or near sustainable limits, future increases in fishmeal or fish oil are unlikely, and alternative sources of protein and oil are needed to sustain further development of the aquaculture industry. In 2020, NOAA Fisheries conducted a 10-week growth study investigating the potential of replacing fishmeal in a marine fish diet with intensively produced mealworms from Beta Hatch, a domestic insect producer. Similar growth and survival were observed among juvenile sablefish receiving the fishmeal diet, the 50 percent mealworm replacement diet, and the 100 percent mealworm replacement diet, indicating that mealworms are a possible feed ingredient substitute. Follow-up studies are planned to evaluate mealworm digestibility and the effect of mealworms on the nutritional composition of sablefish.

GENOMIC ABUNDANCE ESTIMATION FOR WESTERN ATLANTIC BLUEFIN TUNA USING CLOSE-KIN MARK RECAPTURE

NOAA Fisheries advanced research of a genetics-based approach, called close-kin mark recapture, that can allow for the monitoring of trends in domestic stock production and the contribution to catches of other stocks that migrate to U.S. fishing areas. Close-kin mark recapture involves identifying individuals in a population based on the DNA profiles of their closely related family members. In a pilot study evaluation, NOAA identified two parent-offspring matches of Atlantic bluefin tuna that spawned in the Gulf of Mexico in May 2017 and were captured and sampled in Canada later in fall of 2017. The pilot study provided the proof of concept to confidently advance the research toward estimating the population size. In addition to information on bluefin tuna spawning abundance in the Gulf of Mexico, the composition of stocks to fishery catches will be estimated, providing managers and stakeholders with accurate information on population status. NOAA Fisheries collaboratively conducts this work with partners from the Commonwealth Scientific and Industrial Research Organisation, Virginia Institute of Marine Sciences, University of Maine, and Canada Department of Fisheries and Oceans.

AMERICAN LOBSTER, SEA SCALLOPS HABITAT COULD SHIFT OFF THE NORTHEAST

A new study by NOAA Fisheries predicts that climate change will pose management challenges for two commercially important species on the Northeast continental shelf. Researchers used a suite of habitat models to estimate how species will react as ocean waters warm. Results suggest that American lobster in the Gulf of Maine will move further offshore and that sea scallops in the Middle Atlantic Bight will shift to the north in the coming decades. These changes can move stocks into, and out of, fixed management areas. Habitats within current management areas will also experience changes. Some will gain species, others will lose species, and still others will stay the same. This research provides important information for fishery managers, allowing them to more effectively manage for changing ocean conditions.

EDUCATION SPOTLIGHT: STEPHANIE MARTINEZ-RIVERA

Dr. Stephanie Martinez-Rivera knew at a very young age that she wanted to study marine biology. She stated, "Ever since I decided to become a Marine Biologist, one of my career goals has been to explore the ocean ecosystems aboard research vessels". Support from the NOAA EPP/MSI Living Marine Resources Cooperative Science Center enabled Dr. Martinez-Rivera to conduct research aboard the NOAA F/V *Hannah Boden,* where she studied reproductive biology and histology of deep-sea red crabs (*Chaceon quinquedens*). In addition, she participated in several NOAA research cruises, including NOAA Ship *Okeanos Explorer* and R/V *Henry B. Bigelow.* Dr. Martinez-Rivera earned her Ph.D. in Marine Estuarine and Environmental Science from the University of Maryland Eastern Shore and is currently employed as a Fisheries Biologist with the NOAA NMFS Southeast Fisheries Science Center.

Dr. Stephanie Martinez, EPP/MSI Scholar Alumni and NMFS Fisheries Biologist conducted research on NOAA research vessels. Credit: Stephanie Martinez, NOAA (July 2014)

BALANCING CONSERVATION OBJECTIVES AND ANGLER SATISFACTION IN THE RECREATIONAL STRIPED BASS FISHERY

Dr. Andrew Carr-Harris displays a fish caught off the coast of Cape Cod. Credit: Andrew Carr-Harris, NOAA (June 2019)

Understanding how anglers respond to policy changes is key to rebuilding overfished stocks like Atlantic striped bass. For example, anglers place a relatively high value on catching trophy-sized stripers—which are almost exclusively females of spawning size—but if too many of these fish are removed from the fishery the stock has trouble rebuilding. The researchers evaluated the economic and biological consequences of a wide range of policy combinations, including those that restrict harvest of trophy-sized striped bass. Their results showed the types of policies that are expected to achieve conservation objectives while simultaneously maximizing the well-being of anglers. Of the 36 policies examined, only one was found to protect trophy-sized spawning females without significantly affecting angler well-being. That policy was taking one fish per trip in the "harvest slot" of 28 to 36 inches.

EDUCATION SPOTLIGHT: LATREESE DENSON

Dr. LaTreese Denson, EPP/MSI Scholar and NMFS Research Mathematical Statistician completed a graduate internship at the NOAA Alaska Fisheries Science Center. Credit: Dr. LaTreese Denson (October 2020)

Dr. Latreese Denson earned her Ph.D. in Marine Biology at the University of Miami Rosenstiel School of Marine and Atmospheric Science. As an EPP/MSI Living Marine Resources Science Center scholar, Dr. Denson completed research on the effect of environmental variability on King Mackerel abundance indices and the effectiveness of fisheries management. Her dissertation titled "Environmental influences on indices of abundance for King Mackerel in the Gulf of Mexico examined through spatiotemporal geostatistical models" was completed in 2020. She completed her EPP/MSI graduate internship with the Alaska Fisheries Science Center and reported that the experiences received during her support through the NOAA Living Marine Resources Cooperative Science Center provided skills she will utilize in her new position as a research mathematical statistician with the NOAA Southeast Fisheries Science Center in Miami, FL.

NORTHEAST OFFSHORE MUSSEL FARMING POISED TO CONTRIBUTE TO AMERICAN SEAFOOD COMPETITIVENESS

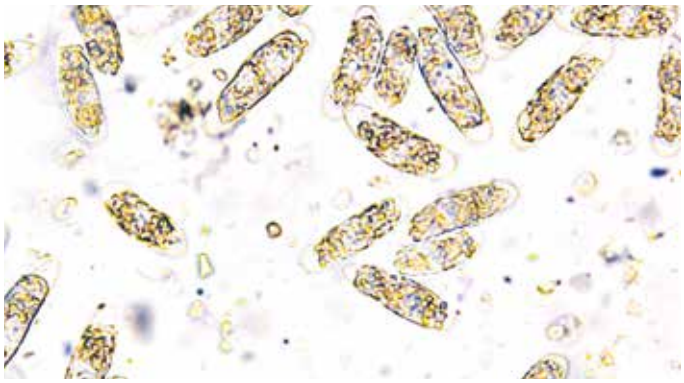
"Developing a local offshore industry for this aquaculture species is important, in terms of local economic benefits and food security, and producing seafood according to national standards of quality and sustainability."—Darien Mizuta, PhD

NOAA Fisheries researchers conducted the first environmental suitability study of offshore northeast waters for blue mussel aquaculture, and found large areas to be highly suitable. Offshore mussel farm sites need to have the right temperature range and food availability, so locating areas with optimal environmental conditions for profitable production is an essential first step. The study identified high summer temperatures as a limiting factor, which can be mitigated by submerging mussel ropes deeper in southern areas of New England. The researchers validated their results by measuring mussel feeding performance at Salem State University's experimental offshore farm off of Cape Ann, MA. Their work suggests that a New England offshore mussel farming industry would be environmentally sustainable and beneficial for food security and the economy, and that risks posed by harmful algal blooms would be similar to those of coastal aquaculture.

Dr. Darien Mizuta, Postdoctoral Researcher at the Milford Laboratory, at sea studying blue mussel performance at an experimental offshore mussel farm near Cape Ann, MA. Credit: Mark Dixon, NOAA Fisheries (October 2019)

NOAA LEADS GLOBAL COLLABORATIVE STUDY OF IMPORTANT SEA TURTLE PARASITE

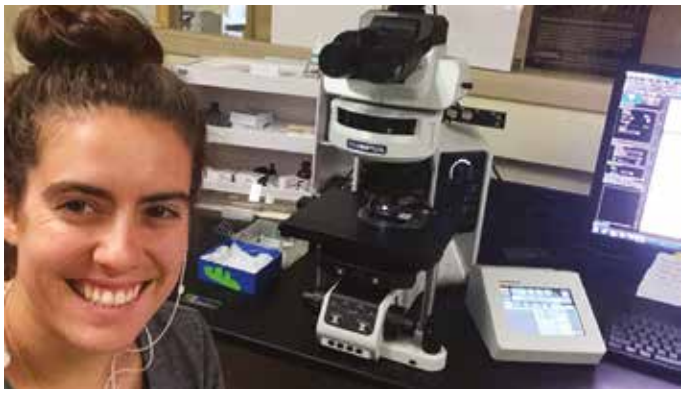
Protozoan parasites are single-celled organisms that are responsible for many important diseases in humans and animals. One group, referred to as *Caryospora*-like organisms, has caused die-offs of green sea turtles in the United States and Australia. A collaborative study—led by NOAA and involving researchers in these countries and sea turtle rehabilitation organizations—used information collected from stranded sea turtles and genetic analysis to show that the parasites appear to have been spread around the world relatively recently and are a previously unrecognized health problem for sea turtles in U.S. waters. Their findings also suggest that human activities have played a role in the spread of this parasitic disease.



Protozoan parasites (*Caryospora*-like organisms) in the feces of a green sea turtle. These parasites damage the lining of the intestine and can cause illness in turtles. Credit: Dr. Brian Stacy, NOAA Fisheries

EDUCATION SPOTLIGHT: NOAA HOLLINGS SCHOLAR HELPS LEAD TEAM THAT SOLVES MYSTERY OF STINGING WATER

Stinging water is a phenomenon that occurs when swimmers venture near beds of upside down jellyfishes (*Cassiopea*), which live in warm shallow waters around the globe. For those unlucky enough to experience it, stinging water causes an itching sensation bordering on pain. To explore this mystery, a large collaborative study led by NOAA Fisheries was published with former Hollings Scholar Anna Klompen as co-lead author. The team discovered and documented small structures that the jellyfish releases with mucus into the water. Dubbed cassiosomes, these multicellular structures are packed with stinging capsules and are capable of locomotion. Laboratory experiments showed that the structures are capable of quickly immobilizing prey and that jellyfish genes that produce a specific venom protein are active in the cassiosomes. The study highlights the importance of the Hollings Internship (Klompen is now a PhD student studying jellyfish venom) and the power of multi-institution collaboration. The study relied on resources and tools from NOAA, the Smithsonian Institution, the Naval Research Laboratory, University of Kansas, and Rice University to solve this long-standing question with an impact on human health.



Anna Klompen using a powerful compound microscope and a microfluidics device to isolate cassiosomes from an upside down jellyfish raised at the National Systematics Lab in the Smithsonian National Museum of Natural History. Credit: NOAA Fisheries/National Systematics Laboratory

COMPLETE GENOME SEQUENCING FOR THE ENDANGERED MARINE MAMMAL THE VAQUITA, AND THE ENDANGERED LEATHERBACK TURTLE

In 2020, NOAA Fisheries, in collaboration with academic partners the University of Massachusetts at Amherst and The Vertebrate Genome Laboratory at Rockefeller University, completed sequencing and assembling the complete genomes of the endangered leatherback turtle and the vaquita, the world's most endangered marine mammal. The vaquita sequence is 2.3 billion base pairs long and is being used to assist in assembling the partial genomes from 19 additional vaquita samples to allow researchers to infer the unique evolutionary history of this Gulf of California species, and potential to recover if the threat of bycatch in fishing nets can be eliminated in their habitat. Leatherback turtles, often referred to as "living dinosaurs," possess unique physiological adaptations, including those that allow them to survive in cold waters beyond what other reptiles can tolerate. The new reference genome is being used to assist in assembling the partial genomes from hundreds of samples collected throughout the world to allow researchers to study the remaining genetic diversity in the species. This type of information is key for conservation initiatives designed to ensure persistence of this critically endangered species.

NOAA TRACKS PACIFIC MARINE HEATWAVES

Through the summer and fall of 2019, NOAA Fisheries tracked a vast marine heatwave that warmed the northeast Pacific Ocean. By November the heatwave retreated from the U.S. West Coast, only to be followed by two more heatwaves in 2020. The successive heatwaves—starting in 2014 with a monster called "The Blob"—have played havoc with coastal ecosystems, fueling harmful algal blooms, depressing salmon returns, and shifting commercial fisheries into new waters. A heatwave tracker developed by NOAA Fisheries has become a highly visited page as fishermen, managers, and researchers seek clues about the likely ecological and economic impacts of the changes.

In addition, a NOAA Fisheries team produced an annual ecosystem status report, which tracks species, and climate and ocean conditions, as barometers of ocean health and productivity. It also draws on social and economic indicators that reflect the state of West Coast communities. These include the size of krill, which are small crustaceans that form the base of the food chain, and trends in fishery landings in port communities. Krill density was very low off much of the West Coast in 2019, and commercial fishery landings dropped eight percent in 2018 compared to the year before. These findings inform Pacific Fishery Management Council and NOAA Fisheries managers as they develop fishing seasons and limits. The report, as part of an Integrated Ecosystem Assessment, also supports NOAA Fisheries' shift toward ecosystem-based fisheries management, which considers interactions throughout the marine food web rather than focusing on a single species.

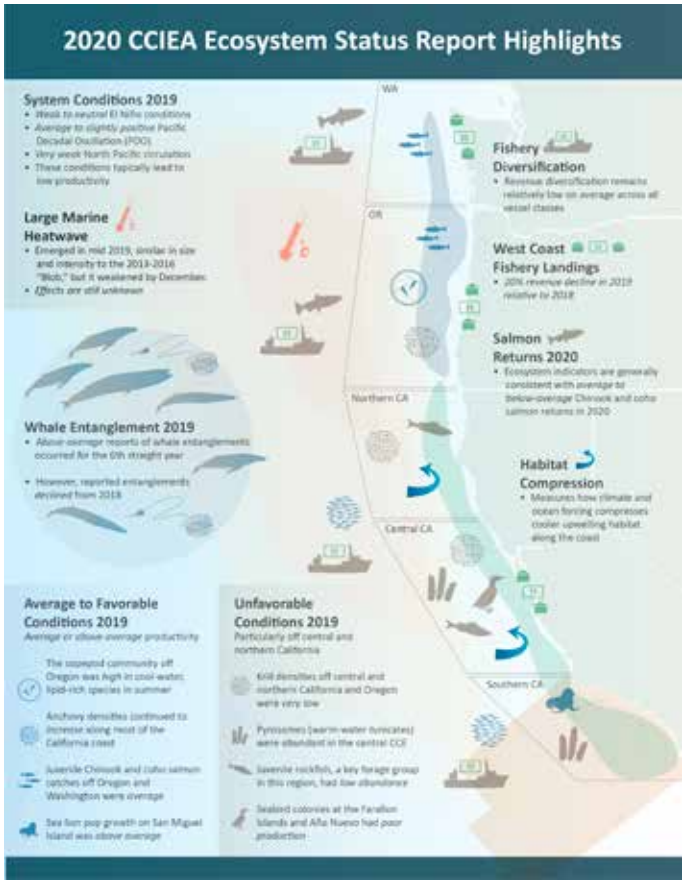


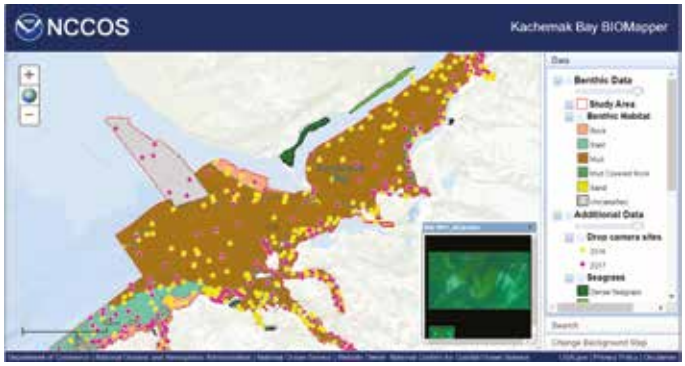
Image taken from 2020 CCIEA Ecosystem Status Report Highlights visually describing the tracking of species and climate and ocean conditions, as barometers of ocean health and productivity. It also draws on social and economic indicators that reflect the state of West Coast communities.

