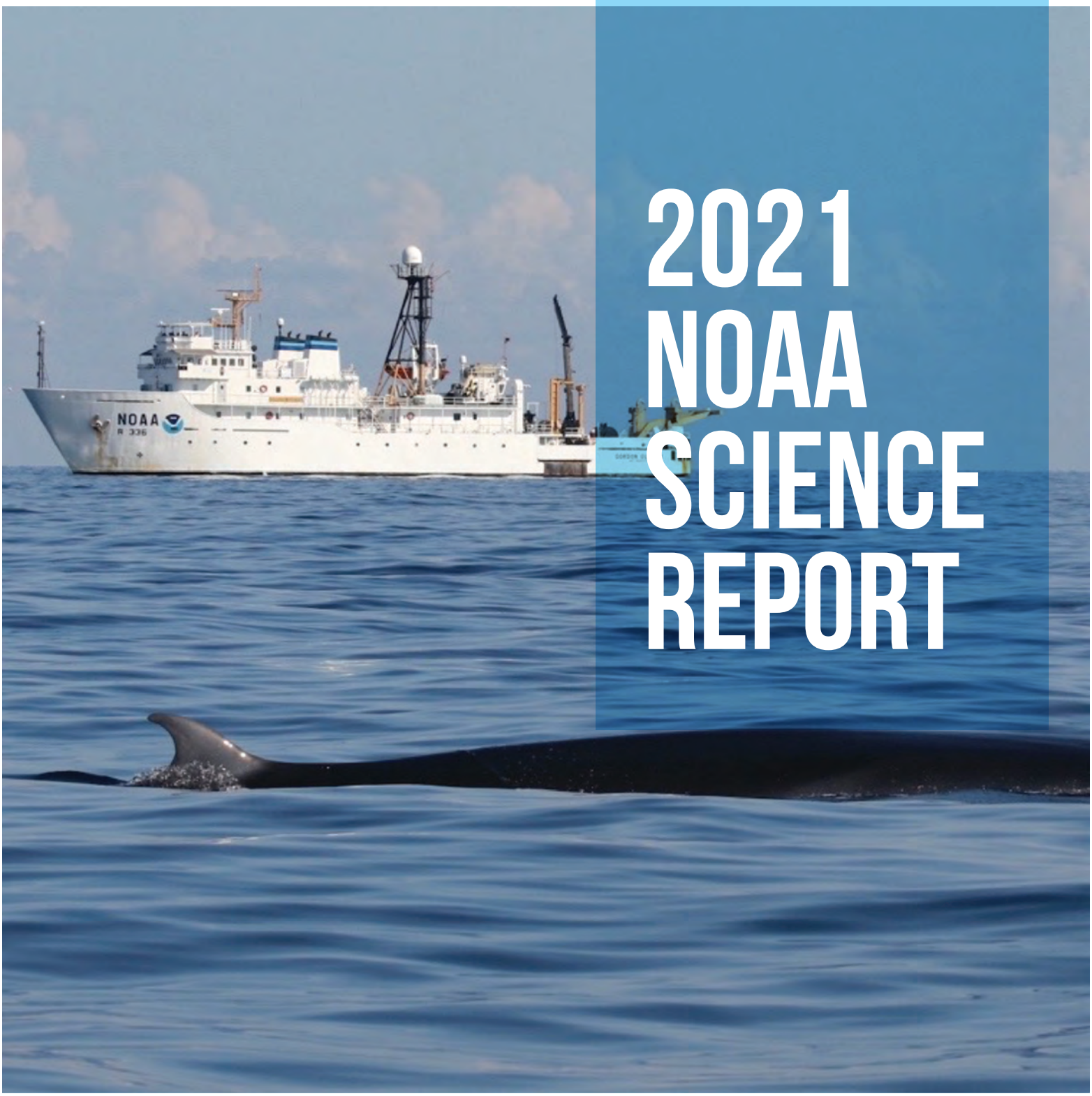

2021 NOAA SCIENCE REPORT

U.S. DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NOAA Technical Memorandum NOAA Science Council - 004

2021 NOAA Science Report

Isha Renta, Gina Digiantonio, Emma Kelley, Gary Matlock, Eric Bayler, Sarah Davis, Judy Ghirardelli, Monica Grasso, Michelle Harmon, Michael Liddel, Anthony Marshak, Laura Newcomb, Stephan Smith, Jeffrey Wielgus

NOAA
Silver Spring, Maryland

March 2022

noaa

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AND ATMOSPHERIC
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/

NOAA Science Council

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UNITED STATES DEPARTMENT OF COMMERCE

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Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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Under Secretary of Commerce for Oceans and Atmosphere

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PHOTO DISCLAIMER

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

COVER PHOTO

NOAA Fisheries researchers and collaborators described a new species of baleen whale from the Gulf of Mexico. Photo credit: Laura Dias, NOAA Fisheries. (NMFS Permit #21938)

FOREWORD

NOAA is the Nation's premier ocean, weather, atmospheric and climate agency, with a commitment to science, service and stewardship. In 2021, still under continuous challenges in the face of the COVID-19 pandemic, our scientists continued—with the appropriate precautions—to execute world class research, development and operations to improve the lives and livelihoods of American citizens and of the world. These scientific achievements have been recognized by numerous outside organizations and are made possible by our highly skilled and dedicated workforce.

This annual NOAA Science Report started when our current Administrator, Dr. Richard Spinrad, was formerly serving as the NOAA Chief Scientist and recognized the value in reporting on research accomplishments. Many of the advances reported are the result of years of work, across a talented federal, university, and contract staff of scientists, engineers and technicians, and supported by the talents of the administrative teams of NOAA.

The scientific highlights, awards, bibliometrics, and educational spotlights in the report clearly demonstrate NOAA's commitment to advancing the opportunities for both ocean prosperity and protection with the new blue economy, the importance of sound climate science to inform society, and Diversity, Equity, Inclusion and Accessibility (DEIA). Please note also that we have redesigned our climate.gov website, provided significant contributions to the Intergovernmental Panel on Climate Change (IPCC) report and provide NOAA's commitments to addressing the climate crisis after the 2021 United Nations Climate Change Conference (COP26). With our changing climate it is imperative that we continue to use our science for the betterment of all communities. NOAA's DEIA principles are well incorporated through a workforce that values diversity and can implement its business practices to effectively meet the needs of all communities.

I hope that all readers find in this report the benefits and impacts of NOAA's research products for the benefit of society. Thank you to every contributor to the report and to the important work described herein. I can only conclude that this Agency's mission attracts the most dedicated and remarkable people who perform their work marvelously for the benefit of the American people. Thank you.

Craig N. McLean
Acting NOAA Chief Scientist

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INTRODUCTION

ENRICHING LIFE THROUGH SCIENCE

Extending from the surface of the sun to the depths of the oceans, NOAA's mission depends on a strong foundation of research and development 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, inform decision-making, enhance life, and sustain critical ecosystems.

NOAA IS A SCIENCE AGENCY

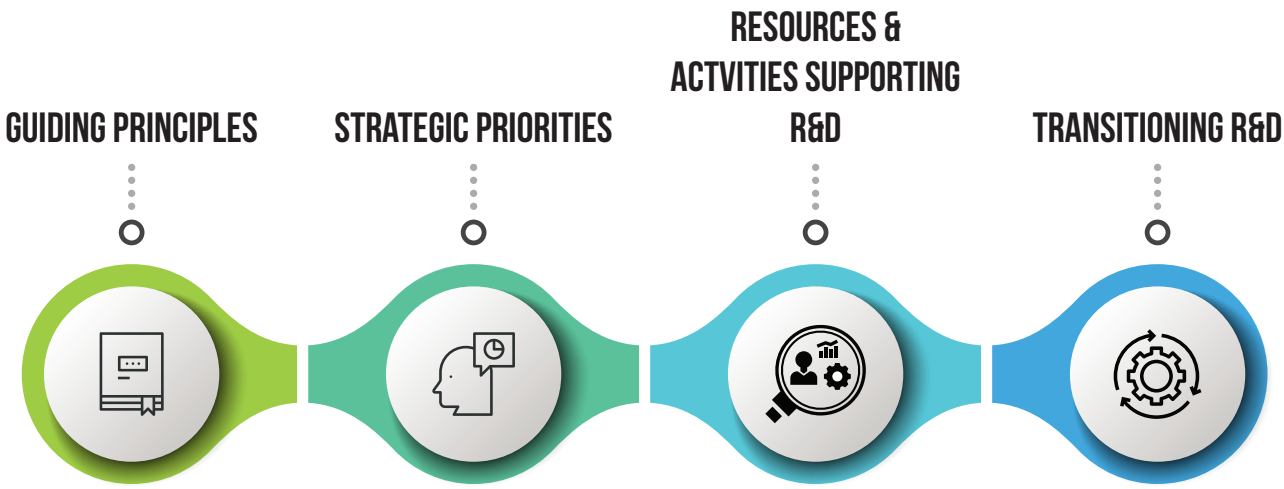
To fulfill its mission to science, service, and stewardship, NOAA's science activities are molded by Guiding Principles and shaped through the development of Strategic Priorities. Resources and activities supporting Research and Development (R&D) enable NOAA to carry out its aim of transitioning R&D into operations, applications, commercialization, and other uses. Following this path, NOAA produces and publishes credible science that is consistently cited in peer-reviewed publications, receives internal and external awards, and is consistently highly recognized during external laboratory and program reviews.