KACHEMAK BAY ECOLOGICAL ASSESSMENT: SUPPORTING ALASKA COASTAL RESOURCE MANAGEMENT

Kachemak Bay is a "natural laboratory" of Alaska coastal habitats, with sandy clam beds, seagrass meadows, and rocky, deep fjords lined with kelp forests. Photo credit: Kris Holderied, NOAA

NOAA NOS is conducting a Kachemak Bay, AK ecological assessment project to knit together a broad range of spatial habitat and environmental data into new information tools for Alaska coastal resource management and planning. Kachemak Bay is a productive, subarctic estuary in southcentral Alaska that contains all the coastal habitats found in the Gulf of Alaska, with fish, shellfish, marine mammal, and bird populations that support recreational and commercial harvests. Kachemak Bay has seen an increase in ecotourism activities and tourism is a significant economic driver for the region.

NOAA, along with federal, state, tribal, industry, and non-governmental organization partners, has produced a pilot "State of Kachemak Bay" report, developed online tools to improve public data access and visualization of spatial data, and is producing an ecological status report in 2021 to highlight regional coastal changes over the past two decades. The project's goal is to provide information tools that help Alaska communities deal with challenges from changing fish and shellfish populations, climate change, harmful algal blooms, and to explore opportunities in shellfish and kelp mariculture.



The NOAA NOS/National Centers for Coastal Ocean Science Kachemak Bay BIOMapper allows users to easily view and overlay different types of habitat mapping and environmental monitoring data online. Credit: NOAA NOS/National Centers for Coastal Ocean Science

TESTING ALTERNATIVE OYSTER RESTORATION STRATEGIES

Spat on shell produced by direct setting, as seen with the naked eye. Photo credit: Jason Spires, NOAA NOS/National Centers for Coastal Ocean Science

NOAA is leading research that uses novel chemical tagging tools to test alternative oyster setting methods. Oyster setting is the process in which larvae attach to a setting material such as shell. In partnership with the U.S. Naval Academy and the Maryland Department of Natural Resources, researcher divers used fluorescently-marked larvae to test releasing oyster (*Crassostrea virginica*) larvae directly onto planted oyster shells in the Chesapeake Bay. The research shows that juvenile oysters can be

established from larvae set directly at the site without using enclosures. The techniques developed in this portfolio may reduce the requirement for scarce shell or other setting material, and reduce the logistical and material handling costs associated with traditional spat-on-shell oyster practices in both restoration and aquaculture sectors. These reductions have the potential to avoid challenges commonly associated with publicly funded restoration projects using alternative substrate, and can make restoration and aquaculture seeding practices more economical.

NOAA-FUNDED RESEARCH EVALUATES DUNE MANAGEMENT OPTIONS IN NORTH CAROLINA

A NOAA-funded observational and modeling study assessed possible beach and dune management actions to help coastal communities make informed decisions in the context of extreme storms and sea level rise. The project, led by researchers at Oregon State University and University of North Carolina, evaluated dune shape as a function of beach nourishment, dune grass planting, sand fencing, and treatment of the wrack line on the Outer Banks, NC. The team discovered that nourishing beaches prior to the storm season, planting dunes with certain species of dune grasses, and allowing a wrack line to remain on the beach all led to taller and wider dunes systems. In contrast, sand fencing created shorter but wider dunes. The models demonstrate how management actions influence dune shape, which has implications for coastal protection and the resilience of beaches and dunes.

Sand fencing on Bogue Banks, NC. Photo: NOAA

NOAA MAPS CORAL FOR IMPROVED MANAGEMENT

In the face of accelerating changes to coral reef ecosystems, it is critical that we document the status and trends of the world's coral reefs to identify resilient reefs and resilience-supporting management practices.

NOAA Fisheries studies reefs across 40 primary islands, atolls, and shallow banks in five regions, visiting 400-600 sites each year. Historically, NOAA Fisheries has used *in situ* visual assessments of coral communities and small area imagery to generate information about which corals are present in an area and how healthy they are. To more efficiently extract this sort of data, NOAA recently assessed the capacity of a widely-used machine-learning image analysis tool—CoralNet—to generate fully-automated estimates from meter-scale imagery. CoralNet was able to generate estimates of site-level coral cover that were highly comparable to those generated by human analysts. To generate a more comprehensive understanding of spatial resilience and consequences of climate change and local threats, NOAA is partnering with computer scientists in academia, the private sector, and the federal government to extract colony-level information from imagery to assess reefscapes up to 150 square meters. The development of training datasets and a scalable processing pipeline that leverages machine learning

and cloud processing has the potential to transform the way we assess and, ultimately, manage coral reefs worldwide.

NOAA uses spatial modeling to predict the distributions of threatened coral species in the U.S. Atlantic (Puerto Rico, U.S. Virgin Islands, and Florida). NOAA is partnering with scientists in academia and the federal government to develop new modeling approaches and applications that provide data-driven spatial predictions for the presence, absence, abundance, and population structure of multiple threatened coral species. The NOAA team is also assembling a spatial database of Atlantic coral ecosystem monitoring in an accessible map format. These products are used to inform management decisions that may affect coral species listed under the Endangered Species Act, such as spatial planning for coral restoration and place-based management.

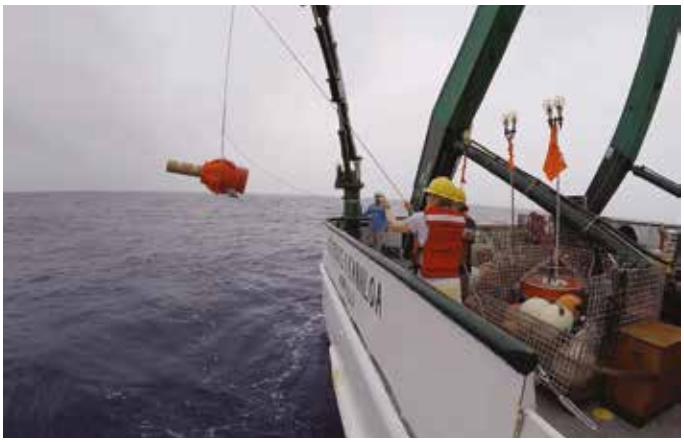
NOAA USES eDNA TO STUDY MARINE LIFE

NOAA is using environmental DNA (eDNA)—the tiny bits of genetic material that marine life sheds into the surrounding water—to study organisms across trophic levels and ecosystems and provide critical information about species interactions in the face of ecosystem change.

NOAA Fisheries is using eDNA as a novel method to monitor the small, endangered population of Gulf of Mexico Bryde's whales and improve knowledge of their distribution. Seawater samples were collected in the field in the flukeprints, calm water formed in the wake of a passing whale, to determine if it is possible to capture their eDNA. In the laboratory, DNA was isolated and molecular genetic techniques were used to successfully identify Gulf of Mexico Bryde's whale eDNA in the seawater samples. For future studies, NOAA is collaborating with the Monterey Bay Aquarium Research Institute (MBARI) to collect automated eDNA samples from an Environmental Sample Processor (ESP) deployed in the northwestern Gulf of Mexico. This novel technique will be coupled with passive acoustic recordings collected near the ESP site to help researchers determine if the integration of these two methods can increase scientists' abilities to detect these rare whales and gain information about their distribution, which is vital for their conservation and recovery efforts.

The U.S. Marine Biodiversity Observation Network (MBON)—coordinated by the U.S. Integrated Ocean Observing System with interagency funding and support—has been a key player in developing best practices for eDNA and demonstrating its utility for biological observing and biodiversity assessment. A team of MBON partners across multiple research institutions and state government agencies used eDNA methods to survey biodiversity in Monterey Bay, CA, during an 18-month period. The team created a dataset from the resulting seawater samples, encompassing 663 taxonomic groups from microorganisms to mammals. The team concluded that "eDNA-based analyses can provide detailed information about marine ecosystem dynamics and identify sensitive biological indicators that can suggest ecosystem changes and inform conservation strategies."

THE ARGO PROGRAM EXPANDS TO REACH MORE OF THE OCEAN THAN EVER BEFORE



A deep Sounding Oceanographic Lagrangian Observer (SOLO) float deployment off the R/V *Ka`imikai-O-Kanaloa* during a Hawai'i Ocean Timeseries (HOT) cruise in the Pacific. Photo credit: Blake Watkins, University of Hawai'i (May 2019)

The Argo Program, an international effort that gathers critical ocean data using a fleet of robotic instruments, is expanding its mission. Currently, most Argo floats take temperature and salinity measurements of the top 2,000 meters of the ocean; newly-upgraded Argo floats will take these measurements to new depths of 6,000 meters (Deep Argo) and others will be equipped with additional sensors to measure biogeochemical variables, such as pH and oxygen. In the winter of 2019 to 2020, NOAA's float group deployed Deep Argo floats (funded by the Paul G. Allen Foundation) in the Brazilian basin from the R/V *Petrel*, establishing the third regional array for Deep Argo floats. In the fall of 2019, four research projects were funded by the National Oceanographic Partnership Program and NOAA to improve biogeochemical sensor technology and test floats in key regions: the tropical Pacific, California current, and northwest Atlantic ocean. Since 1999, the Argo Program has grown to a fleet of nearly 4,000 robotic floats that collect data on important ocean health indicators that inform stakeholders about ecosystem health, fisheries management, climate, and weather prediction. On average, one or more scientific papers a day is published using Argo data.

> "The Argo Program is a hallmark of NOAA's ocean observing systems. It has revolutionized our ability to track changes in our global ocean. Information from systems like Argo are paramount for accurate weather and climate predictions."
> —David Legler, PhD, Director of NOAA Research's Global Ocean Monitoring and Observing Program

NOAA FUNDED PROJECT PROVIDES AQUACULTURE SITING RESOURCE TO ALASKA GROWERS

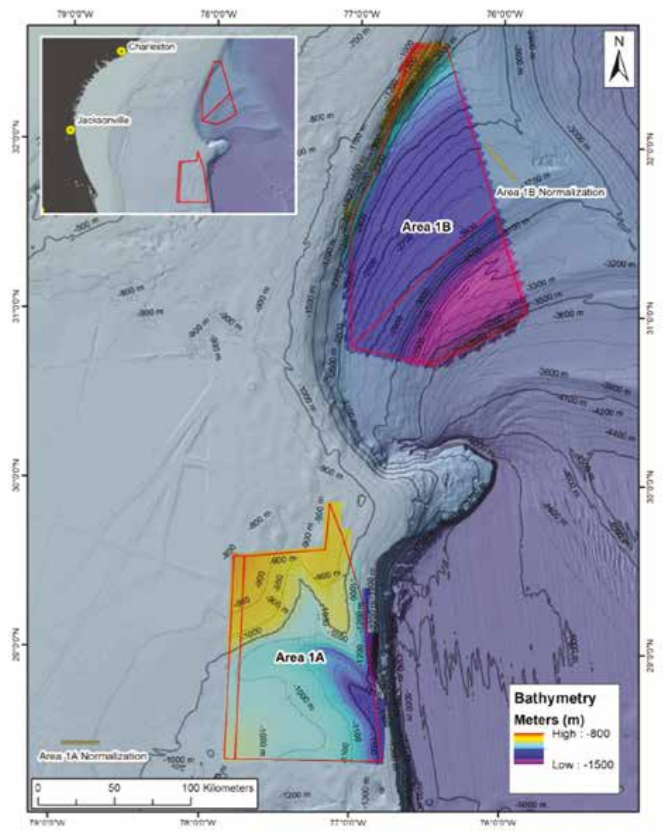
Development of mariculture, a branch of aquaculture that involves growing fish and other marine organisms in the open ocean, in Alaska has historically been restricted by a lack of information needed to determine the benefits of investing in it. Alaska Sea Grant and partners used existing data and input from stakeholders (i.e., planners, regulators, investors, existing and prospective growers) to develop a state-specific visual planning tool to better inform and focus mariculture investment. The goal of the tool is to use spatial planning (mapping and other

Trevor Sande (pictured) raises oysters in Alaska. Trevor is one of many mariculturists in the region growing ecologically and environmentally important species such as oysters, salmon, and kelp. Credit: Alaska Sea Grant (April 2018)

visual datasets) to increase profits in Alaska from mariculture through an increase in farmed seafood and seaweed, support continued expansion of new and existing mariculture sites, and increase public awareness about the economic and environmental benefits of mariculture. The project team has received positive feedback and additional funding to expand the project into "Mariculture Map 2.0," which will add additional and more complicated data layers and revise the display of data for the most user-friendly displays for users. The project has now expanded far beyond Alaska Sea Grant's initial work, and they continue to be involved. The tool can be accessed at https://mariculture.portal.aoos.org/.

INNOVATIVE TECHNOLOGY AND PARTNERSHIP LEADS TO NEW SEAFLOOR MAPPING OF U.S. EEZ

The U.S. Exclusive Economic Zone (EEZ) spans over 13,000 miles of coastline and contains 3.4 million square nautical miles of ocean, making it one of the largest EEZs in the world and larger than the land area of all 50 states combined. Yet only 46 percent of the U.S. EEZ is mapped to modern standards, and even less of it is explored and characterized. The complete mapping of U.S. EEZ is required for effective balance of the sustainable use of ocean resources with conservation and management efforts. NOAA is looking for innovative solutions to address this challenge. The team of NOAA scientists and experts from Fugro, a private sector NOAA partner, developed a new approach to leverage planned Fugro transits to map deepwater areas of the EEZ, and tested new technologies to improve communications and transparency of surveying activities in near real time. As a result of this first "proof-of-concept" ocean exploration Fugro survey, NOAA acquired more than 30,000 square kilometers—about 8,750 square nautical miles—of mapping data in support of ocean exploration, in a previously unmapped section of the U.S. EEZ off the coasts of Georgia and Florida. NOAA and Fugro also collaborated to collect data in support of establishing shallow and deepwater reference areas that can be used in the future by NOAA and other vessels to cross calibrate multibeam sonars to provide consistent data on the characteristics of the seafloor. The project aligns with the goals and objectives of the National Strategy for Mapping, Exploring, and Characterizing the U.S. Exclusive Economic Zone issued in June 2020 and complements global initiatives such as The Nippon Foundation—General Bathymetric Chart of the Ocean, Seabed 2030 Project, and the United Nations Decade of Ocean Science for Sustainable Development.