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.



GUIDING PRINCIPLES

Mandates, societal needs, and policies shape NOAA's scientific enterprise and ensure high-quality output

STRATEGIC PRIORITIES

Strategic plans and R&D priorities drive a balanced R&D portfolio and diverse workforce

RESOURCES & ACTIVITIES SUPPORTING R&D

Conducting science activities requires expertise, infrastructure, and other resources, as well as the means for NOAA to train and retain the next generation of scientists and cultivate a diverse and inclusive workforce.

TRANSITIONING R&D

In order to realize value from NOAA R&D investments, NOAA transitions its science to commercialization, operations, applications, and other uses to improve the lives of the American public.

GUIDING PRINCIPLES

WHY DOES NOAA INVEST IN RESEARCH?

NOAA requires investment in R&D to expand capabilities and improve the quality of NOAA's products and services for the Nation. NOAA develops products and services through dynamic engagement between the agency and stakeholders, communicating their needs to NOAA, generating development and new research initiatives to meet the needs of the people, as well as to address legislative mandates.

By integrating internally conducted research with partner efforts, including cooperative institutes, universities, other government agencies, and the private sector, NOAA can better transform concepts into the data, tools, and information needed by stakeholders. NOAA balances a broad research portfolio to further the NOAA mission and serve a wide spectrum of end users.

WHAT KINDS OF RESEARCH AND DEVELOPMENT DOES NOAA SUPPORT?

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

In the context of the classical treatment for characterizing research efforts [Stokes, 1997], NOAA significantly invests in both the "Pasteur - User Inspired" and the "Edison - Applied Research" quadrants (Figure 1), while including critical investments aimed at advancing fundamental understanding. NOAA strategically invests across the risk-reward spectrum, pursuing a range of projects, from low-risk projects that result in incremental gains to high-risk projects with high potential gains but less certainty of success. This balanced approach sets NOAA on the cutting edge of R&D while still ensuring that user needs and expectations are met.

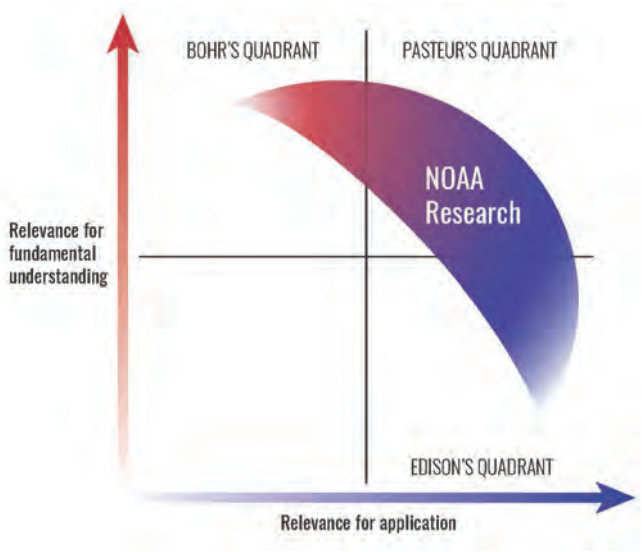


Figure 1. Donald Stokes proposed the above chart in his 1997 book *Pasteur's Quadrant: Basic Science and Technological Innovation*. This chart portrays that, while some research largely focuses on fundamental understanding (Bohr's quadrant upper left) or application (Edison's quadrant, lower right), 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 follow 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, results, equipment, and facilities of leading universities, Federal agencies, private companies, non-governmental organizations, 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 R&D Agreements with the private sector.

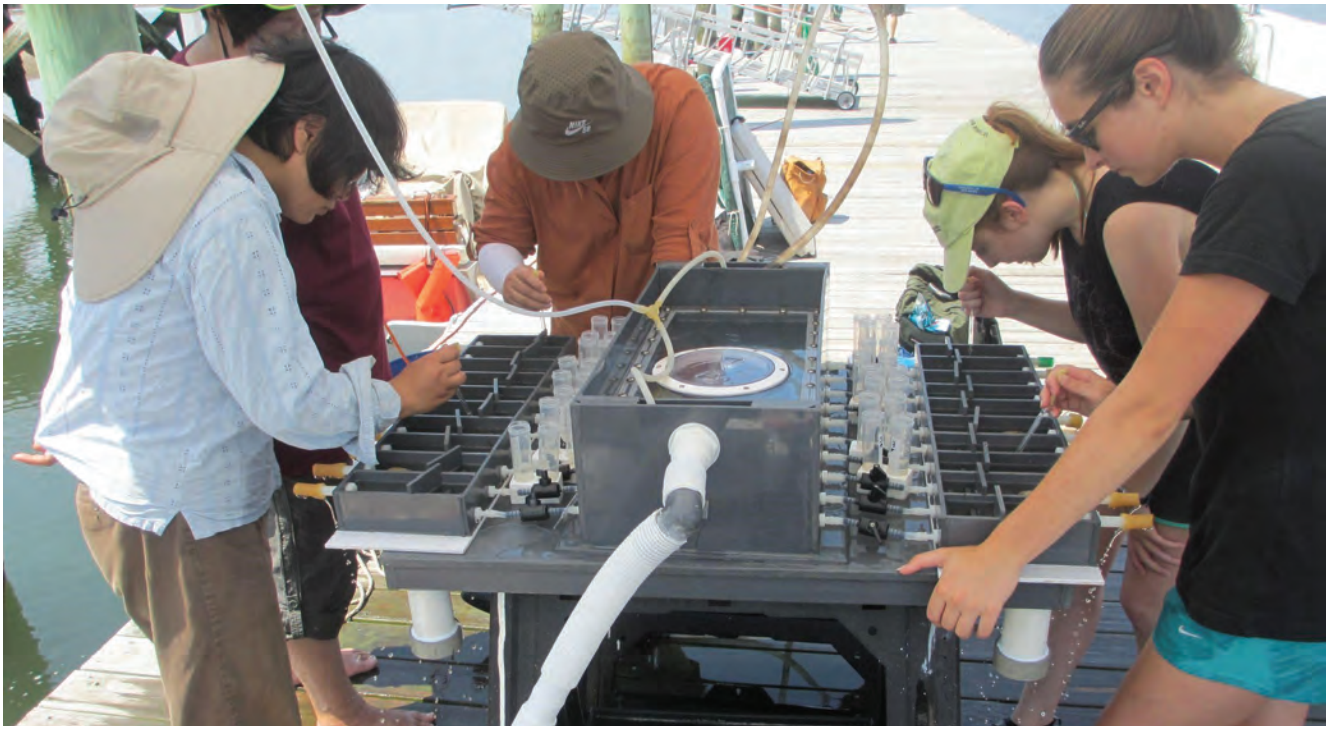
The ice breaker U.S. Coast Guard Cutter Mackinaw keeps channels and harbors open to navigation. In this photo taken in 2014, the USCGC Mackinaw arrives in Duluth via Lake Superior. Credit: NOAA

SCIENTIFIC INTEGRITY

As stated in NOAA's Scientific Integrity Policy (NAO 202-735D-2 [NOAA, 2021]), NOAA has a scientific integrity policy "to promote a continuing culture of scientific excellence and integrity, and to establish a policy that ensures the integrity of the agency's scientific activities used to inform management and policy decisions. In addition, the intent of this policy is to strengthen universal confidence – from scientists to decision-makers to the general public – in the quality, validity, and reliability of NOAA science. It also denotes the agency's commitment to a culture of support for NOAA's employees, which are its principal science asset."