Locations of seafloor bathymetry and backscatter normalization areas from Fugro surveys conducted off the coasts of Georgia and Florida. Credit: Fugro

SURVEYING DEEP-SEA CORALS, SPONGES, AND FISH HABITAT OFF THE U.S. WEST COAST

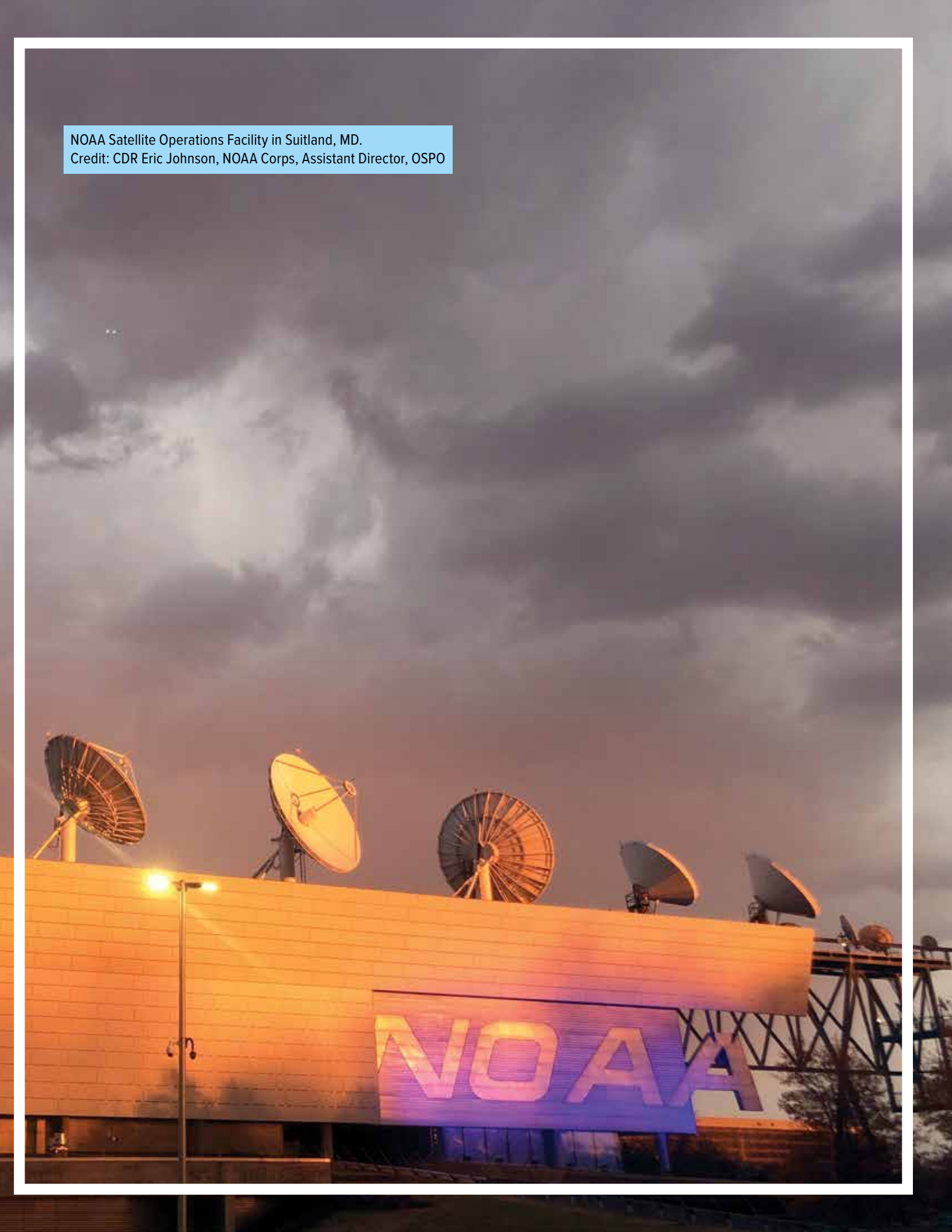
In October 2019, NOAA led a month-long, multi-agency expedition along the U.S. West Coast to expand our understanding of deep-sea coral, sponge, and methane seep ecosystems. Using telepresence-enabled surveys and a suite of advanced technologies, researchers investigated areas where relatively large amounts of coral and sponge are unintentionally caught as bycatch by fishing vessels; explored unknown deepwater areas of our National Marine Sanctuaries; collected specimens and environmental DNA; and discovered potential new species. Data were gathered to provide a baseline prior to changes in essential fish habitat and rockfish conservation area fishing regulations in January 2020, and to inform potential offshore renewable energy development and other resource management decisions. The expedition was led by NOAA and included the Bureau of Ocean Energy Management, the U.S. Geological Survey, and the Global Foundation for Ocean Exploration. The expedition, made possible by the NOAA Deep Sea Coral Research and Technology Program and supported by the National Oceanographic Partnership Program, enabled telepresence capabilities for the first time on a NOAA Fisheries West Coast expedition.

Remotely operated vehicle Yogi collects a sponge sample for taxonomic identification and habitat characterization. Credit: NOAA and the Global Foundation for Ocean Exploration.

UNDERSTANDING AND MITIGATING MARSH VULNERABILITY TO ENVIRONMENTAL CHANGES

Tidal marshes, which provide key habitat for fisheries and valuable community protection against storm surge, are increasingly threatened by sea level rise. Scientists are using consistent monitoring protocols in National Estuarine Research Reserve System (NERRS) sites around the nation to better track marsh vulnerability and research the interactions of fauna, habitat, and inundation. As a result, a NOAA-funded team has developed and released new guidance for restoration approaches of sediment addition (thin layer placement) for coastal managers.

NERRS scientists in Maryland inspect a test plot where dredged sediment was applied. Photo credit: Chesapeake Bay Maryland NERR (2019)



NOAA Satellite Operations Facility in Suitland, MD.
Credit: CDR Eric Johnson, NOAA Corps, Assistant Director, OSPO

3. A ROBUST AND EFFECTIVE RESEARCH, DEVELOPMENT, AND TRANSITION ENTERPRISE

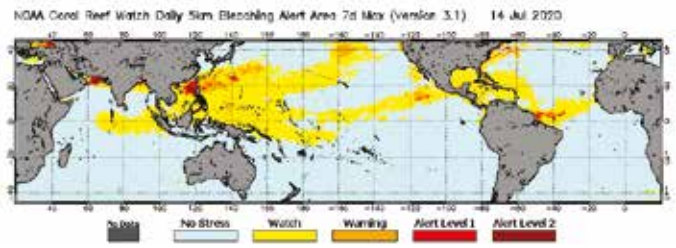
Earth observations, models, and data form a foundation for NOAA science, and integrating social sciences into NOAA's foundational processes increases the accessibility, comprehension, and utility of NOAA's R&D.

In 2020, NOAA's scientific accomplishments for building a robust and effective research, development, and transition enterprise included the following:

- NOAA Launches Next-Generation Satellite-Based Products That Monitor Coral Bleaching Heat Stress
- Integration Of Satellite Data In Flood Mapping Software For Flood Monitoring And Forecasting
- NOAA Leverages Artificial Intelligence For Enhanced Exploitation Of Satellite Ocean Color Observations
- Scientific Data Stewardship And Product Development For Subsurface Oceanographic Datasets
- Education Spotlight: Adedoja Adeyeye
- Nature's Archives: Piecing Together 12,000 Years Of Earth's Climate Story
- Precision Marine Navigation Dissemination
- Telepresence Science Missions In National Marine Sanctuaries
- NOAA Development Of A Webcam Coastal Observing Network
- Hurricane Gliders Patrol Surface Waters To Improve Hurricane Forecasts
- Tracking A Different Kind Of Hazard: Hysplit Models The Trajectory Of An Unprecedented Surge In Desert Locust Swarms
- Development Of The Next Generation Model For Seasonal To Decadal Prediction
- Measuring The U.s. Marine Economy
- NOAA Releases Updates To Geomagnetism Models
- Making Use Of The Public Cloud For Non-Alerting Dissemination Applications
- Three-Tier Categorization Of Damage Threat Levels In Nws Severe Thunderstorm Warnings
- Improved Tropical Web Services Allow Public To Better Prepare For Tropical Cyclones
- NOAA Updates Algorithm To Improve Sea Ice Concentration Estimates
- NOAA Utilizes Uncrewed Systems To Collect Observations In Remote Environments
- NOAA Launches Uncrewed Systems To Monitor Changes In The U.s. Arctic
- NOAA Development Of An Experimental Sea Ice Forecast System

NOAA LAUNCHES NEXT-GENERATION SATELLITE-BASED PRODUCTS THAT MONITOR CORAL BLEACHING HEAT STRESS

Higher resolution satellite-based products have been NOAA Coral Reef Watch's number one user request for many years. Earlier this year, Coral Reef Watch transitioned from its heritage suite of global satellite products (delivered at 50km-resolution, twice-weekly), which served the U.S. and international coral reef communities for more than 20 years, to its next-generation global satellite products (delivered at 5km-resolution, daily). Coral Reef Watch now provides remote monitoring of 95 percent of coral reefs globally, at or near the resolution of an individual reef. By introducing a higher-resolution landmask, processing of data right up to the shoreline, and reduced cloud contamination, the 5km satellite products have significantly reduced data gaps compared with prior versions. Additionally, Coral Reef Watch now offers 35 years of 5km product data from January 1, 1985, to the present. The daily global 5km satellite products are the core of Coral Reef Watch's decision support system for coral reef management. They help resource managers, scientists, decision makers, and the public monitor how climate impacts reef ecosystems worldwide; understand links between environmental conditions and ecosystem impacts; assess when reefs are vulnerable or resilient to climate change and its impacts (especially coral bleaching); and prepare and prioritize resources to implement timely, effective protective responses and adaptation actions (including restoration efforts). This helps improve coral reef management and regulation in a warming climate.



NOAA Coral Reef Watch's daily global 5km satellite coral Bleaching Alert Area (7-day maximum) product for July 14, 2020. The Bleaching Alert Area (7-day maximum) is a composite product that outlines the current locations, coverage, and potential risk level of coral bleaching heat stress around the world. Data and images are produced globally at 5km-resolution and are updated daily. Photo credit: NOAA NESDIS/Coral Reef Watch.

"NESDIS satellite products, especially those produced by Coral Reef Watch for use over coral reefs are vital to coral reef science and to marine park management in Florida. Coral Reef Watch's importance to coral reef managers in Florida cannot be stressed enough. It is critical that NOAA provide Coral Reef Watch with sustainable funding in perpetuity."— Billy Causey, Ph.D. (retired, former Director, NOAA Florida Keys National Marine Sanctuary)

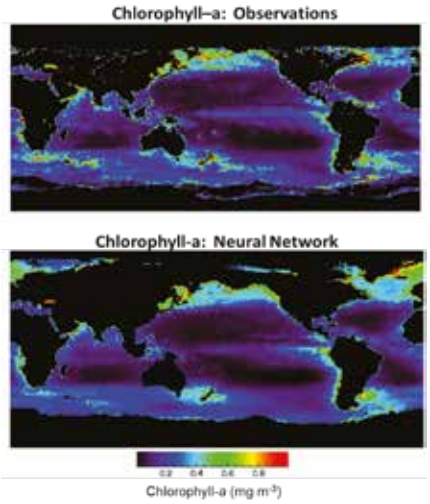
In response to NOAA Coral Reef Watch's daily global 5km satellite products, users have implemented protective measures for corals, such as reducing local stressors during high heat stress (e.g., by closing major scuba diving and fishing areas), rescuing rare corals, and shading/cooling key coral reefs in nurseries. The 5km satellite products also regularly inform multiple national and international assessments of coral reef conditions.

INTEGRATION OF SATELLITE DATA IN FLOOD MAPPING SOFTWARE FOR FLOOD MONITORING AND FORECASTING

The Advanced Baseline Imager (ABI) flood mapping system uses data from the NOAA NESDIS GOES-16 and GOES-17 satellites, which allows it to produce more timely flood maps. With the availability of ABI imagery every 5-10 minutes, this system detects floods in near real-time and updates flood maps every hour in mid-low latitudes covering America mainland and islands from early morning to late afternoon. It captures the most clear-sky coverage for flood mapping and provides flood maps most frequently, which makes it possible to show the dynamic change of floodwater. The ABI flood maps are integrated with those earlier developed using the JPSS polar orbiting VIIRS imagery. These new capabilities in flood mapping provide river forecasters and decision-makers with flood maps more efficiently. For example, during the 2020 spring break-up season, the ABI/VIIRS flood maps were used as a starting place for identifying areas with floodwaters in Minnesota counties along the Red River that were potentially outside of the flood warning polygons. When combined with other satellite imagery, forecasters were able to pinpoint areas of interest to gather information about flooding impacts and used the ABI/VIIRS flood maps for messaging. Similar applications were used during 2020's Hurricane Laura and Hurricane Delta in the gulf region, which provided the Federal Emergency Management Agency (FEMA) and NOAA NWS with the earliest flood situational information for decision making. The ABI/VIIRS flood maps have been adopted by NWS and FEMA for situational awareness, river forecasting, and disaster mitigation. The flood maps are also distributed through GEONETCast-Americas for agencies in other countries of Central and South America to use in their flood operations.

NOAA LEVERAGES ARTIFICIAL INTELLIGENCE FOR ENHANCED EXPLOITATION OF SATELLITE OCEAN COLOR OBSERVATIONS

NOAA is applying artificial intelligence algorithms to the large amount of data from its satellites in order to reduce computation time and better identify trends. NOAA NESDIS and NOAA NWS are researching and developing a technique for filling spatial and temporal gaps in satellite ocean color observations, in particular chlorophyll-a concentrations that enable biogeochemical modeling for ecosystem applications such as sustainable fishing and water-quality monitoring. The technique involves using artificial intelligence (machine-learning) to link ocean biological processes revealed by satellite ocean color data with physical measurements from buoys and other *in situ* data. This methodology provides more accurate and complete ocean



The figure depicts the close representation of large-scale features in observed chlorophyll-a concentration values and those computed by the neural network methodology for October 26, 2016.

initial conditions for use by models. NOAA has been transitioning its base model and data assimilation system to advance future developments with ocean color, both research and transition to operations using NOAA's Unified Forecast System (UFS) and Joint Effort for Data assimilation Integration (JEDI) frameworks. Enhanced coupled modeling of bio-physical processes linked to ocean color observations potentially can improve seasonal and interannual predictions, such as El Niño events, which can significantly affect the world's water cycle and impact the Blue Economy.

SCIENTIFIC DATA STEWARDSHIP AND PRODUCT DEVELOPMENT FOR SUBSURFACE OCEANOGRAPHIC DATASETS

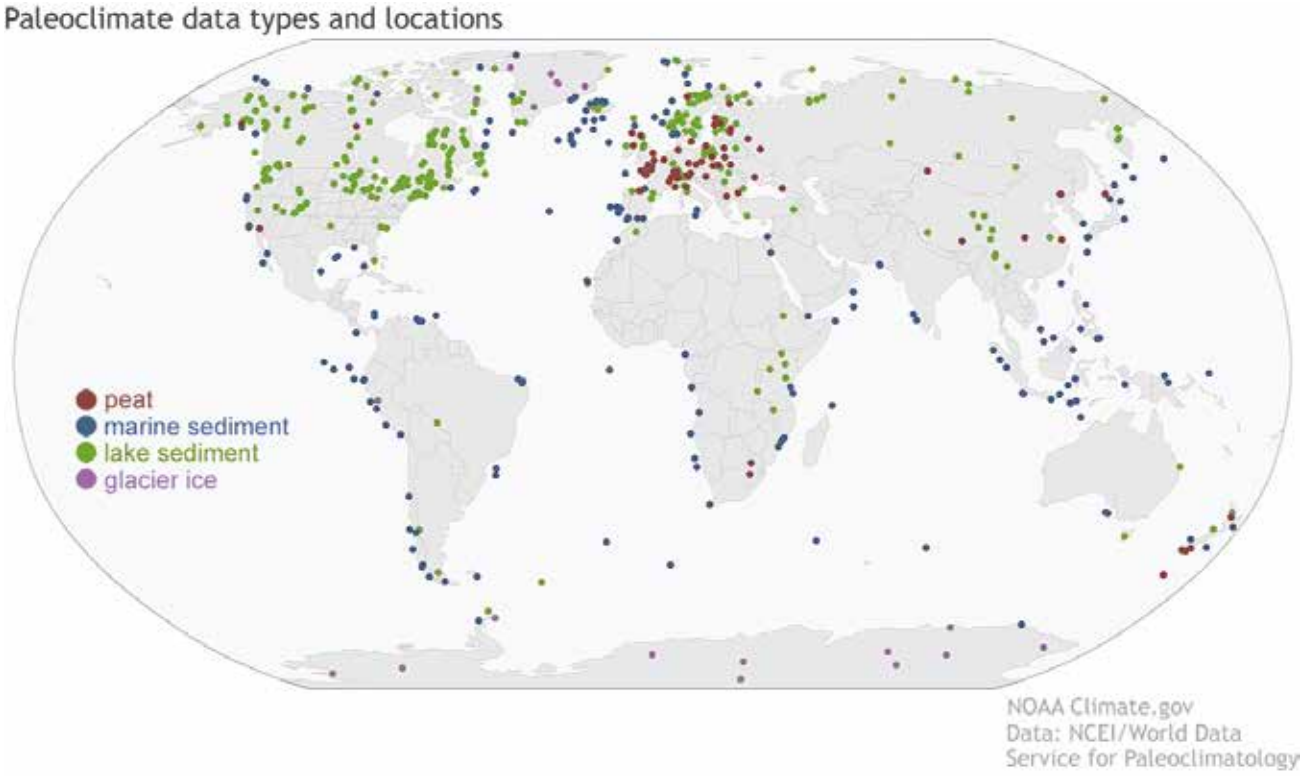
NOAA systematically gathers and provides all available national and international subsurface ocean water column data. High quality physical, chemical, and biological subsurface ocean measurements—past and present—provide a means to understand the changing ocean environment. To gather this data, researchers are using innovative observation systems such as ocean gliders, autonomous floats, and instrumented pinnipeds. The project emphasizes scientific quality control, standardized formatting, direct and easy public access, and incorporation into scientifically vetted products and tools for researchers and laymen alike to study, monitor, and understand the changing ocean. Roughly 500,000 oceanographic casts have been added to the World Ocean Database since October 1, 2019 to bring the total number of historic and recent oceanographic casts to 17.2 million.

EDUCATION SPOTLIGHT: ADEDOJA ADEYEYE

Adedoja Adeyeye is an oceanographic database manager progressing the integration of data to modern cloud technologies at the NOAA NESDIS Center for Coasts, Oceans, and Geophysics. Adedoja graduated from the City University of New York with a Master's degree in Civil and Environmental Engineering as a NOAA EPP/MSI Center for Earth System Sciences and Remote Sensing Technologies (CESSRST) Fellow. There he utilized the cloud and remote sensing technologies to facilitate data management and developed pipelines for real-time meteorological data upload for a weather station network dispatched across the five boroughs of New York City, NY. Adedoja conducted his EPP/MSI graduate internship at NOAA NESDIS where he developed an algorithm to validate satellite measurements from NOAA's Soil Moisture Operational Products System.

Adedoja Adeyeye, EPP/MSI Scholar alum and competitively selected as NESDIS Oceanographic Database Manager for NOAA Centers for Environmental Information. Credit: Adedoja Adeyeye

NATURE'S ARCHIVES: PIECING TOGETHER 12,000 YEARS OF EARTH'S CLIMATE STORY



"These records will help us determine if current warming has exceeded the range of temperature changes throughout the last 12,000 years," said Dr. Carrie Morrill, study co-author and research scientist with the University of Colorado Boulder and NOAA NESDIS. Credit: NOAA

Much like how archaeologists dig up artifacts to piece together stories of ancient civilizations, climate scientists dig up natural "artifacts" to piece together stories of past climates. From fossil pollen to air bubbles trapped in ice cores, these artifacts, or "proxies," allow scientists to compare current climate change to the past.

In April 2020, NOAA released the most comprehensive database ever assembled of proxies—many available publicly for the first time—that can tell scientists about temperatures since the last ice age ended roughly 12,000 years ago. By using records from multiple proxy sources, the scientists were able to cover every continent and ocean for a more complete reconstruction of Earth's climate over the past 12,000 years. In addition, comparing multiple proxy sources against each other allows scientists to reconstruct a more reliable and consistent story. Though our climate today is likely warming more rapidly than it has in the past, studying warm periods captured in the database might point out other consequences of global warming to help society plan for the future. This effort is the result of an international partnership between NOAA, academic universities, the U.S. and Swiss National Science Foundations, the Heising-Simons Foundation, and the Past Global Changes Project.

PRECISION MARINE NAVIGATION DISSEMINATION

NOAA is creating new online navigation services that will enable mariners to access critical marine navigation data in one convenient place. The Data Processing and Dissemination System uses cloud technology to enable machine-to-machine dissemination of integrated datasets, allowing mariners to make decisions efficiently when planning, transiting, and approaching ports. This new system also allows mariners' existing navigation software to automatically discover if NOAA has made new data available and ingest the data directly into their system. NOAA is working closely with industry partners to ensure that the service NOAA develops effectively disseminates navigation data. In September 2020, NOAA hosted a workshop with navigation equipment and navigation system manufacturers, pilots, and other federal agencies to collect feedback on the new online services. In July 2020, NOAA NOS released a new reformatted data service for surface water current forecasts. These data are now available for companies to test using different types of navigation software.

TELEPRESENCE SCIENCE MISSIONS IN NATIONAL MARINE SANCTUARIES

Hannah MacDonald (Office of National Marine Sanctuaries) hosts a live broadcast featuring footage of shipwrecks in Stellwagen Bank National Marine Sanctuary. Credit: Woods Hole Oceanographic Institution/NOAA (August 2020)

Dr. Kirstin Meyer-Kaiser (Woods Hole Oceanographic Institution) examines biological specimens collected from Stellwagen Bank National Marine Sanctuary shipwrecks under a microscope. Credit: Woods Hole Oceanographic Institution/NOAA (October 2020)

In 2020, NOAA NOS invited the public to participate in science missions facilitated through the use of underwater exploration systems. Using ship-to-shore technology, scientists led remotely operated vehicle exploration at Stellwagen Bank, Olympic Coast, Monterey Bay, and Channel Islands National Marine Sanctuaries. Students and the public participated in dozens of virtual, interactive sessions as well as live feeds of the exploration and sample collection. In total, more than 1.3 million people viewed the videos. The objectives included exploring deep-sea canyon and coral communities, assessing changes over time at octopus brooding areas and the sites of decomposing whale carcasses, and surveying biological and archaeological features of shipwrecks. These missions were made possible through partnerships with groups including the Global Foundation for Ocean Exploration, Ocean Exploration Trust, and Woods Hole Oceanographic Institution.

NOAA DEVELOPMENT OF A WEBCAM COASTAL OBSERVING NETWORK

The Buxton, NC (left) and Miami Beach, FL (right) webcams installed as part of the pilot webcam observation network. Image Credit: Surfline Inc.

NOAA NOS launched a pilot observation network to collect imagery from a series of web-enabled cameras mounted along the southeast coast of the United States. The collected imagery provides a new way to collect data on rip currents, high tide flooding, and other coastal hazards. Images are also used to identify marine mammals along the coast, as well as to track human uses of natural resources —including beach use during the COVID-19 pandemic. Images are acquired and processed in a standardized way so they may be incorporated into a wide range of downstream scientific applications and products. The pilot program is a public-private partnership that includes NOAA, the Southeast Coastal Ocean Observing Regional Association, the U.S. Geological Survey, Surfline Inc., the University of North Carolina Wilmington, and University of South Carolina.

HURRICANE GLIDERS PATROL SURFACE WATERS TO IMPROVE HURRICANE FORECASTS

Hurricane gliders help improve the accuracy of intensity forecasts by collecting critical data about ocean temperature and salinity in a storm environment. When these data are used in research and included in hurricane models, scientists have been able to significantly reduce forecast intensity error. These and other ocean observations provide key contributions that allow for a better assessment of the ocean conditions under the storm in advance of landfall. In 2020, NOAA, the U.S. Navy, U.S. Integrated Ocean Observing System, and academic partners completed a total of 47 glider missions with a combined 2,275 days at sea and almost 180,000 ocean profiles that were transmitted in real-time to data centers, used in analyses, and assimilated into NOAA operational forecast models.

TRACKING A DIFFERENT KIND OF HAZARD: HYSPLIT MODELS THE TRAJECTORY OF AN UNPRECEDENTED SURGE IN DESERT LOCUST SWARMS

In 2020, the worst desert locust swarms in a quarter century decimated crops in parts of Africa and Asia. In response to this emergency, two NOAA scientists created and released a web application used operationally by the Food and Agriculture Organization (FAO) of the United Nations to help forecast the global movement of these historically unprecedented numbers of desert locusts. The app, which is based on NOAA's HYSPLIT dispersion model, allows FAO to issue forecasts and warnings to affected countries, giving local officials time to facilitate countermeasures—such as aerial spraying—to protect the food supply in already vulnerable regions. The FAO and other organizations had already been using NOAA's

HYSPLIT model to forecast swarm movements, and, in collaboration with the FAO Senior Locust Forecasting Officer, the model was expanded to include parameters specific to the locusts' known behaviors and to provide a user-friendly interface customized for locust forecasting. NOAA's powerhouse HYSPLIT model is widely used for determining where air pollutants originated and predicting their likely path of transport, dispersion, and deposition based on NOAA meteorological forecasts. This new application is further proof that HYSPLIT is highly valuable in addressing not only public safety concerns, but also economic and ecological challenges. While originally developed to support FAO, the new web app is now being used widely by other stakeholders in locust-threatened regions to aid in their response planning.

> "This has really improved our ability to assess the desert locust situation and forecast its developments globally. This is vital to the affected countries for better planning and implementation of the necessary control operations on time."— Keith Cressman, FAO's Senior Locust Forecasting Officer

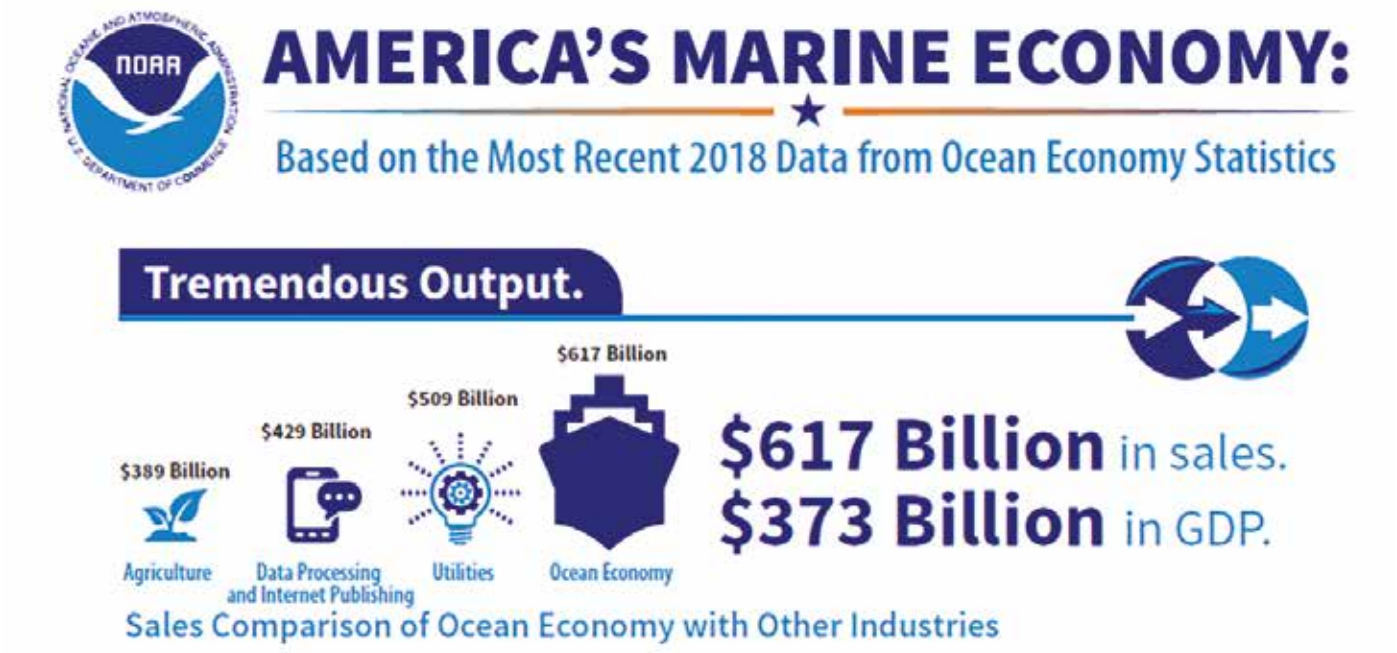
DEVELOPMENT OF THE NEXT GENERATION MODEL FOR SEASONAL TO DECADAL PREDICTION

NOAA's next generation seasonal to multi-decadal prediction and projection system, called Seamless system for Prediction and EArth system Research (SPEAR), takes advantage of many recent modeling advancements including the FV3 dynamical core, MOM6 ocean code, LM4 land model, and SIS2 sea ice model, all developed by NOAA Research. SPEAR is able to simulate many aspects of Earth's climate system with a high degree of accuracy, including regional precipitation and extremes, the El Niño-Southern Oscillation, the Pacific Decadal Oscillation, and the Atlantic Meridional Overturning Circulation. This model will also be used in experimental decadal prediction, as well as a suite of research activities on seasonal to centennial time scales. For example, SPEAR-based predictions will be used to inform NOAA's seasonal outlooks for temperature and precipitation, NOAA's seasonal hurricane outlook, and experimental Arctic sea ice extent predictions. This project advances NOAA's capacity to improve society's ability to plan for and respond to changing environmental risks.

MEASURING THE U.S. MARINE ECONOMY

NOAA and the Bureau of Economic Analysis are working to produce an "Ocean Economy Satellite Account (OESA)," a statistical account measuring the U.S. marine economy. This three-year effort builds on decades of research on defining and measuring the marine economy, with significant contributions by the Middlebury Institute's Center for the Blue Economy. The prototype results, published in June 2020, show that the U.S. marine economy, including goods and services, yielded $617 billion in gross output (total production) and contributed about $373 billion to the nation's gross domestic product in 2018. OESA's experimental results include statistics for 55 marine industry groups, organized into ten major sectors: tourism and recreation, including recreational fishing; national defense and public administration; offshore minerals, including oil and gas; transportation and warehousing; living resources, including commercial fishing and aquaculture; ship and boat building;

power generation; research and education; construction; and professional and technical services. These data show that the marine economy is vital to the nation, with total production that is greater than the agriculture or public utility industries. The data, currently spanning 2014 to 2018, will help national policy makers, marine industries, and investors make informed decisions about how to plan for the future—protecting our people, our economy, and our environment for future generations. In addition, this data can serve as a baseline to measure the magnitude of the impacts of COVID to the marine economy. The data, report, and other materials are available at https://www.bea.gov/data/special-topics/ocean-economy and any questions can be sent to OceanEconomy@noaa.gov.



NOAA RELEASES UPDATES TO GEOMAGNETISM MODELS

In 2020, NOAA released upgrades for geomagnetism models that are used for navigation and energy activities.

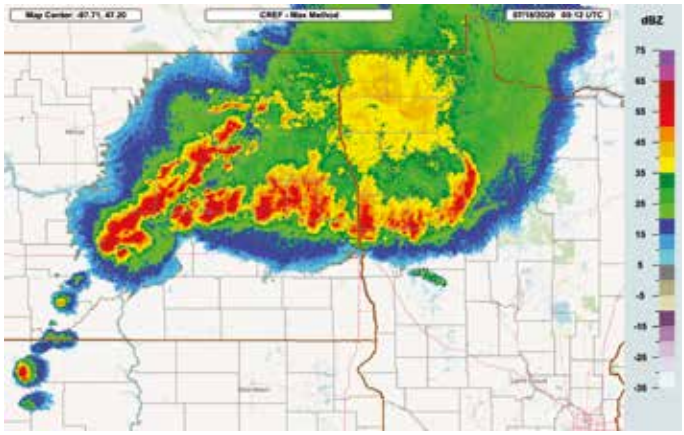
NOAA NESDIS released the World Magnetic Model 2020 (WMM2020), a model that is widely used in navigation and heading (the direction in which a vehicle/vessel is pointed) systems, including smartphones. Scientists from NOAA, the British Geological Survey, and the National Geospatial-Intelligence Agency published a technical report that provides a comprehensive description of the WMM2020, how the model was constructed, and how its uncertainties were estimated. It also includes a description of the new blackout zones used in updated U.S. Department of Defense Safety of Navigation guidance. The WMM is the standard model used by the U.S. Department of Defense, the U.K. Ministry of Defence, the North Atlantic Treaty Organization (NATO), and the International Hydrographic Organization (IHO), for navigation, altitude, and heading referencing systems using the geomagnetic field.

NOAA NESDIS and the Cooperative Institute for Research in Environmental Sciences developed updates to two geomagnetic models in collaboration with the oil and gas industry. The High Definition

Geomagnetic Model (HDGM) is a global, high-resolution model providing values of the main and crustal magnetic fields at any point near the Earth's surface. The HDGM Real-Time (HDGM-RT) additionally provides, in real-time, magnetic fields generated by electric currents in the magnetosphere and the ionosphere. Well planners can use HDGM and HDGM-RT to compute magnetic reference values, as well as easily integrate the two models into their directional drilling software.

MAKING USE OF THE PUBLIC CLOUD FOR NON-ALERTING DISSEMINATION APPLICATIONS

In support of NOAA's cloud-smart strategy, NOAA NWS has leveraged the NOAA Cloud Utility Contract to begin initial application development on the public cloud. The public cloud is where a service provider makes resources available to the public via the internet versus on-premise where a given organization hosts the hardware and software themselves. NWS made its decision on using the public cloud based on public access, increased flexibility, and possible cost savings. An example of using the public cloud is the development version of the multi-radar/multi-sensor system (MRMS) application in the Amazon cloud space. NWS also started software development in the public cloud on the new NWS Enterprise National GIS Viewer, leveraging a code base developed by NOAA. Hosting the applications in the public cloud enables greater development flexibility and frees resources for disseminating critical weather information.