NOAA's Scientific Integrity Policy, along with its accompanying Procedural Handbook, establish a Code of Scientific Conduct and a Code of Ethics for Science Supervision and Management, setting the responsibilities 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 produces an annual scientific and research misconduct report that summarizes allegations that are being investigated and those that have been closed. In order to ensure that everyone in NOAA understands the principles of Scientific Integrity and how to apply them, NOAA requires covered individuals to take scientific integrity training, which is provided in an online module.

Through NOAA's comprehensive scientific integrity policy,and resulting culture of excellence, NOAA scientists continue to conduct exemplary research and development. For further information about scientific integrity in NOAA, the Scientific Integrity Commons website contains relevant resources and documents.



Field experiments to measure feeding and nutrient uptake by shellfish in the Greenwich watershed in 2015. Photo credit: NOAA Fisheries

STRATEGIC PRIORITIES

NOAA'S PRIORITY OBJECTIVES

The NOAA Research and Development Vision Areas:2020-2026 identifies priority foci for NOAA R&D. The priority areas include:

1. Reducing societal impacts from hazardous weather and other environmental phenomena
2. Sustainable use and stewardship of ocean and coastal resources
3. A robust and effective research, development, and transition enterprise

In aligning R&D to these vision areas, NOAA supports two priority objectives in the Department of Commerce's Strategic Plan [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.

In carrying out the objectives in the Vision Areas, NOAA strategically focuses transformative advancements in the quality and timeliness of NOAA's products and services in the following areas:

1. Harnessing 'omics approaches, from DNA sequencing to small molecule analysis;
2. Maximizing value of uncrewed systems for science-based mission support;
3. Maximizing the value of NOAA data;
4. Applying the power of the crowd through citizen science;
5. Utilizing artificial intelligence analytics for next-generation Earth science; and
6. Adopting and using information technology cloud services.

DIVERSITY, EQUITY, INCLUSION, AND ACCESSIBILITY (DEIA)

NOAA requires a diverse workforce to better meet the diverse needs of communities around the nation. A recent Boston Consulting Group study suggests that increasing the diversity of leadership teams leads to more and better innovation and improved financial performance. NOAA recognizes the importance of Diversity, Equity, Inclusion, and Accessibility (DEIA) and prioritizes these topics through its Diversity & Inclusion (D&I) Strategic Plan and D&I Action Plan.

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

NOAA's vision for Diversity and Inclusion 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 these goals NOAA identified objectives, actions, and metrics along with how NOAA can collaboratively achieve the goals.

> NOAA commits to provide our workforce and job applicants with a full and fair opportunity for employment, career advancement, and access to resources and programs. NOAA values the unique differences and shared values of each member of the NOAA team.

NOAA is committed to incorporating the principles of diversity as a core value. Empowering a workforce that includes diversity of thought, diversity in its people, and diversity in its business practices demonstrates the capability to understand and respond effectively to the workforce's needs and mission. We pledge to create and promote a workplace where the talents of all individuals are recognized and appreciated.

NOAA'S 2021 DIVERSITY, EQUITY, INCLUSION, AND ACCESSIBILITY (DEIA)/SEXUAL ASSAULT AND SEXUAL HARASSMENT (SASH) SUMMIT.

In 2021, NOAA continued its tradition of delivering a phenomenal Diversity, Equity, and Inclusion (DEIA) & Sexual Assault and Sexual Harassment (SASH) Summit. The annual summit is the agency's premier event to propel efforts to foster and sustain a culture of respect where DEIA is embraced and every workforce member feels safe and valued. This year's theme was "Turning the Tide on DEIA & SASH." Some of the industry's most talented professionals were acquired to educate, share valuable insights, and offer best practices to empower NOAA's workforce to lead the charge. The virtual platform increased accessibility across regions and allowed for a robust program consisting of 33 live webinars and 19 virtual booths, which showcased NOAA's Employee Resource/Affinity Groups. More than 1,300 NOAA employees registered for the 2-day event. The annual summit remains instrumental in broadening awareness of NOAA's DEIA and SASH initiatives supporting the agency's strategic goals.

We Are NOAA Week recognized the challenges of advancing diversity, equity, inclusion and accessibility (DEIA) at NOAA; the progress made; and the outstanding opportunities ahead. This banner highlights NOAA employees displaying their pride by holding "I am NOAA" handwritten signs.

RESOURCES AND ACTIVITIES SUPPORTING R&D

SCIENTIFIC AWARDS AND ACHIEVEMENTS

Resources — which include money, people, external reviewers, and infrastructure — are essential for putting strategic priorities into practice and advancing NOAA's scientific activities. Arguably, NOAA's greatest scientific resource is its people. Time and time again, NOAA employees are recognized 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 its principal R&D focus areas.

Outstanding R&D achievements are recognized through a variety of internal and external awards, some of which are presented in this report. In addition to scientific achievement, many individuals within NOAA receive awards for leadership, professional excellence, heroism, and more. Award winners (e.g., Department of Commerce Gold, Silver, and Bronze Medals and the NOAA Administrator's Award) can be found within the NOAA Office of Human Capital Services website.

NOAA has 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, many of whom are doing so at the highest levels. The corresponding visibility of NOAA scientists has a powerful impact on NOAA's ability to recruit and retain top scientific talent. A list of NOAA personnel serving on boards at the end of Fiscal Year 2021 can be found on the NOAA Science Council website.

In 2021, 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)

AMS Fellow – Huug M. van den Dool was elected as an AMS Fellow. AMS Fellows shall have made outstanding contributions to the atmospheric or related oceanic or hydrologic sciences or their applications during a substantial period of years.

Award for Outstanding Contribution to the Advance of Applied Meteorology – Awarded to David P. Ruth for extraordinary leadership in developing and implementing software for primary NOAA NWS systems, including the Interactive Forecast Preparation System and National Digital Forecast Database

Francis W. Reichelderfer Award – Chad M. Gravelle was awarded this for leadership, dedication, and the innovative use of technology in preparing forecasters to integrate GOES-R imagery and associated products into NOAA NWS operations

Charles L. Mitchell Award – Awarded to John M. 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

PROFESSIONAL SOCIETIES AND ASSOCIATIONS:

Award for Exceptional Specific Prediction – Awarded to Bryan T. Smith for a highly specific and accurate prediction of a strong supercell event with long lead time that saved lives

AMERICAN GEOPHYSICAL UNION (AGU)

2021 Ocean Sciences Award – Awarded to Alistair Adcroft. The Ocean Sciences Award is presented biennially in odd-numbered years and recognizes outstanding leadership or service to the ocean sciences by a senior scientist.

2021 Bert Bolin Award and Lecture – Thomas Delworth was awarded for ground-breaking research and/or leadership in global environmental change.

AMERICAN PHYSICAL SOCIETY (APS)

2021 APS Fellow – V. Ramaswamy was named a 2021 APS Fellow, which recognizes members who have made exceptional contributions in physics research, important applications of physics, leadership in or service to physics, or physics education.

NATIONAL ASSOCIATION OF COMMISSIONED OFFICERS

2020 NOAA AGO Engineering Award – Awarded to LTJG Patrick Pope in recognition of outstanding application of advanced GIS techniques, adding to knowledge of spatial data layers in Puget Sound and allowing for accurate mapping of salmon natal estuaries.

MARINE TECHNOLOGY SOCIETY (MTS

Ocean News and Technology Young Professional Award – Awarded to Mathew Biddle for exceptional work of supporting the integration and management of marine life data for the U.S. Integrated Ocean Observing System (IOOS)

THE OCEANIC SOCIETY

Ocean Observing Team Award – Awarded to the RAPID-MOCHA-WBTS 26°N Team (Molly O. Baringer, Pedro L. Pena, Ulises F. Rivero, Ryan H. Smith, Andrew J. Stefanick, George A. Berberia, Ricardo Domingues, Rigoberto F. Garcia, James A. Hooper, Grant T. Rawson, Diego P. Ugaz, Denis L. Volkov) for transforming understanding of Atlantic circulation with a breakthrough in observing system design, providing continuous, cost-effective measurements.

ASSOCIATION OF MARKETING AND COMMUNICATION PROFESSIONALS (AMCP)

Hermes Creative Platinum Award for Outstanding TV Placements and Outstanding Overall Publicity Campaign – Awarded to the NOAA's National Coral Reef Monitoring Program team in recognition of the media impact of NOAA's Coral Reef Condition Status Report, with more than 521 million impressions with coverage in 46 states, plus Washington, DC, for the coral reef status report press event.

NATIONAL WEATHER ASSOCIATION (NWA)

Dr. T. Theodore Fujita Research Achievement Award – Awarded to Pam Heinselman for outstanding leadership of the NOAA/NSSL Warn-on-Forecast research and development program, particularly her work in developing collaborations with the operational community that have strengthened the research-to-operations and operations-to-research pipelines.

INTERNATIONAL ASSOCIATION FOR GREAT LAKES RESEARCH (IAGLR)

IAGLR Lifetime Achievement Award – Awarded to Henry Vanderploeg in recognition of important and continued contributions to the field of Great Lakes research over a period of 20 years or more.

PROFESSIONAL SOCIETIES AND ASSOCIATIONS:

John R. (Jack) Vallentyne Award – Awarded to Margaret Lansing for recognition of important and sustained efforts to inform and educate the public and policymakers on great lakes issues, thereby raising awareness and support for great lakes protection and restoration. Individuals or teams eligible for this award can be from any great lake of the world, including North American Great Lakes, African Great Lakes, or others.

OTHER GROUPS OR INSTITUTIONS:

ROYAL SWEDISH ACADEMY OF SCIENCES
2021 Nobel Prize in Physics - Syukuro "Suki" Manabe was awarded one-half jointly of the Nobel Prize in Physics for the physical modeling of Earth's climate, quantifying variability and reliably predicting global warming.

U.S. FOREST SERVICE
2020 Under Secretary's and Chief's award for Customer Experience – Awarded to Erika Ammann for work on the Copper River Watershed Enhancement Project, which improved watershed health in a signature Alaska landscape, helping restore the productivity of salmon fisheries, thereby benefiting rural communities and economies.

U.S. FOREST SERVICE
Samuel J. Heyman Service to America Medal (the "Sammies") - 2021 Finalist for Paul A. Volcker Career Achievement Award – C. Mark Eakin led the development of a satellite-based monitoring system that provides accurate forecasts and early warnings to environmental officials worldwide at a time when rising ocean temperatures threaten the health of coral reefs.

ASSOCIATION FOR UNMANNED VEHICLE SYSTEMS INTERNATIONAL
Order of Prometheus – Awarded to John Walker for the body of work he has compiled in support of Autonomous Operations.

SCIENTIFIC PEER-REVIEWS OR CITATIONS:

AMERICAN GEOPHYSICAL UNION (AGU)
AGU 2020 Editors' Citation for Excellence in Refereeing - Water Resources Research – Awarded to Matt Collins for providing outstanding, in-depth peer reviews that greatly improved the final published papers in Water Resources Research.

AMERICAN METEOROLOGICAL SOCIETY
AMS Editors Award for Weather and Forecasting – Awarded to Michael Coniglio for consistently providing high quality, constructive, and rigorous reviews that help to uphold the high standards of AMS journals committees.

AMS Editors Award for Weather and Forecasting/Monthly Weather Review/Journal of Applied Meteorology and Climatology – Awarded to John Knaff for providing multiple rigorous, timely, and constructive reviews across three AMS journals, and also for contributing consistently excellent reviews over a period of many years.

AMS Editors Award for the Bulletin of the American Meteorological Society – Awarded to Kelly Mahoney for insightful, thorough, and constructive reviews that contributed to improving impactful manuscripts.

OTHER GROUPS OR INSTITUTIONS:

INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)
Expert in Environmental Pesticide Analysis – Awarded to NOAA Northwest Fisheries Science Center's Environmental Chemistry Program in recognition of our laboratory's expertise in analyzing environmental samples for legacy pesticides, pursuant to our participation in an IAEA quality assurance exercise.

STEPHEN D. CAIRNS, SMITHSONIAN INSTITUTION
Name change in coral species to honor Dr. Thomas Hourigan – A Caribbean deep-sea stony coral was renamed Desmophyllum hourigani Cairns, 2021 in honor of Dr. Hourigan, Chief Scientist for NOAA's Deep Sea Coral Research and Technology Program.

REUTERS
Name change in coral species to honor Dr. Thomas Hourigan – A Caribbean deep-sea stony coral was renamed Desmophyllum hourigani Cairns, 2021 in honor of Dr. Hourigan, Chief Scientist for NOAA's Deep Sea Coral Research and Technology Program.

CAREER COMMUNICATIONS GROUP, INC. WOMEN OF COLOR MAGAZINE
Women of Color Award – Awarded to Rita Williams, recognizing significant minority achievement in Science, Technology, Engineering, and Math (STEM).

Technology Rising Star Award - Awarded to Tiffany House. Rising Stars are young women, under 15 years in the workforce, who are helping to shape technology for the future.

UNIVERSITY OF MICHIGAN
Research Faculty Recognition Award – Awarded to Casey Godwin for exceptional scholarly achievements, as evidenced by publications and other activities in an academic field of study.

SOUTH KOREAN MINISTRY OF ENVIRONMENT
Minister's Commendation – Awarded to Hyun Cheol Kim for contributions to South Korean air quality research.

PENN STATE UNIVERSITY COLLEGE OF EARTH AND MINERAL SCIENCES
125th Anniversary Fellows – Chidong Zhang and Benjamin DeAngelo. The college recognizes that the success and reputation of the college is defined substantially by the achievements of its graduates. To honor their accomplishments the college has selected a prominent group of 134 alumni whose contributions to the fields of science and engineering have set them apart from their peers and named them 125th Anniversary Fellows.

THE CENTER FOR CLIMATE AND SECURITY, THE AMERICAN SECURITY PROJECT, AND THE WILSON CENTER'S ENVIRONMENTAL CHANGE AND SECURITY PROGRAM
2021-2022 Climate and Security Advisory Group's Climate Security Fellow – Brittany Croll was selected as one of 15 rising leaders from diverse backgrounds across the U.S. government and the civil and private sectors, as emerging experts on the links between climate change and national security.

AMERICAN GEOPHYSICAL UNION

AGU Fellow – Chidong Zhang and Thomas Knutson were named AGU Fellows. AGU Fellows are elected each year for their visionary leadership and scientific excellence. This designation is conferred upon less than 0.1% of all AGU members in any given year, as a tribute for those who have made exceptional scientific contributions.

ROYAL METEOROLOGICAL SOCIETY

Reviewer's Certificate – Awarded to Michael S. Fisher for the thoroughness and quality of a large number of reviews on tropical cyclones, maintaining the high standards for papers appearing in the Quarterly Journal of the Royal Meteorological Society.

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

NOAA made advancements in having a workforce that represents Individuals with Targeted Disabilities in 2020 with representation at 2.52%,0.52% above the federal goal established by the Equal Employment Opportunity Commission.

In 2020, the representation of Hispanics, White Females, African Americans, American Indian or Alaska Natives and two or more races in NOAA's workforce were below the civilian labor force (CLF) for the last five fiscal years (data from the Office of Inclusion and Civil Rights). In 2021, NOAA supported several initiatives to advance a more diverse and inclusive work environment.

NOAA is fully committed to advancing DEIA at all levels to achieve our mission goals and business objectives and maximize the potential of our workforce and the organization as a whole.

We recognize that diversity is about more than race and gender and strive to foster an inclusive culture for everyone by advancing our diversity and inclusion through initiatives, programs, and groups hosted by he Office of Inclusion and Civil Rights (OICR). NOAA's OICR currently leads a growing number of Employee Resource and Affinity Groups to connect employees for support, collaboration, and action, promoting diversity, equity, and inclusion resulting in a more productive professional environment that champions mission achievement.

OICR also hosted nine Special Emphasis Program Observances (SEPO) events with an average of over 300 attendees at each event,

NOAA also served as the sponsor of the FY20 Women of Color Science, Technology, Engineering, and Mathematics (STEM) Conference, and the premier sponsor in five major national conferences: Becoming Everything You Are (BEYA), Society for Advancement of Chicanos/Hispanics, and Native Americans in Science (SACNAS), Federal Asian Pacific American Council (FAPAC), American Indian Science and Engineering Society (AISES) and Federally Employed Women (FEW) National Training Programs.