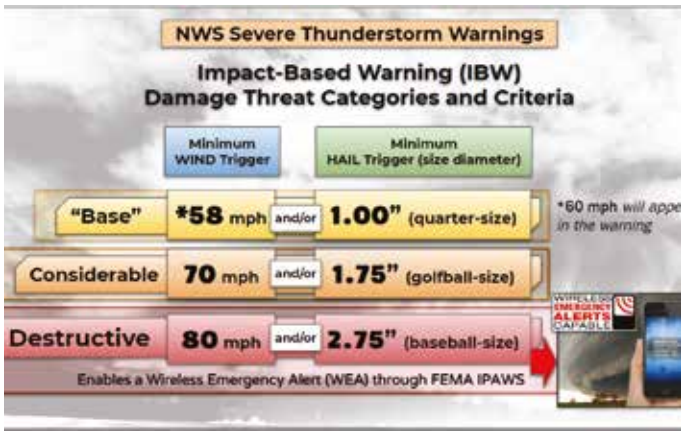
Composite reflectivity field at 0012 UTC July 17, 2020 over the north-central United States produced by the Multi-Radar Multi-Sensor (MRMS) system using code hosted on the public cloud.

THREE-TIER CATEGORIZATION OF DAMAGE THREAT LEVELS IN NWS SEVERE THUNDERSTORM WARNINGS

Since the devastating "Super Derecho" plowed through the Upper Midwest and Mid Atlantic Regions on June 29, 2012, the NWS has been working to address the need for different levels of severity in thunderstorm warnings. While destructive thunderstorms are rare, they pose a unique threat to life and property with nearly 30 fatalities each year attributed to straight-line wind or hail. To address this risk, the NWS will outfit the warning generation software with enhancements to the current "Impact-Based Warning" (IBW) format that more closely aligns with Tornado and Flash Flood Warnings. As such, Severe Thunderstorm Warnings will contain new "damage threat" tags which categorize the storm's wind and/or hail threats into one of three levels. These threats that reach the highest tier (the "destructive" damage threat tag) will instantly sound specially tailored Wireless Emergency Alert messages, which will activate emergency alert-enabled smartphones within the warned area. Internal studies have shown that only about 10 percent of thunderstorms annually would reach this level, thus

ensuring the special alert will only occur for the most destructive storms. Future research and development efforts, specifically with the Forecasting A Continuum of Environmental Threads (FACETs)-related research and outputs tools, may further enhance this paradigm by including regional and localized climatological and societal impact-based services for severe thunderstorms, as well as the added benefits from the potential utilization of the Common Alerting Protocol (CAP)standard.

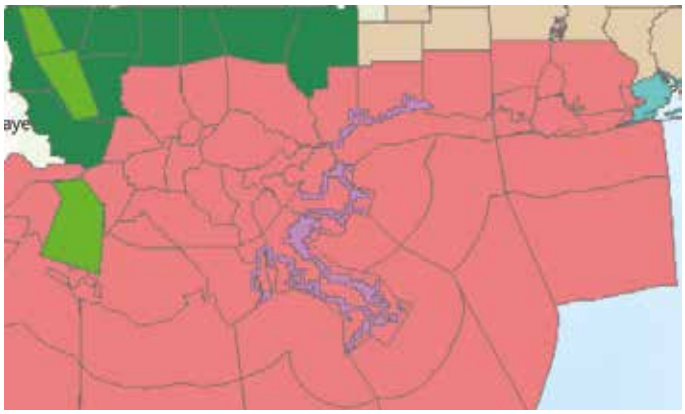
The new three-tiered damage threat categories and associated criteria that will be enabled in NWS Severe Thunderstorm Warnings, beginning in the spring of 2021. The highest of the tiers, if reached within a specific warning or update to a warning, will trigger a Wireless Emergency Alert for smartphones within the warned area.



The new three-tiered damage threat categories and associated criteria that will be enabled in NWS Severe Thunderstorm Warnings, beginning in early 2021. The highest of the tiers, if reached within a specific warning or update to a warning, will trigger a Wireless Emergency Alert for smartphones within the warned area.

IMPROVED TROPICAL WEB SERVICES ALLOW PUBLIC TO BETTER PREPARE FOR TROPICAL CYCLONES

NOAA NWS implemented two new tropical services to update existing geographic information system (GIS) services.The new tropical web services now provide highly requested information depicting the earliest arrival time of tropical winds as well as higher resolution of coastal storm surge and watch/warning location information. Now our partners and the public can better prepare for tropical cyclones in their area. In addition, with NWS's improved GIS systems users can retrieve and ingest data from the National Hurricane Center, improving the display of selected data layers.



New Tropical Watch/Warning/advisory-Storm Surge Watch/Warning GIS web service. The purple fill is the higher resolution information provided via the NWS's National Hurricane Center files.

NOAA UPDATES ALGORITHM TO IMPROVE SEA ICE CONCENTRATION ESTIMATES

Through tracking sea ice concentration—the fraction of an area covered by sea ice—NOAA NESDIS produces authoritative data on how much sea ice concentrations have changed on a daily and monthly basis in the Arctic and Antarctic. In 2020, NOAA updated the algorithm for processing the satellite data to improve ice concentration estimates. This climate data record is measured using satellite passive microwave data, where microwaves can penetrate clouds to detect sea ice regardless of cloud cover

and the time of day. By making these measurements over both poles, NESDIS scientists can estimate the fraction of ocean area covered by sea ice. These data are used by many stakeholders, including physical scientists studying the interaction between the ocean, sea ice, and atmosphere; biologists studying ice-dependent species; oceanographers examining how changes in sea ice affect ocean circulation; and permafrost scientists investigating the effect of increased ice-free periods on thawing of permafrost in coastal regions.

NOAA UTILIZES UNCREWED SYSTEMS TO COLLECT OBSERVATIONS IN REMOTE ENVIRONMENTS

Collecting observations is a critical part of doing research, but it can be a lengthy, challenging process, and in some cases—especially when dealing with severe weather or treacherous terrain—it can pose a danger to scientists. That's where uncrewed systems, such as saildrones, can play a big role in the data-collection process.

A new study by researchers at NOAA Fisheries demonstrated that unmanned wind- and solar-powered drones can be valuable tools to learn more about a declining population of northern fur seals on the remote island of St. Paul in the Bering Sea. Researchers used satellite tags and a saildrone to follow individual fur seals as far as 150 kilometers and collect data on the prey and ocean conditions that the seals experienced. This study marks the first time saildrones have been used to track a marine mammal. Collected data will help scientists better understand the environmental and biological features that influence an animal's ability to find prey. This information is particularly valuable for developing management strategies for this declining population and similar research could provide useful data for other protected species managed by NOAA Fisheries.

NOAA NOS worked with several partners to develop and test novel autonomous underwater vehicles (AUV) and multispectral uncrewed aircraft systems (UAS) for characterizing oil in the water after oil spills. Rapid characterization of oil in the water column and floating on the water surface during and after oil spills is critical information for both oil spill response and natural resource damage assessments. Testing from a U.S. Coast Guard (USCG) vessel at the Coal Point oil seep site near Santa Barbara, CA, demonstrated how these systems have advanced the ability to respond to and assess impacts from oil spills. The AUV REMUS 600 and sensor/sampling systems conducted three-dimensional mapping of dissolved hydrocarbons and oil droplets in the water column beneath the oil slick while the UAS conducted surface mapping of the oil slick. These data can be provided to spill responders for situational awareness and rapid response decision-making. The project was conducted by a partnership that includes NOAA, Woods Hole Oceanographic Institute, the Bureau of Safety and Environmental Enforcement, the Environmental Protection Agency, the USCG, Water Mapping LLC, and the Coastal Response Research Center.

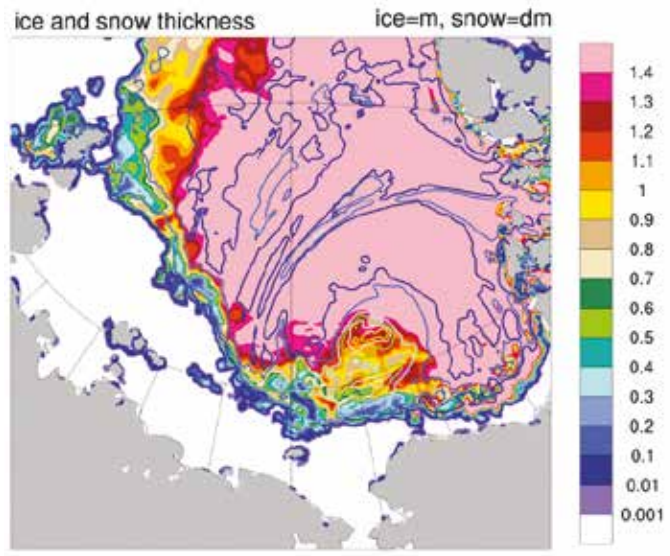
NOAA LAUNCHES UNCREWED SYSTEMS TO MONITOR CHANGES IN THE U.S. ARCTIC

In May 2019, NOAA, in partnership with NASA and Saildrone, Inc., launched six uncrewed saildrones loaded with scientific instruments and cameras from a dock in Dutch Harbor, AK to monitor ongoing changes to the U.S. Arctic ecosystem food chain, ice movement, carbon dioxide, and large-scale climate and weather systems. This was the first year NOAA Research scientists and collaborators used saildrones to get as close to the Arctic's ice edge as possible, allowing them to gather data in this hostile and remote environment. This is also the first time saildrone observations were compared to operational numerical weather predictions in real time, allowing scientists to see gaps in the accuracy of the forecasts.

NOAA's Pacific Marine Environmental Lab has been using saildrones to better understand Arctic Sea Ice. Over the course of the five-month mission, the saildrones sailed into the ice edge dozens of times. Credit: Saildrone Inc.

NOAA DEVELOPMENT OF AN EXPERIMENTAL SEA ICE FORECAST SYSTEM

A NOAA Research-developed high-resolution, forecast modeling system provides tailored daily sea ice forecasts as experimental guidance to stakeholders. This experimental sea ice forecast information takes into account the influence of the atmosphere and ocean on the annual sea ice freeze/melt cycle and is used to guide marine and transportation safety decisions. NOAA Research and NOAA NWS used this experimental forecast system to assess the performance of development versions of the NOAA Unified Forecast System (UFS) for the Arctic region, and to improve operational UFS-based forecasts. Additionally, the information is being used by the NWS Alaska Region and other stakeholders including the National Ice Center in preparing operational sea ice forecasts and to guide marine and transportation safety decisions.



One of the experimental sea-ice forecast products available from the NOAA Physical Sciences Laboratory (PSL). This product provides forecasts of Arctic ice and snow thickness up to 10 days in advance using the NOAA-PSL Coupled Arctic Forecast System. Photo credit: NOAA and Cooperative Institute for Research in Environmental Sciences

BIBLIOMETRICS

This chapter represents a rigorous assessment of NOAA's scholarly research output between 2015 and 2019. Through analysis of publications authored during that time period, NOAA's core research areas were identified and used to establish a robust scholarly performance metric to demonstrate NOAA's productivity and impact within these research areas. As a benchmarking exercise, these metrics were then compared with those of other federal agencies conducting research in these disciplines.

The research areas listed below represent the bulk of NOAA's scholarly output between 2015 and 2019, with approximately 86 percent of all NOAA articles identified falling within one or more of these eight disciplines, all of which are strongly aligned with the agency's mission objectives.

1. Meteorology and Atmospheric Sciences
2. Environmental Sciences
3. Marine and Freshwater Biology
4. Oceanography
5. Ecology
6. Fisheries
7. Geosciences
8. Remote Sensing

For each research area, we then compared NOAA's productivity and impact metrics with those of the four other Federal agencies that were most productive in that research area.

List of comparison agency abbreviations:

DOD: U.S. Department of Defense

DOE: U.S. Department of Energy

DOI: U.S. Department of the Interior

EPA: Environmental Protection Agency

NASA: National Aeronautics and Space Administration

USDA: U.S. Department of Agriculture

SI: Smithsonian Institution

METHODOLOGY

Scholarly data and metrics for this report were obtained using InCites (Clarivate Analytics), a web-based platform that allows for the assessment of the research productivity and relative impact of research organizations based on peer-reviewed articles indexed in Web of Science. For the purposes of this report, a "NOAA article" is defined as a peer-reviewed publication indexed in the Web of Science (WoS) Core Collection and identified by WoS indexers as having one or more authors who list their affiliation as National Oceanic and Atmospheric Administration.

This report analyzes articles that fit these criteria and were published between 2015 and 2019 and indexed in the InCites dataset as of September 16, 2020. Articles that only acknowledge the receipt of financial, logistical, or other support from NOAA or any NOAA office or program are not included in this report. Also not included in this analysis are book chapters, conference papers, technical reports, and other items including some journal articles which are not indexed by WoS. As such, the publication counts presented in this report can be assumed to be undercounts of the actual number of publications produced by NOAA. However, the reported counts can be considered a representative sample of NOAA's research output between 2015 and 2019.

This report focuses on NOAA's eight core research areas, determined by using the WoS research schema, comprised of approximately 250 research areas assigned to articles based on the journals in which they are published. Within each research area, productivity and impact was assessed based on the total number of published articles and the following citation metrics: i) Hirsch-Index or H-Index; ii) percent of documents which have received citations; iii) percent of documents in the top 10 percent of articles cited. For benchmarking purposes, productivity and impact data were collected for the fourmost productive federal agencies aside from NOAA, within each core research area. The articles on which these data are based are identified using the same methodology used for identifying NOAA articles. Additional productivity and citation metrics have been included which illustrate NOAA's research output as a whole and provide context for the rest of the analysis. These metrics include total number of NOAA-authored peer-reviewed publications, total citations received, percent of articles cited, percent of articles in the top 10 percent by citation, and international collaborations and were obtained using InCites and WoS. The international collaboration map was created using the Science of Science Tool (Sci2) using the country or territory associated with author affiliations for coauthors of NOAA-articles for which that data were available. The analysis in this report is distinct from that presented in the Bibliometrics Analysis of Articles by NOAA-affiliated and Funded Authors Published During Fiscal Year 2019 as the time period covered and dataset analyzed differ significantly. The analysis in that report is based on a curated bibliography of NOAA articles published since fiscal year 2012 as identified by the staff in the NOAA Central Library. Any discrepancies in publication counts or indicators is due to this difference in methodology.

REFERENCES:

NAS (2012). Best Practices in Assessment of Research and Development Organizations, The National Academies Press.

D.Hicks, P. Wouters, L. Waltman, S. de Rijke, I. Rafols. (2015). The Leiden Manifesto for Research Metrics, Nature(520)429-431.

Bibliometrics

NOAA Peer-reviewed articles 2015-2019

10,270
Total Publications

110
h-index

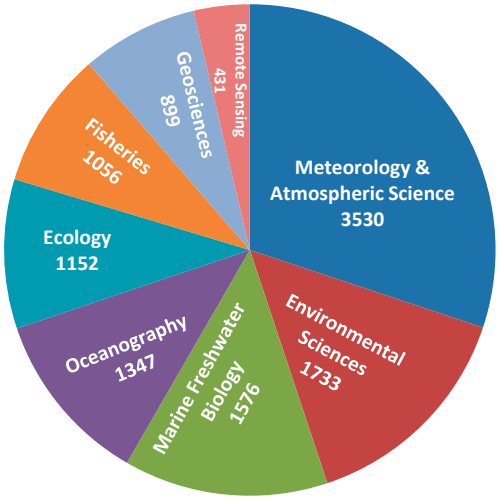
137,281
Sum of Times Cited

77.9%
% of Articles Cited

10.11%
of Articles in Top 10% by citation

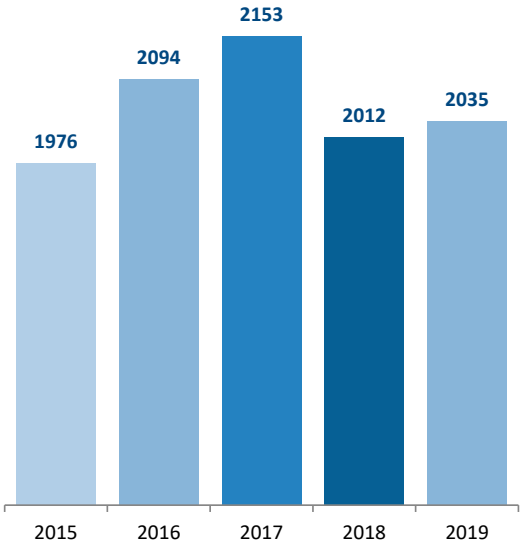
A "NOAA article" is defined as a peer-reviewed publication indexed in the Web of Science (WoS) Core Collection and identified by WoS indexers as having one or more authors who list their affiliation as National Oceanic and Atmospheric Administration. This report analyzes articles that fit these criteria and were published between 2015 and 2019 and indexed in the InCites dataset as of September 16, 2020. As an organization, NOAA has an *h*-index of 110 meaning that of the 10,270 articles published by NOAA authors in the period this report reflect, 110 have been cited at least 110 times.