In addition, in 2021, the Office of Marine and Aviation Operation's (OMAO) graduating Basic Officer Training Class (BOTC) 138 was NOAA's most diverse. OMAO used "total candidate engagement" to support candidates, which support the graduation of this diverse class.

Empowering a workforce that includes diversity of thought, diversity in its people, and diversity in its business practices demonstrates that we can understand and respond effectively to the needs of our workforce and our mission.

NOAA is also planning regular assessments of Line and Staff Offices for possible deficiencies and to develop strategies to remove barriers.

From left to right, Dr. Jeanette Davis, Cindy Woods, Melissa Hooper, and Jennifer Dickens, were recognized at the annual Women of Color in STEM conference, which was held virtually October 8-10, 2020. These awards highlight significant achievements in science, technology, engineering, and math (STEM). (NOAA)

HOW DOES NOAA INVEST IN THE DEVELOPMENT OF THE NEXT GENERATION OF SCIENTISTS TO HELP PROMOTE DEIA?

The NOAA Office of Education (OEd) supports education from pre-kindergarten through doctoral level students and collaborates with universities to prepare exceptional talent, in NOAA-mission fields, including from diverse backgrounds. OEd supported programs play an important role in contributing to NOAA's DEIA goals.

The Educational Partnership Program with Minority-Serving Institutions (EPP/MSI) supports the education, training, professional development, and graduation of post-secondary students at NOAA-supported minority serving institutions where a majority of the student population are from traditionally underrepresented and historically excluded communities. NOAA funding also supports 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 students who have earned a total of 2,593 degrees that includes 1,599 Bachelors, 626 Masters, and 334 PhDs and 34 other (i.e. Associates and Professional degrees). More than 300 EPP/MSI alumni have entered federal service as employees or contractors, 70 of which are currently full time employees in the NOAA workforce.

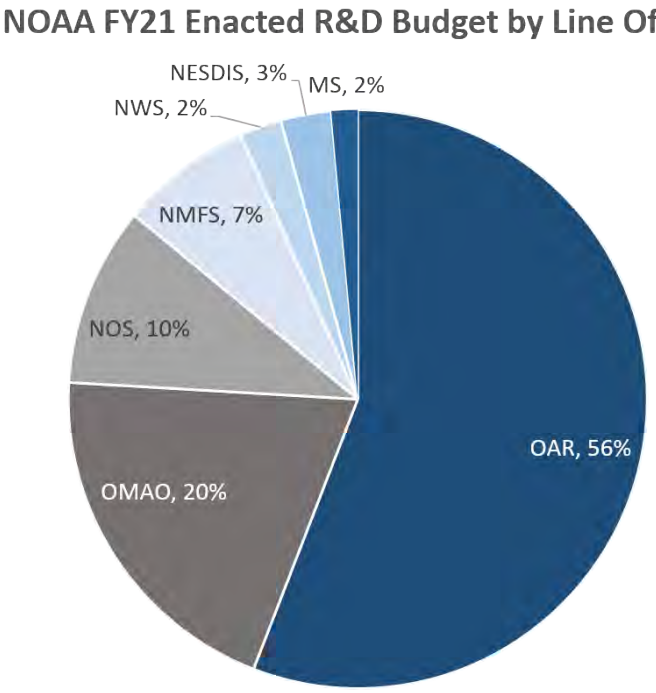
EPP/MSI supports four Cooperative Science Center (CSC) awards aligned to core NOAA mission areas. Established through national competition, the CSCs partner with 24 additional universities and collaborate in the training of post-secondary students in fields that directly support NOAA's mission. Students 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 a 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.

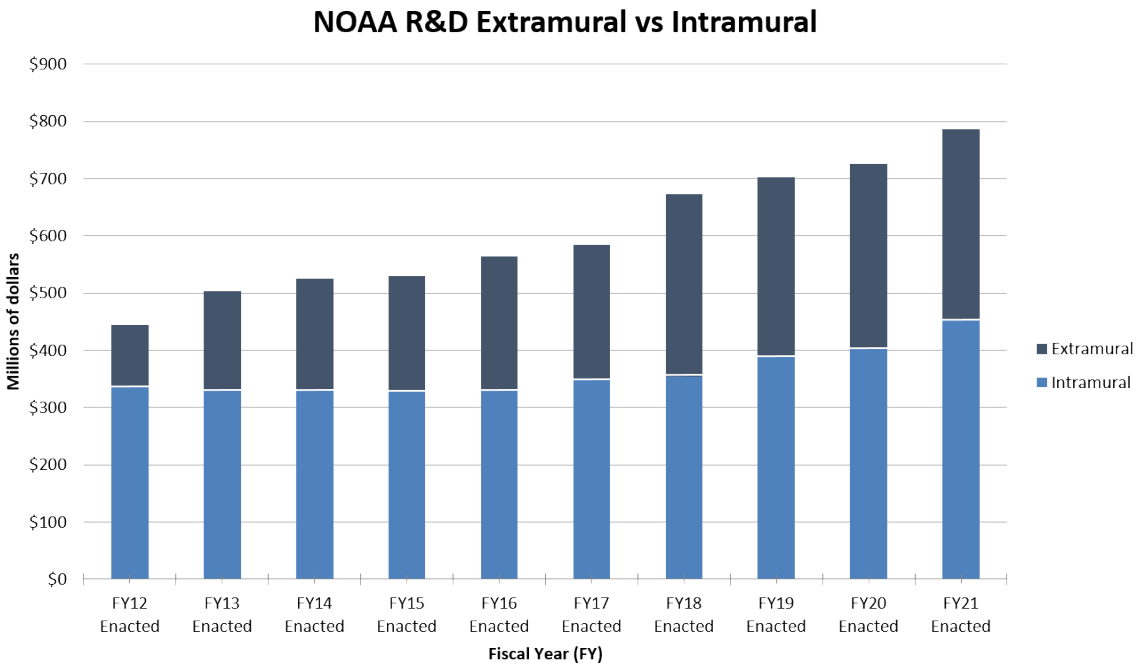
From 2003-2019, EPP/MSI CSCs graduated more than 50 percent of African-Americans who received PhDs in atmospheric sciences and meteorology and 35 percent and 29 percent of African-Americans receiving PhDs in marine science and environmental sciences, respectively. Additionally, EPP/MSI CSCs also graduated 39 percent of Latinos receiving PhDs in marine science and 21 percent and 18.5 percent of Latinos receiving PhDs in atmospheric sciences and meteorology and environmental sciences, respectively.

WHAT IS THE BUDGET FOR NOAA RESEARCH?

NOAA dedicated $1,024.9 million, approximately 19 percent of the agency's total budget, to R&D in fiscal year 2021 (FY21), with R&D defined as all research and development activities, including expenditures on R&D-related facilities and equipment purchases. This continues a nine-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: Mission Support (MS) includes construction of R&D facilities. NOAA's satellite acquisition programs, which design, build, and launch NOAA's operational satellites, are not included.





WHERE DOES IT GO?

Approximately 58 percent of NOAA's FY20 R&D budget went to internal R&D efforts, with the remaining 42 percent set aside for extramural research, enabling partnerships and collaborations with non-NOAA entities.

Note: This graph excludes 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.

LABORATORY AND PROGRAM SCIENCE REVIEWS

Scientific evaluations assess the strength and appropriateness of NOAA's R&D endeavors, as well as identify gaps and emerging issues and capabilities and 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. To assess the robustness and appropriateness of NOAA's scientific endeavors, the reviews focus on the quality, performance, and relevance of the R&D. Per NAO 216-115A, individual NOAA laboratories and science programs are reviewed every five years 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;

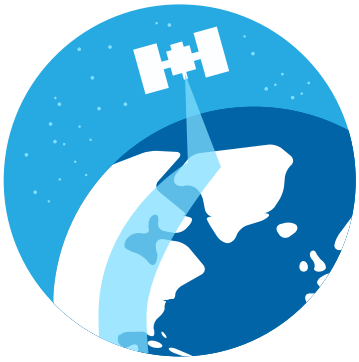
- Strategically position the laboratory/program for planning its future science by identifying gaps and emerging areas of science;
- Ensure research is linked to the strategic plan, mission, and priorities of NOAA, the laboratory/program, and the appropriate inter-agency working group(s);
- Deliver evidence 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.

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

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 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 (NSRS) for all federal geospatial activities. These efforts enable NOS to better manage the sea/shore boundary for coastal resiliency and planning.



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 the 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 Oceanic and Atmospheric Research (OAR), also known as NOAA Research, provides the research foundation for understanding the complex earth systems that support our planet. OAR's role is to provide unbiased science to better manage the environment nationally and globally. The science and technology that OAR 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. OAR 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 (IDSS).

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. Recently, OMAO established a new Unmanned Systems Operations Program to support the rapidly expanding use of these systems across the agency. 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.

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TRANSITIONING R&D

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. Examples of NOAA transitions include operational weather forecasting systems, products that inform resource management decisions, and commercially available sensors. NOAA characterizes and tracks the maturity of NOAA scientific projects through research, development, demonstration, and deployment. Transition plans guide the R&D maturation and transition to planned end use, helping ensure agreement between researchers and planned adopters with regards to content, format, schedule, and resources. NOAA transitioned products and services serve as tangible scientific outcomes that serve NOAA's mission and benefit the American people.

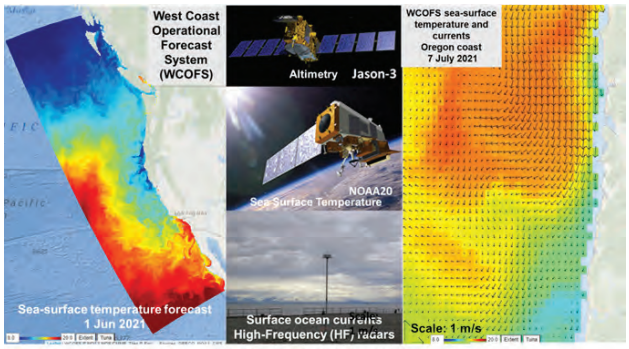
NOAA's 12 testbeds and proving grounds enable pre-deployment testing of NOAA's research and development, facilitating the transition into forecasts, warnings, products, services, and decision support. NOAA's testbeds and proving grounds are:

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 TRANSITIONS

DEVELOPMENT OF THE DATA-ASSIMILATING WEST COAST OPERATIONAL FORECAST SYSTEM

In March 2021, NOAA began using its first NOS operational coastal model with capabilities to assimilate data. Data assimilation is the process by which observational data are brought into models. This project, known as the West Coast Operational Forecast System (WCOFS), forecasts the coastal and shelf waters of Washington, Oregon, and California. It uses a three-dimensional fluid dynamics model to forecast water levels, currents, temperature, and salinity. By assimilating coastal high-frequency radar, satellite sea-surface temperature, and satellite observations of the height of the sea surface, WCOFS produces more accurate forecasts. These forecasts support marine navigation, offshore industries, fisheries, and habitat applications, with users spanning the state governments of Washington, Oregon, and California, Native American entities, and the private sector, as well as academia.



Development of the Data-assimilating West Coast Operational Forecast System. Image credits: NOAA

HABITAT ASSESSMENT: PROTECTING FISH SPAWNING AGGREGATIONS IN FLORIDA KEYS

Events where hundreds to thousands of reef fish gather to spawn are known as reef fish spawning aggregations. These gatherings often put fish at risk of overfishing due to their large concentrations, high catchability, and regular recurrence in specific offshore locations during particular times of year. In order to better manage these stocks, NOAA interviewed the fishing community to gather local ecological knowledge, and used this information as a basis to guide field assessments with the goal of mapping the reef habitats where fish species aggregated. To do this, NOAA scientists used fishery sonar and validated the sonar results with divers. Observations from 2011-2017 at Western Dry Rock near Key West Florida noted at least four aggregating species (mutton, gray and yellowtail snapper, and permits). The Florida Fish and Wildlife Conservation Commission (FWC) used these observations to establish monitoring programs. In 2020, FWC worked with conservation advocates to propose an annual seasonal closure from April - July to protect the spawning aggregations of these species. The measure passed unanimously by the Commission on February 26, 2021.

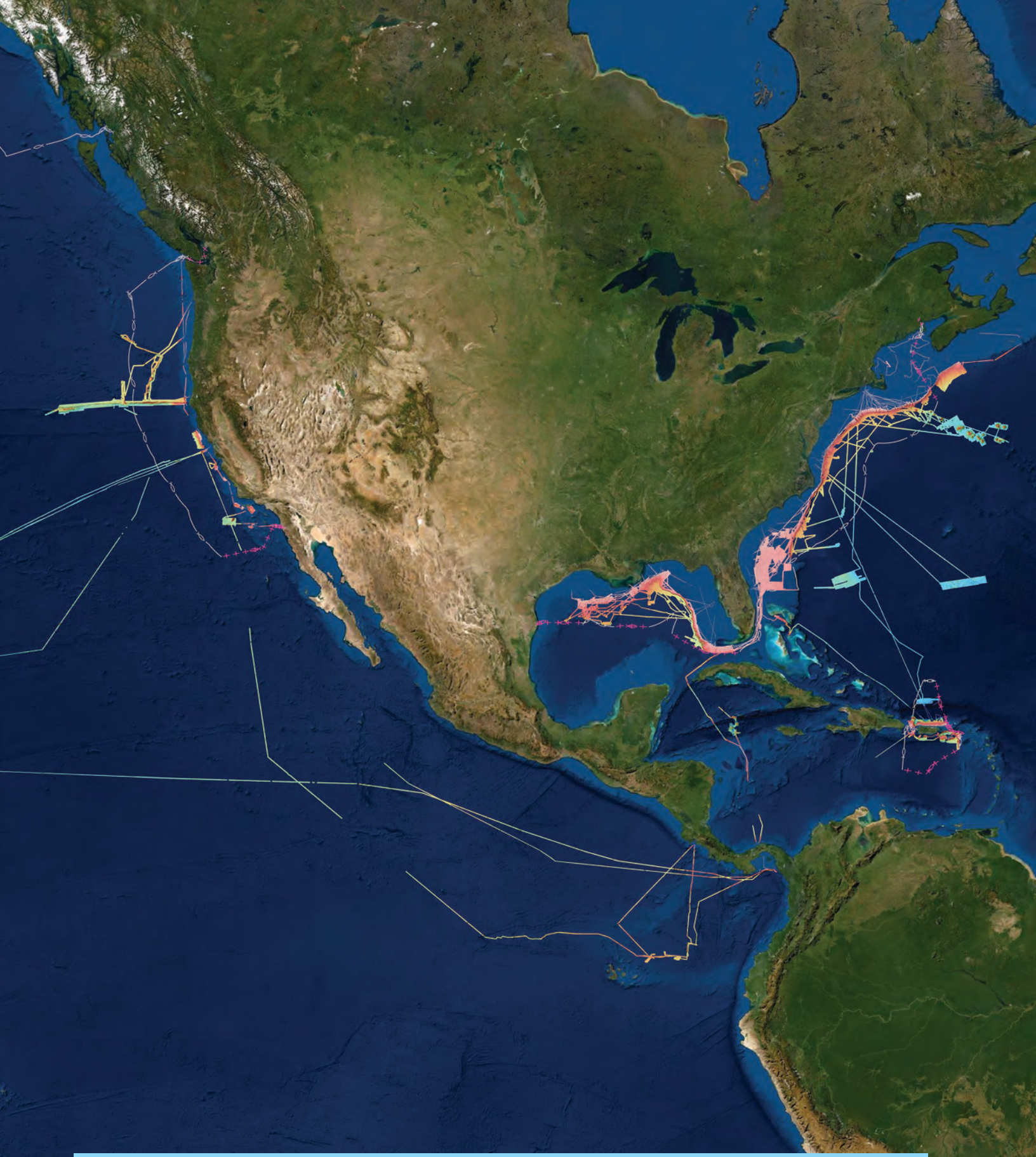
NOAA OPERATIONAL MODEL FORECASTS THE GLOBAL DISTRIBUTION OF AEROSOLS

NOAA transitioned into operations an atmospheric composition model that integrates weather and air quality to produce an air quality forecast. The model, called the Global Ensemble Forecast System-Aerosols (GEFS-Aerosol), produces seven-day forecasts of the global distribution of some primary air pollutants (smoke, soot, organic carbon, sulfate, and particles of dust and sea salt), collectively known as aerosols. The new model can predict the atmospheric impact of volcano eruptions, which can widely disperse ash and other particulates. The GEFS-Aerosols also includes an existing biomass burning plume rise module, which determines at what height above the ground fire emissions are injected. To do this it uses real-time data from satellites that give information on how hot and large the wildfires or agricultural burnings are.