Top Research Areas



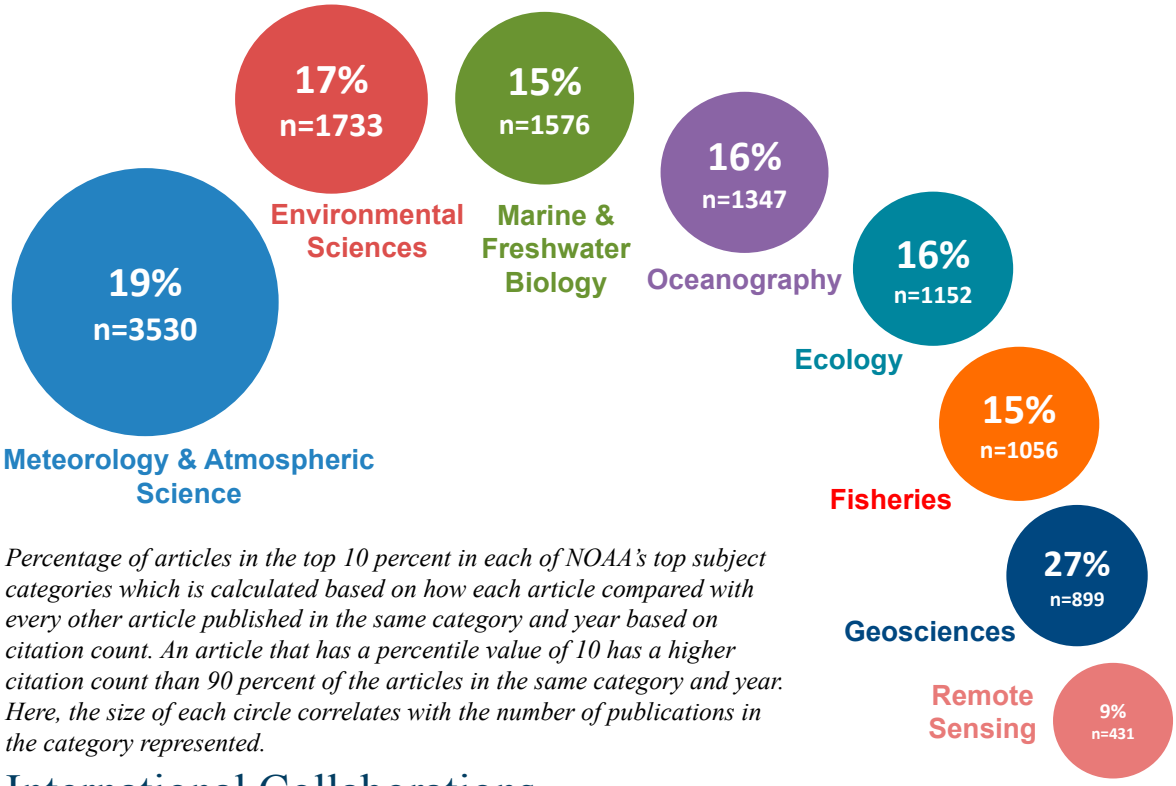
86 percent of NOAA articles fall within these eight subject categories. Subject categories are defined, and assigned to articles, by Web of Science based on the journal in which each article was published. A single article may be assigned to multiple subject categories.

Articles per year



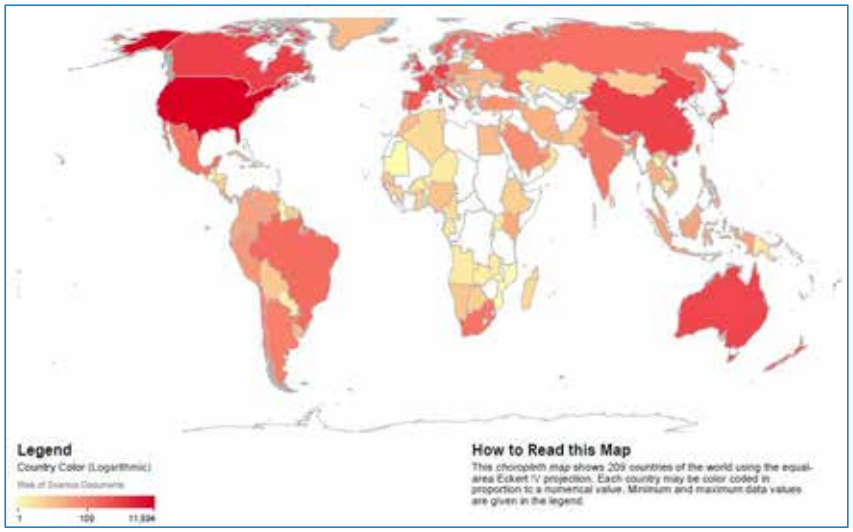
Non-cumulative number of NOAA articles published per year. On average NOAA authors have published 2,054 articles annually between 2015 and 2019.

Percentage of Articles in Top 10 Percent by Citation



Percentage of articles in the top 10 percent in each of NOAA's top subject categories which is calculated based on how each article compared with every other article published in the same category and year based on citation count. An article that has a percentile value of 10 has a higher citation count than 90 percent of the articles in the same category and year. Here, the size of each circle correlates with the number of publications in the category represented.

International Collaborations



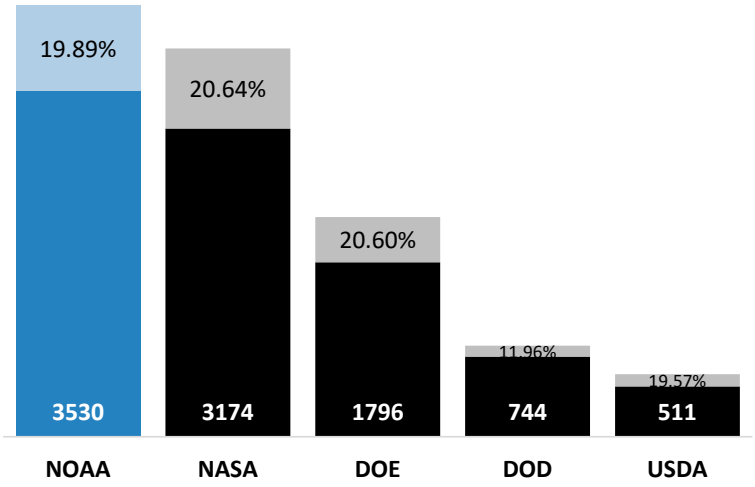
NOAA authors have collaborated with authors at **2,115** institutions in **154** countries and territories.

How to Read this Map

In this map each country is color coded in proportion to a numerical value which represents co-authorship on NOAA publications. Darker shades correlate with more articles coauthored with NOAA authors. Minimum and maximum data values are given in the legend.

Meteorology and Atmospheric Sciences

Total Number of Articles by Agency



Between 2015 and 2019, NOAA published an average of 706 articles per year in the field of meteorology and atmospheric sciences, resulting in a total of 3530 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in meteorology & atmospheric sciences.

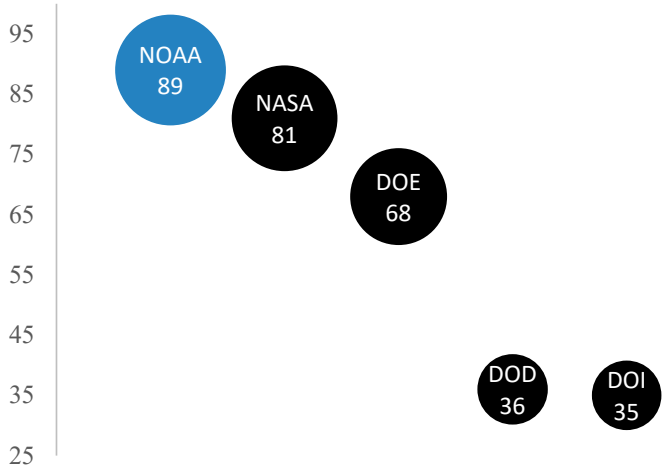
Top Journals where NOAA Publishes

- Journal of Climate
- Bulletin of the American Meteorological Society
- Atmospheric Chemistry and Physics
- Journal of Geophysical Research - Atmospheres
- Monthly Weather Review

Highly Cited NOAA Articles

- Huang, et al. 2017. Extended Reconstructed Sea Surface Temperature Version 5 (ERSSTv5): Upgrades, Validations, and Intercomparisons. J Climate.
- Newman, et al. 2016. The Pacific Decadal Oscillation, Revisited. J Climate.
- Benjamin, et al. 2016. A North American Hourly Assimilation and Model Forecast Cycle. Monthly Weather Review.

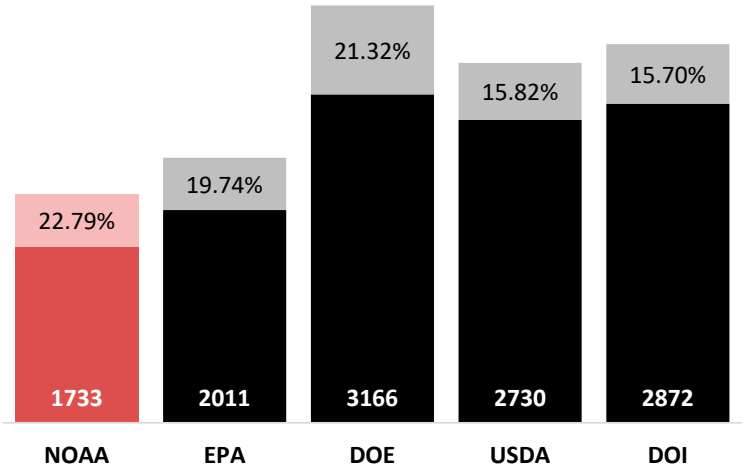
H-Index



Within the field of meteorology and atmospheric sciences, NOAA has an *h-index* of 89 - meaning that 89 of these articles have been cited in the peer-reviewed literature at least 89 times

Environmental Sciences

Total Number of Articles by Agency



Between 2015 and 2019, NOAA published an average of 347 articles per year in the field of environmental sciences, resulting in a total of 1733 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in environmental sciences.

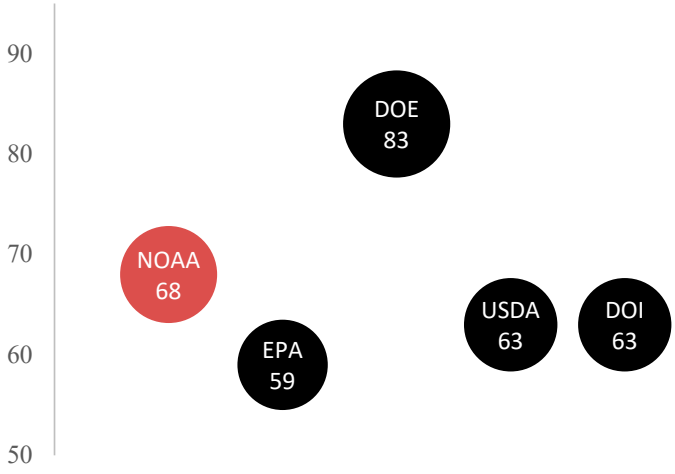
Top Journals where NOAA Publishes

- Atmospheric Chemistry and Physics
- Nature Climate Change
- Environment Science & Technology
- Atmospheric Environment
- Remote Sensing of the Environment

Highly Cited NOAA Articles

- Rolph,et al. 2017. Real-time Environmental Applications and Display sYstem: READY. Environ Model & Soft.
- Di Lorenzo & Mantua. 2016. Multi-year persistence of the 2014/15 North Pacific marine heatwave. Nature Climate Change.
- Milly & Dunne. 2016. Potential evapotranspiration and continental drying. Nature Climate Change.

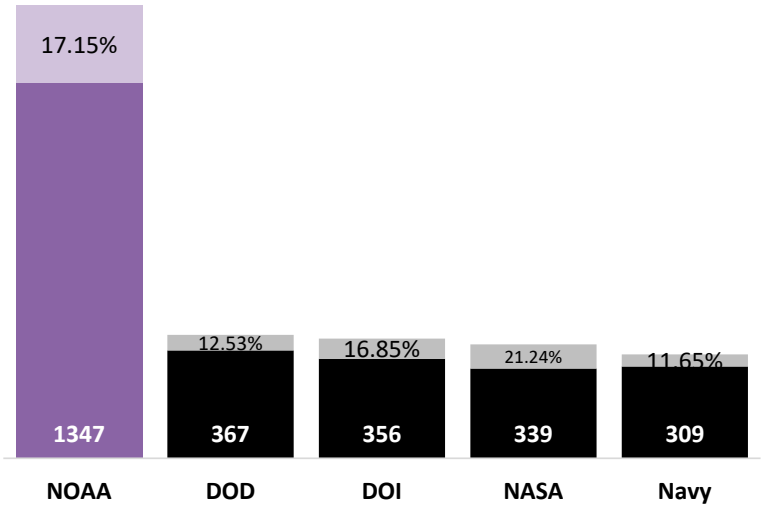
H-Index



Within the field of environmental sciences, NOAA has an *h-index* of 68 - meaning that 68 of these articles have been cited in the peer-reviewed literature at least 68 times.

Oceanography

Total Number of Articles by Agency



Between 2015 and 2019, NOAA published an average of 269 articles per year in the field of oceanography, resulting in a total of 1,347 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in oceanography.

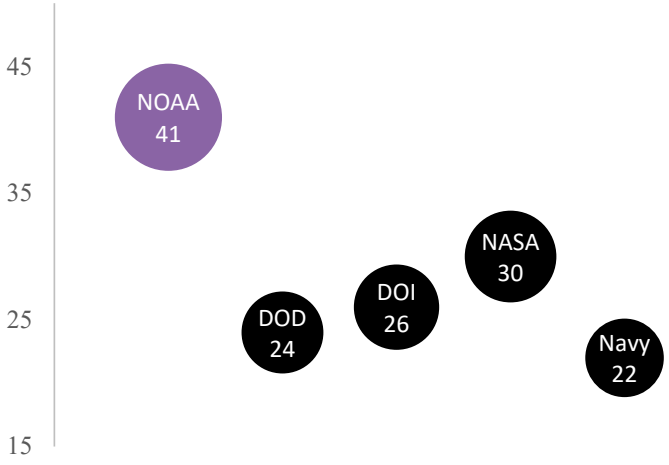
Top Journals where NOAA Publishes

- Marine Ecology Progress Series
- Journal of Geophysical Research - Oceans
- ICES Journal of Marine Science
- Deep Sea Research - Part II
- Ocean Modelling

Highly Cited NOAA Articles

- Saba, et al. 2016. Enhanced warming of the Northwest Atlantic Ocean under climate change. JGR – Oceans.
- Johnson, et al. 2017. Biogeochemical sensor performance in the SOCCOM profiling float array. JGR – Oceans.
- Danabasoglu, et al. 2016. North Atlantic simulations in Coordinated Ocean-ice Reference Experiments phase II. Ocean Modelling.