NOAA BOOSTS MARINE FORECAST CAPABILITIES WITH UPGRADES TO FLAGSHIP OCEAN FORECASTING SYSTEM

NOAA NWS's Global Real-Time Ocean Forecast System (RTOFS) provides predictions for up to eight days of ocean currents, salinity, temperature, and sea ice conditions around the world. NOAA updated the RTOFS to include a high-resolution ocean data assimilation capability for the first time, which provides realistic representation of initial model states for accurate model forecasts. The upgraded Global RTOFS improved hurricane track and intensity forecasts for coupled hurricane models and provided more detailed and improved sea ice concentrations in the Arctic and Antarctic. Forecast improvements were also seen in sea surface temperature and near-surface ocean conditions in all global oceanic basins. NOAA NWS forecasters use the RTOFS model to inform marine forecasts and warnings that protect lives and enhance the maritime economy and the U.S. Coast Guard also uses it routinely, especially during search and rescue operations.

SCIENCE HIGHLIGHTS



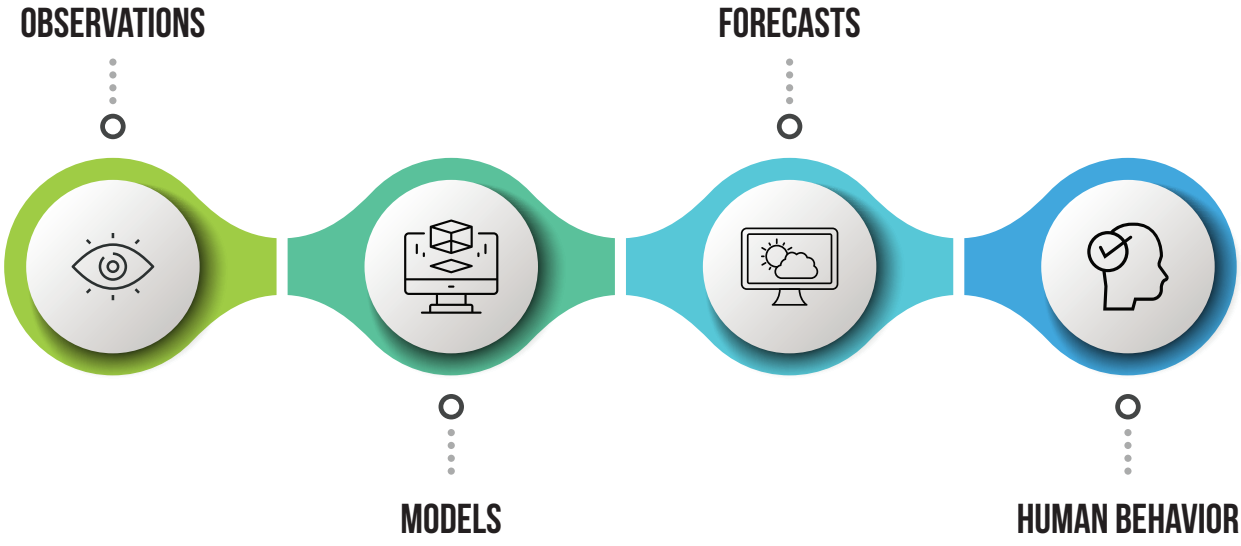
From 2008 through early November 2021, NOAA Ocean Exploration mapped 2 million square kilometers (772,204 square miles) of seafloor aboard NOAA Ship Okeanos Explorer. Okeanos Explorer is equipped with state-of-the-art multibeam sonar systems that use beams of sound to map the ocean floor. This map shows the cumulative multibeam mapping coverage. The gray lines indicate the boundaries of the U.S. Exclusive Economic Zone. Image courtesy of NOAA Ocean Exploration.

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

NOAA research and development improves the forecasts and warnings that provide accurate, timely information to the public about hazardous weather and environmental events. Through a better understanding of weather and climate phenomena, as well as human perception and behavior in response to risk communication, NOAA science helps save lives and property.NOAA's scientific accomplishments for 2021 have been divided into two groups: reducing societal impacts from hazardous weather and reducing societal impacts from climate change (particularly for at-risk and underserved communities).

1.A REDUCING SOCIETAL IMPACTS FROM HAZARDOUS WEATHER

The Weather Research and Forecasting Innovation Act of 2017 (Public Law 115-25, often referred to as the "Weather Act") was signed into law in April 2017, with goals (a.) to improve NOAA's weather research through investments in observational, computing, and modeling capabilities, (b.) to support improvement in weather forecasting and prediction of high impact weather events, and (c.) to expand commercial opportunities for the provision of weather data. In 2020, the record-breaking hurricane season and 22 weather/climate disaster events with losses exceeding $1 billion emphasize the importance of the scientific and operational advances described in the Weather Act. NOAA research and development aim to reduce the societal impacts of hazardous weather events by understanding (observations and models), forecasting, and communicating these threats to life and property.



OBSERVATIONS

NOAA observes environmental conditions through the use of radar, satellites, buoys, uncrewed systems, aircraft, weather balloons, and other instruments. These observations undergo quality control checks and are used as initial conditions for constraining models, among other uses. Past hazardous weather events also serve to inform future forecasts and decision making.

MODELS

NOAA models future environmental conditions using observations, mathematical relationships, and information from past weather events. NOAA's models span various time scales (hindcasts to decades) and spatial scales (local to solar) so that they can be best suited for different forecasts of hazardous environmental phenomena.

FORECASTS

NOAA issues forecasts of potentially hazardous weather based on models to provide advance warning of these conditions so that people can take action to protect their lives and property.

HUMAN BEHAVIOR

NOAA uses social science to understand human perception and behavior and the impacts of hazardous weather phenomena in order to better communicate forecasted threats and reduce societal impacts.

SPOTLIGHT

OBSERVATIONS

Satellite imagery, aircraft observations, and uncrewed systems provide observations about tropical storm conditions. Details about the shape and structure of a tropical storm's eye and eye wall are needed to accurately predict the intensity of a tropical storm. It has only been in the past decade that models have been able to more accurately capture those details.

MODELS

Tropical cyclone model predictions are updated as new observational data become available. Modern models have benefited from advancements in computing power and are better able to predict tropical cyclones at more detailed resolutions.

FORECASTS

With these improved models and observations, NOAA NWS forecasters predicted Hurricane Laura's landfall point within one mile 3.5 days prior to its landfall on August 27, 2020. NOAA NWS forecasters successfully forecasted the rapid intensification of Hurricane Laura 15 hours in advance. Forecasters predicted 15 to 20 feet of inundation - conditions that are far beyond life-threatening.

HUMAN BEHAVIOR

One day prior to Hurricane Laura's landfall, the NWS issued a warning of "unsurvivable storm surge" in a tweet that was amplified by media partners and shared more than 12,000 times. While it is difficult to definitively state the extent to which this language influenced people's behavior, there were no known fatalities directly caused by storm surge from Hurricane Laura.

1.A.1 OBSERVATIONS

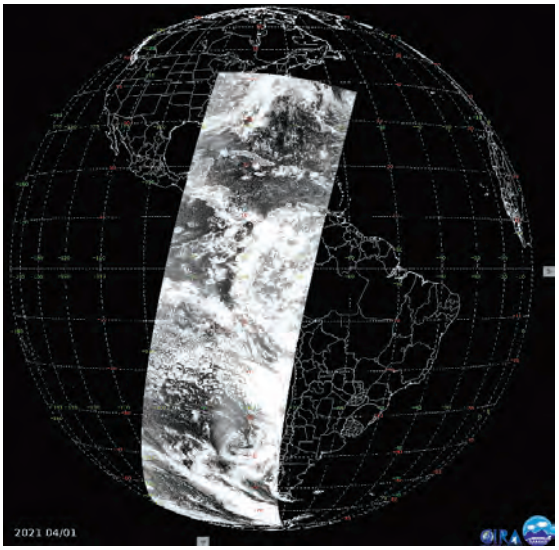
MACHINE LEARNING USING SATELLITE DATA AIDS ENVIRONMENTAL PREDICTION

NOAA scientists applied machine learning techniques to better predict weather phenomena. Radar allows forecasters to monitor and predict severe weather hazards. There are challenges in predicting precipitation and severe storms in areas with poor or no radar coverage, such as over mountains or above the open ocean. In order to improve forecasts in these areas, scientists extracted high-resolution information from instruments on the GOES-16 satellite to predict three-dimensional profiles of radar data using machine learning techniques; in effect using satellite data to provide a picture that until now has only been possible with radar. These simulated radar images can be used for various applications, such as to predict the movement of air masses in the atmosphere in numerical weather prediction models.