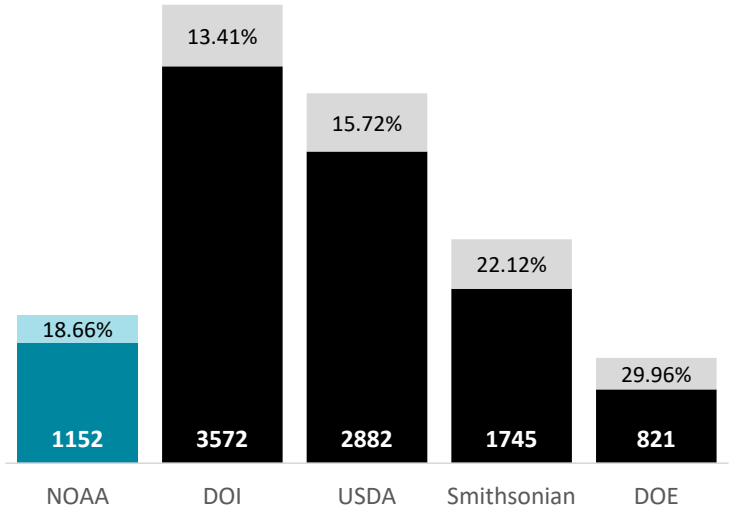
H-Index



Within the field of oceanography, NOAA has an *h-index* of 41 - meaning that 41 of these articles have been cited in the peer-reviewed literature at least 41 times

Ecology

Total Number of Articles by Agency



Between 2015 and 2019, NOAA published an average of 230 articles per year in the field of ecology, resulting in a total of 1,152 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in ecology.

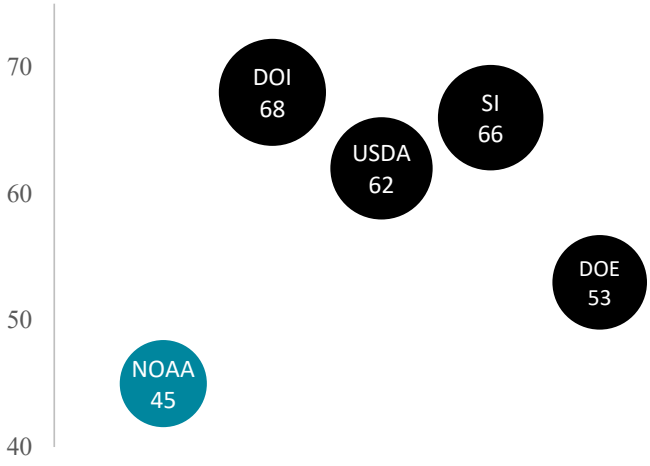
Top Journals where NOAA Publishes

- Marine Ecology Progress Series
- Biogeosciences
- PLOS One
- Proceedings of the Royal Society B
- Global Change Biology

Highly Cited NOAA Articles

- Gill, et al. 2017. Capacity shortfalls hinder the performance of marine protected areas globally. Nature.
- Heymans, et al. 2016. Best practice in Ecopath with Ecosim food-web models for ecosystem-based management. Eco Modelling.
- Roberts, et al. 2016. Habitat-based cetacean density models for the US Atlantic and Gulf of Mexico. Sci Rep.

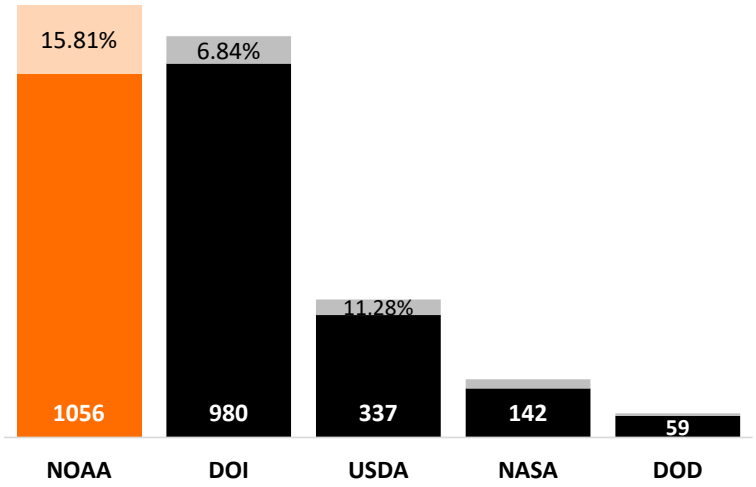
H-Index



Within the field of ecology, NOAA has an *h-index* of 45 - meaning that 45 of these articles have been cited in the peer-reviewed literature at least 45 times.

Fisheries

Total Number of Articles by Agency



Between 2015 and 2019, NOAA published an average of 211 articles per year in the field fisheries, resulting in a total of 1,056 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in fisheries.

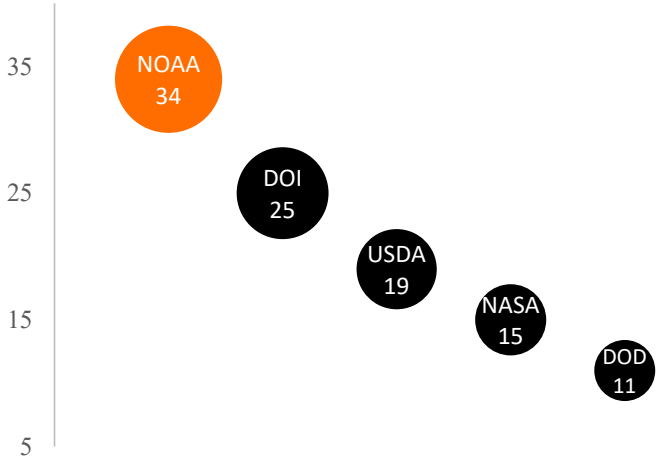
Top Journals where NOAA Publishes

- ICES Journal of Marine Science
- Can Journal of Fisheries & Aquatic Science
- Fisheries Research
- Transactions Amer Fisheries Society
- Fishery Bulletin

Highly Cited NOAA Articles

- Hare, et al. 2016. A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast US Continental Shelf. PLOS One.
- Collie, et al. 2016. Ecosystem models for fisheries management: finding the sweet spot. Fish & Fisheries.
- Erisman, et al. 2017. Fish spawning aggregations: where well-placed management actions can yield big benefits for fisheries and conservation. Fish & Fisheries.

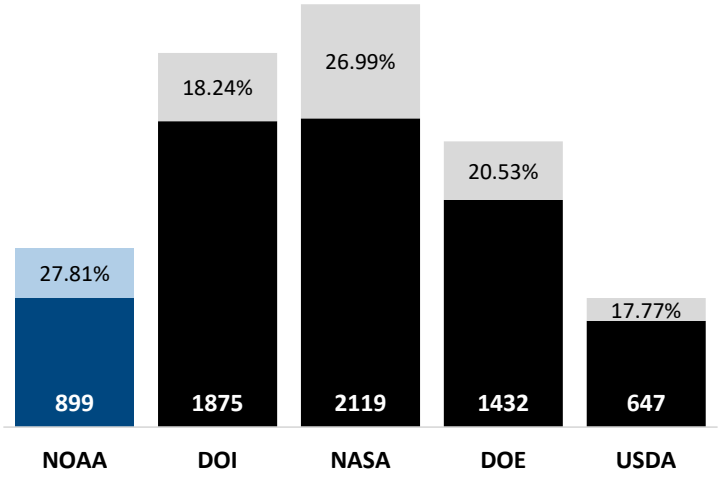
H-Index



Within the field of fisheries, NOAA has an *h-index* of 34 - meaning that 34 of these articles have been cited in the peer-reviewed literature at least 34 times.

Geosciences

Total Number of Articles by Agency



Between 2015 and 2019, NOAA published an average of 180 articles per year in the field of geosciences, resulting in a total of 899 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in geosciences.

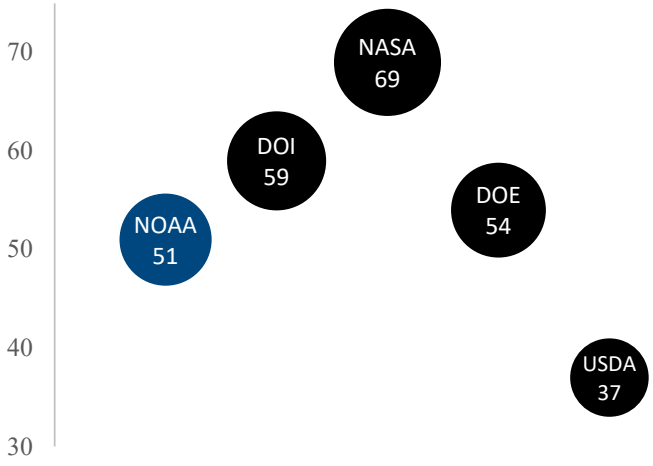
Top Journals where NOAA Publishes

- Geophysical Research Letters
- Nature Geoscience
- Biogeosciences
- Geoscientific Model Development
- Global Biochemical Cycles

Highly Cited NOAA Articles

- Eyring, et al. 2016. Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. Geosci Model Devel.
- Nisbet, et al. 2016. Rising atmospheric methane: 2007-2014 growth and isotopic shift. Global Biochem Cycles.
- Jacox, et al. 2016. Impacts of the 2015-2016 El Nino on the California Current System. Geophys Res Lett.

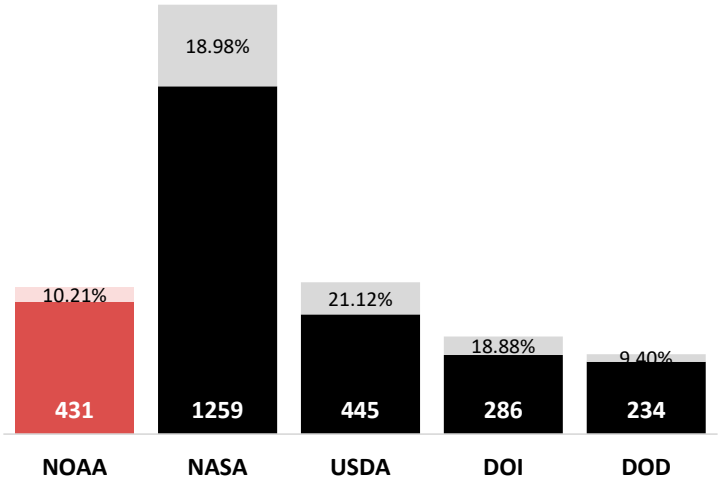
H-Index



Within the field of geosciences, NOAA has an *h-index* of 51 - meaning that 51 of these articles have been cited in the peer-reviewed literature at least 51 times.

Remote Sensing

Total Number of Articles by Agency



Between 2015 and 2019, NOAA published an average of 86 articles per year in the field of remote sensing, resulting in a total of 431 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in remote sensing.

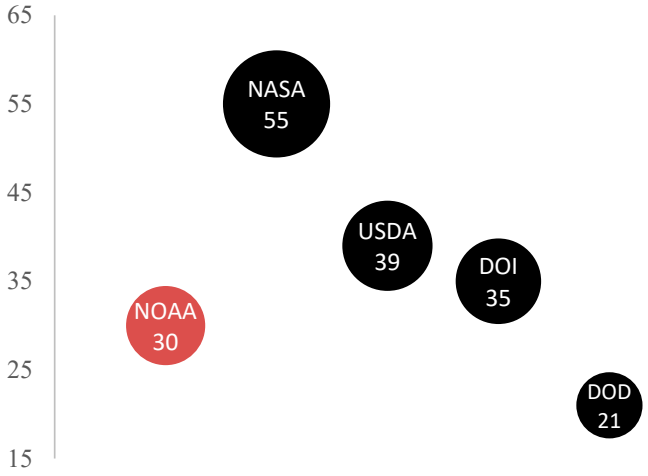
Top Journals where NOAA Publishes

- IEEE Transactions on Geosciences & Remote Sensing
- Remote Sensing
- Remote Sensing of Environment
- International Journal of Remote Sensing
- Journal of Applied Remote Sensing

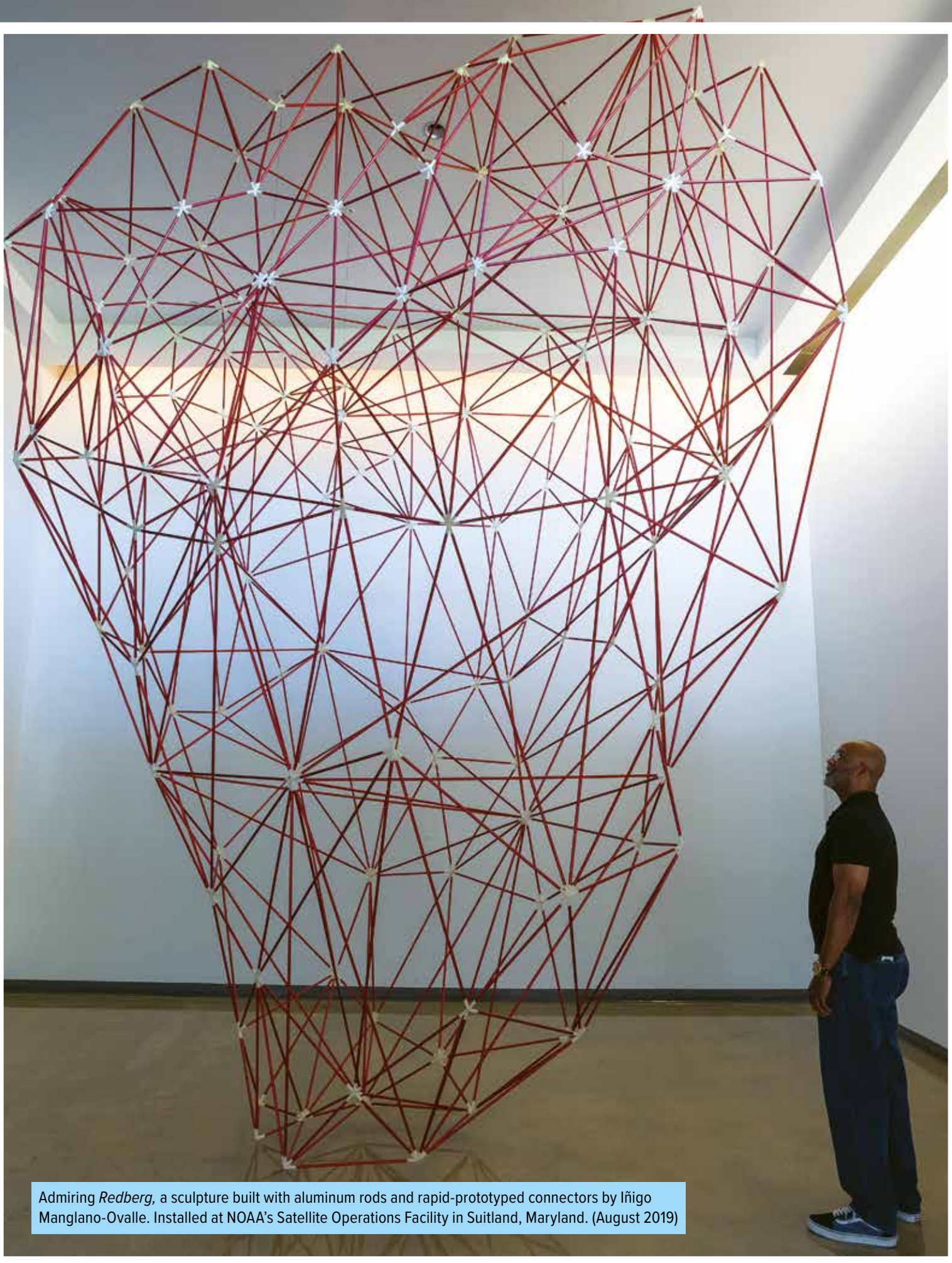
Highly Cited NOAA Articles

- Chan, et al. Assessment of the SMAP Passive Soil Moisture Product. IEEE Trans Geosci Remote Sensing.
- Kyba, et al. 2017. Artificially lit surface of Earth at night increasing in radiance and extent. Science Advances.
- Elvidge, et al. 2017. VIIRS night-time lights. Intl J Remote Sensing.

H-Index



Within the field of geosciences, NOAA has an *h-index* of 30 - meaning that 30 of these articles have been cited in the peer-reviewed literature at least 30 times.



Admiring *Redberg,* a sculpture built with aluminum rods and rapid-prototyped connectors by Iñigo Manglano-Ovalle. Installed at NOAA's Satellite Operations Facility in Suitland, Maryland. (August 2019)

SCIENTIFIC WORKFORCE

SCIENTIFIC AWARDS AND ACHIEVEMENTS

NOAA employees are recognized time and time again for their research and development efforts and preeminence through appointments to leadership positions in professional societies, external awards, invitations to speak at prestigious events, and more, establishing NOAA as a leader amongst federal agencies in the majority of its principal R&D focus areas.

NOAA has developed procedures and policies to ensure that employees are encouraged to serve in an official capacity as an officer or board member of a non-profit organization. These prestigious positions give our scientists the opportunities to help frame and direct research agendas and priorities within their relevant technical communities. As a result, NOAA has scientists serving in these capacities, many of whom are doing so at the highest levels. The impact this will have on our ability to recruit and retain top scientific talent into the federal government is quite powerful.

A list of NOAA personnel serving on boards at the end of fiscal year 2020 can be found on the NOAA Science Council website.

Outstanding R&D achievements are recognized through a variety of awards. In 2020, NOAA employees and team members were presented with external science awards for their excellence. The list below highlights a subset of these external awards.

PROFESSIONAL SOCIETIES AND ASSOCIATIONS:

AMERICAN METEOROLOGICAL SOCIETY (AMS)

2020 American Meteorological Society Charles L Mitchell Award – Awarded to Dr. John Brown for selfless dedication during more than four decades of service in developing forecast techniques, advancing model performance, training forecasters, and forecasting for large field programs.

AMS Bernhard Haurwitz Lecturer – Dr. Rong Zhang was selected for advancing scientific understanding of the causes and impacts of Atlantic multidecadal variability and Arctic sea ice variations through insightful analysis of models and observations.

Charles E. Anderson Award – Awarded to Dr. Kandis Boyd for career-long efforts through mentoring, education, and community service to champion diversity for women and under-represented minorities to promote a more inclusive workforce. The AMS Council has also voted to elevate Kandis Boyd to the grade of Fellow of the AMS, which is the highest honor of the society.

AMERICAN GEOPHYSICAL UNION (AGU)

AGU James R. Holton Award – Awarded to Dr. Nadir Jeevanjee for his groundbreaking contributions to atmospheric sciences, in particular, to the fundamental understanding of convection.

2020 Jule Gregory Charney Lecture – Dr. Venkatachalam Ramaswamy was selected in recognition of the leadership role he has played in a range of problems central to climate modeling and the study of climate change, especially in the areas of fundamental radiative transfer, radiative forcing due to ozone and aerosols, radiative signatures of climate change agents, and the contrasting climatic effects of aerosols and greenhouse gases.

SALMONID RESTORATION FEDERATION

Golden Pipe Award – Dr. Michael Pollock received the Golden Pipe award from the Salmonid Restoration Federation at their annual (38th) Salmonid Restoration Conference. The award is given to stream and watershed restoration innovators in the salmon restoration field.

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE (AAAS)

2019 AAAS Fellow – Awarded to Dr. Patricia Quinn for exceptional scientific contributions to our understanding of atmospheric aerosols and their climate impact.

MARINE TECHNOLOGY SOCIETY (MTS)

2020 MTS Fellow – Christian Meinig has contributed to MTS as a technical expert and unifying source of engagement to bring government, industry, and academia together in joint pursuits of marine engineering since 2000. As Director of Engineering at NOAA's premier marine engineering facility, he has led and delivered technology advancements such as the Deep-ocean Assessment and Reporting of Tsunamis (DART) warning Buoys, CO2 sensors for ocean acidification detection and monitoring, ocean current sensors, the world's deepest hydrophone for the Challenger Deep, and other enabling technologies that have advanced the entire field of marine engineering.

SOCIETY FOR RISK ANALYSIS (SRA)

Dr. Gina Eosco received the SRA-Risk Communication Specialty Group inaugural Award for Excellence in Risk Communication Research and Practice.

NATIONAL WEATHER ASSOCIATION

Operational Achievement Award – David Rudack, Dr. Tom Hamill, and the NWS Meteorological Development Laboratory/Statistical Modeling Branch were recognized for improving the accuracy and consistency of forecasts across the weather enterprise via free access to the groundbreaking National Blend of Models (NBM).

SCIENTIFIC PEER-REVIEWS OR CITATIONS:

CLARIVATE

Clarivate Highly Cited Researchers 2020 – Drs. Michael Alexander, Russell Vose, Mark Eakin, Michael McPhaden, Thomas Delworth, Richard Feely, Stephen Griffies, Andrew Wittenberg, Stephen Montzka, Scott Heron, John Dunne, Vaishali Naik, Colm Sweeney, and Larry Horrowitz. This list identifies scientists and social scientists who produced multiple papers ranking in the top one percent by citations for their field and year of publication, demonstrating significant research influence among their peers.

AMERICAN GEOPHYSICAL UNION

AGU 2019 Editors' Citation for Excellence in Refereeing – Awarded to Dr. Jessica Cross for outstanding reviewing in Geophysical Research Letters.

AMERICAN METEOROLOGICAL SOCIETY

AMS Bulletin of the American Meteorology Society Editor's Award – Awarded to Dr. Robert Banta for thorough, insightful, and impartial reviews of a particularly provocative manuscript.

AMS Bulletin of the American Meteorology Society Editor's Award – Awarded to Dr. Kelly Mahoney for insightful, thorough, and constructive reviews that contributed to improving impactful manuscripts.

Monthly Weather Review Editor's Award – Awarded to Dr. Michael Scheuerer for providing a large number of high-quality reviews extremely quickly.

ROYAL METEOROLOGICAL SOCIETY

2019 Quarterly Journal of the Royal Meteorological Society Reviewer's Certificate – Awarded to Dr. Michael Scheuerer in recognition of his important contribution as reviewer for the Quarterly Journal of the Royal Meteorological Society. He has provided reviews in the rapidly developing areas of ensemble forecasting, statistical post-processing and probabilistic forecasts, maintaining high quality together with an enviable average turnaround of reviews in under 5 days.

AMERICAN ASSOCIATION OF PUBLISHERS

2020 PROSE Award in the Textbook/Biological Science Category – Awarded for a book co-authored by Dr. Jay Orr titled, "Fishes of the Salish Sea: Puget Sound and the Straits of Georgia and Juan de Fuca."

ICES JOURNAL OF MARINE SCIENCE

Editor's Choice Award – Awarded to Dr. Tom Helser, Irina Benson, and their co-authors for a paper titled, "Age estimation of red snapper using FT-NIR spectroscopy."

Editor's Choice Paper – Awarded to Caitlin Allen Akselrud, Andy Whitehouse, and co-authors for a paper titled, "The trade-off between biodiversity and sustainable fish harvest with area-based management."

GOVERNMENT:

ENVIRONMENTAL PROTECTION AGENCY (EPA)

EPA National Honor Bronze Team Award – Awarded to Dr. Ashley Elgin and Paul Glyshaw for work on the 2019 Lake Erie Cooperative Science and Monitoring Initiative (CSMI) project. CSMI is a binational effort to coordinate science and monitoring activities in each of the Great Lakes.

FLORIDA DEPARTMENT OF THE ENVIRONMENT

Coral Champion – Florida DEP recognized Dr. Jim Bohnsack as a Coral Champion for his work with the Southeast Florida Coral Reef Initiative. His work especially in 2015 helped Florida create the Southeast Florida COral Reef Ecosystem Conservation Area (Coral ECA) that includes the northern coral reef tract.

U.S. CLIMATE VARIABILITY AND PREDICTABILITY PROGRAM (US CLIVAR)

Early Career Leadership Award – Awarded to Dr. Michael Jacox for contributions in area of Predictability, Predictions, and Applications Interface for outstanding contributions to interdisciplinary community activities to synthesize understanding of climate and marine ecosystem predictability, including leading national and international task teams and working groups, organizing community conferences, and developing innovative prediction tools for community use.

Early Career Leadership Award – Awarded to Dr. Elizabeth Thompson for contributions in the area of Phenomena, Observations, and Synthesis for outstanding leadership of, and contributions to international and interdisciplinary community activities to advance understanding of the upper ocean, atmosphere, and air-sea interactions, including the deployment of state

of the art instrumentation and using observations to improve process level understanding of the ocean's role in climate variability.

DEPARTMENT OF LABOR

Notable Recognition Award – Awarded to Dr. William Otto, member of the Denver Field Federal Safety and Health Council, for its commitment to the Occupational Safety and Health Administration's initiative to improve worker safety and health in the federal sector.

NASA

Silver Achievement Medal – Group – Greg Mandt, Timothy Walsh, John Longenecker, Linda Neely, Heather Kilcoyne were part of the JPSS Polar Follow-on Baselining Team which also included a number of their NASA colleagues. The award was given for expertly and confidently conveying the technical and programmatic story of JPSS to successfully baseline the project, leading to continued critical national weather forecasting observations.

Outstanding Leadership Medal – Greg Mandt received the award for outstanding leadership overseeing the launches of the GOES-R and JPSS satellites while facilitating the relationships between NASA, NOAA and the National Weather Service.

CO-LABS

2019 Colorado Governor's Award for High-Impact Research – NOAA staff and affiliates from the Physical Sciences Laboratory, Global Systems Laboratory, NOAA NWS Office of Water Prediction, and NOAA NWS Boulder Weather Forecast Office were given a group award for the Pathfinding Partnerships project: "Avoiding deadly floods through innovative partnerships: Estimating extreme precipitation in the 21st century to enhance dam safety and community resilience."

OFFICE OF THE FEDERAL COORDINATOR OF METEOROLOGY

2020 Richard H. Hagemeyer Award – Awarded to Morris Bender in recognition of the career of an individual that has made "major contributions in the field of tropical meteorology and the prediction of tropical cyclones."

OTHER GROUPS OR INSTITUTIONS:

FEDERAL EXECUTIVE ASSOCIATION OF THE GREATER CHARLESTON AREA

Federal Employee of the Year Award, Outstanding Professional Employee of the Year for 2020. Dr. Paul Pennington was recognized for outstanding contributions to the NOAA mission through his innovative development of new technology testing in the NCCOS Charleston's estuarine mesocosm challenge facility.

FEDERAL LABORATORY CONSORTIUM (FLC) FOR TECHNOLOGY TRANSFER

The 2020 Impact Award was awarded to the GSL Science On a Sphere Explorer™ team. The FLC Impact Award honors employees of FLC member laboratories and non-laboratory staff whose technology transfer efforts have made a lasting and tangible impact on the populace or marketplace, ranging from a local to a global scale.

COLORADO STATE UNIVERSITY DEPARTMENT OF ATMOSPHERIC SCIENCE

Outstanding Alum Award – Awarded to Dr. Jennifer Mahoney for a distinguished career and service to the college, university, state, nation or world that has brought honor to the department, the College of Engineering, Colorado State University and themselves.

WORLD CLIMATE RESEARCH PROGRAMME (WCRP) AND THE WORLD WEATHER RESEARCH PROGRAMME (WWRP)

International Prize for Model Development – Awarded to Dr. Baoqiang Xiang for skill in developing

multiple modeling systems, and in particular for leading the development of GFDL's next generation coupled atmosphere-ocean models for prediction on the challenging seasonal-to-subseasonal timescale.

THE BILLFISH FOUNDATION

Paxson H. Offield Lifetime Science Achievement Award – This award was awarded to Joe Yurt, who meticulously collected and recorded data on landed billfish and tuna taken in waters off Louisiana. His work was pivotal in what became the most comprehensive billfish science data resource in the Gulf of Mexico, estimated to have provided 90% coverage of billfish landings and effort in the region.

BLACK ENGINEER OF THE YEAR AWARDS (BEYA)

Career Achievement in Government award – Awarded to Dr. Kandis Boyd. The nominee is beyond the midpoint (with over 15 years in the workforce) of his or her career but not close to retirement age, and has made significant achievements in engineering titles in industry or government. The committee looks less at the degrees earned than at the body of work produced by the nominee, its broad, social and economic value and impact, and the nominee's performance as a role model and mentor for minorities in technology.

DEPARTMENT OF GEOGRAPHY AND URBAN-REGIONAL STUDIES AT YOUNGSTOWN STATE UNIVERSITY, OHIO.

2020 David T. Stephens Outstanding Alumni Award – Awarded to Larry Spencer. The award recognizes individuals who have contributed to the department through their work after graduation. It also recognizes individuals who have shown tremendous personal and professional growth through their activities as employees in work related to their undergraduate training at YSU.

COASTAL CONSERVATION ASSOCIATION (CCA) FLORIDA

CCA Florida Star Tournament – Derke Snodgrass was awarded First Prize for collecting over 8,100 gallons of marine debris. The second and third prize winners collected around 5,000, and 1,300 gallons, respectively.

GROUP ON EARTH OBSERVATIONS

GEO Individual Excellence Award - Dr. Paul DiGiacomo of NESDIS STAR was the inaugural awardee in November 2019 for his leadership in championing water quality observations in GEO for more than 10 years. He has been instrumental in developing GEO Blue Planet and GEO AquaWatch Initiatives into active and impactful activities.

2020 Earth Observations for Sustainable Development Goals (EO4SDG) award - Dr. Emily Smail and GEO Blue Planet initiative won an award for their collaboration with Esri to develop and execute a methodology for quantifying the impact of eutrophication using satellite-derived chlorophyll-a measurements. These tools will assist countries by identifying locations of potential eutrophication hot spots and target in-situ nutrient sampling. For more information visit SDG 14.1 Hub Site https://chlorophyll-esrioceans.hub.arcgis.com.

INTERNAL AWARDS

In 2020, awards for NOAA personnel from NOAA, the Department of Commerce, and the Executive Office of the President included:

AWARDEES	AWARD	AWARD ORGANIZATION
8 individuals representing 3 groups	NOAA Technology Transfer Award	NOAA
1 branch and 46 individuals representing 6 groups	Gold Medal Award for Scientific/ Engineering Achievement	Department of Commerce
5 individuals representing 3 groups	Silver Medal Award for Scientific/ Engineering Achievement	Department of Commerce
1 team, 1 center, and 82 individuals representing 12 groups	Bronze Medal Award for Scientific/ Engineering Achievement	Department of Commerce
6 individuals	Distinguished Career Award for Scientific Achievement	NOAA

In addition to scientific achievement, many individuals within NOAA receive awards for leadership, professional excellence, heroism, and more. Additional award winners can be found within the NOAA Office of Human Capital Services website (e.g., Department of Commerce Gold and Silver Medals and NOAA Administrator's Award).

LABORATORY AND PROGRAM SCIENCE REVIEWS

Scientific evaluations assess the strength and appropriateness of NOAA's R&D endeavors, as well as make recommendations for improving scientific innovation and output to ensure activities meet NOAA's mission needs (Handbook for NAO 216-115A). Reviews of NOAA's laboratories and programs include an independent panel of experts, reflecting the importance NOAA places on scientific peer review. The reviews focus on the quality, performance, and relevance of the R&D to assess the robustness and appropriateness of NOAA's scientific endeavors. Individual NOAA laboratories and science programs are reviewed every five years, per NAO 216-115A, to:

- Evaluate quality, relevance, and performance of research conducted at the laboratory or the science and outreach conducted or funded by the program;
- Evaluate laboratory/program management and impact with respect to stated strategic goals, which may be defined in the laboratory/program's strategic plan or shaped by an inter-agency working group plan;
- Strategically position the laboratory/program for planning its future science by identifying gaps and emerging areas of science;
- Ensure research is linked to the strategic plan, mission, and priorities of NOAA, the laboratory/program, and the appropriate inter-agency working group(s);
- Deliver evidence to stakeholders of the benefits of NOAA research and development;
- Report collectively on the quality of NOAA science programs;
- Identify common themes and priorities so that NOAA can determine mechanisms, policies, or actions to address corporately.

Feedback gathered during the evaluation process helps shape NOAA's world-class science. NOAA appreciates the efforts of the organizers and review panels in facilitating thoughtful, independent reviews. A list of NOAA's program and laboratory science reviews can be found on the NOAA Science Council website, along with links to review summary reports and responses.

A NOAA marine debris removal team hauls a mass of nets out of the water near Midway Atoll.
Credit: Steven Gnam