IMPROVING TROPICAL CYCLONE FORECAST CAPABILITIES USING THE JPSS DATA SUITE

NOAA scientists used data from the Joint Polar Satellite System (JPSS) to develop new applications to better estimate tropical cyclone position, intensity, and wind structure. The JPSS data includes high quality temperature and moisture profiles from the Advanced Technology Microwave Sounder (ATMS) and imagery from the Visible Infrared Imaging Radiometer Suite's Day-Night Band, which makes visible-like nighttime imagery possible. The Day-Night Band allows scientists to capture nighttime lights from human sources (for example, from city lights and fishing boats) and natural sources (for example, from moonlight and auroras) and is used to detect low clouds, smoke, and dust. In 2021, NOAA scientists either updated or completed the following applications:

- Moisture In-Flux Storm Tool: Important for predicting storm intensification since too much dry air inhibits convection. This tool detects and quantifies dry intuitions in storms.
- objective Radius of Maximum Wind from microwave imagery: Identifies the location of the strongest surface winds in tropical cyclones. Important to determine where there is the most potential for wind and storm surge damage.



An example of Visible Infrared Imaging Radiometer Suite's Day-Night Band imagery in GOES-16 projection on RAMMB-CIRA SLIDER. Image credit: Cooperative Institute for Research in the Atmosphere (CIRA)

- Visible Infrared Imaging Radiometer Suite's Day-Night Band in GOES-16/-17 projection: Important to identify tropical cyclone's center location at night, which affects track and intensity forecasts. Use of geostationary projection makes VIIRS data easier to view and compare with geostationary and model data.

The new applications demonstrated the potential to improve operational forecasts for tropical cyclone intensity and structure, and the potential to improve the availability and usefulness of visible-like nighttime imagery.

INTEGRATED OCEAN OBSERVING FOR THE ATLANTIC HURRICANE SEASON

Improving NOAA's hurricane intensity forecasts will require closing gaps in oceanic and atmospheric observations.To address this, NOAA formed the first integrated ocean observations team to coordinate the use of different in situ observing platforms (for example, gliders, drifters, floats, small uncrewed aircraft systems (sUAS), etc.) to improve hurricane intensity forecasts. The group leveraged existing observations and sought opportunities for co-deployments and simultaneous observations of the ocean and atmosphere throughout the 2021 Atlantic hurricane season in the Gulf of Mexico, tropical Atlantic, and Caribbean regions. NOAA employed concentrated efforts to seek opportunities for colocated observations for five major (Category 3 or above) hurricanes in 2021: Grace, Henri, Ida, Larry, and Sam. Ahead of and during Hurricane Sam, NOAA gathered observations from gliders, buoys, drifters, Argo floats, saildrones, expendable bathythermographs (XBTs, which are probes deployed from ships to measure water temperature), and A-XBTs (XBTs deployed from a NOAA P-3 plane). A Saildrone, modified with specially designed

A specially designed hurricane saildrone prior to its July 2021 launch from St. Thomas, Virgin Islands. Photo credit: Saildrone, Inc.

"hurricane wings" to enable it to operate in extreme conditions, battled 50 foot waves and winds of more than 120 miles per hour to collect critical scientific data from Hurricane Sam, providing the first video footage gathered by an uncrewed surface vehicle (USV) from inside a major hurricane. This air-sea data—as well as the data from all the colocated observing systems—will help scientists understand the processes that occur as storms intensify, with the goal of improving forecast models.

UNIFIED FORECAST SYSTEM UPGRADED WITH MOVING NEST TECHNOLOGY TO BETTER REPRESENT AND TRACK STORMS

NOAA scientists have created the first-ever global prediction model with a moving grid, capable of providing a very high resolution region around hurricanes, called the Hurricane Analysis and Forecast System (HAFS). This new system aims to provide

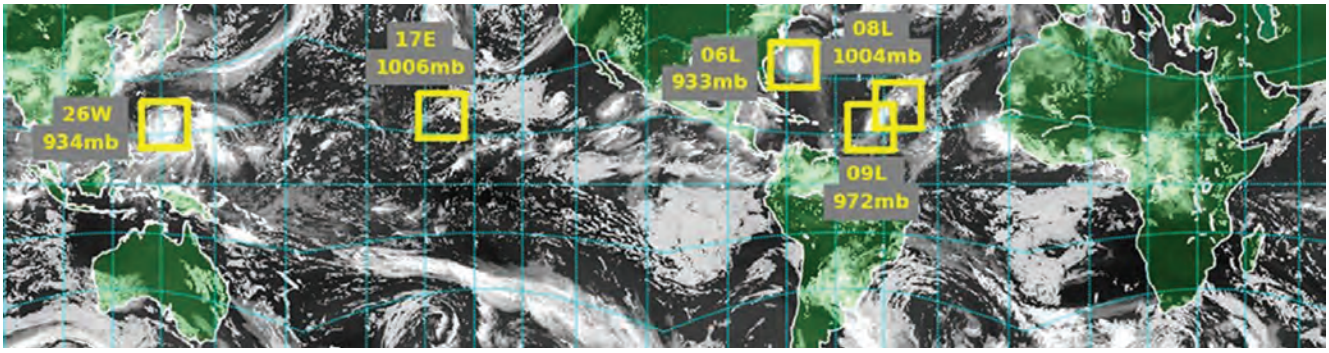
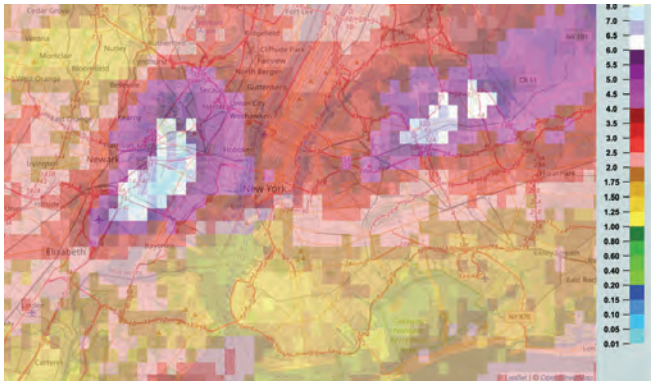


Image of the HAFS model showing the multiple moving grids in yellow boxes, which allows the model to provide very high resolution around the hurricanes anywhere in the globe. Image credit: William Ramstrom, NOAA Research/AOML

reliable and skillful guidance on tropical cyclone track, intensity, and structure, including rapid intensity changes, genesis, and storm size. A key development of the model is the Finite Volume 3 dynamical core with an embedded moving grid. This upgrade allows researchers to track the storm activity inside the core of the hurricane at high (1-2 km) resolution, where the winds are the strongest and most destructive. This high resolution around the hurricanes is critical for improving hurricane structure and intensity predictions.

NOAA DEMONSTRATES USE OF CLOUD-BASED DEVELOPMENT FOR THE TIMELY OPERATIONAL IMPLEMENTATION OF THE MULTI-RADAR MUTI-SENSOR PRODUCT

The Multi-Radar Multi-Sensor (MRMS) product suite integrates data from multiple observing systems, providing key inputs to hydrological, severe weather, and aviation products that support warning and forecast decision-making by NOAA NWS and its core partners. In operational use since 2014, NOAA NWS updated the MRMS application to expand most MRMS products to Alaska, Hawai'i, Guam, and the Caribbean; improve estimation of precipitation to address extreme rainfall; and to better identify and predict short-term hazardous weather and water conditions such as severe weather and flash floods. In partnership with NOAA Research, MRMS development was conducted in an off-premise real-time cloud environment then transitioned directly to NOAA NWS for operational implementation. Moving the MRMS development from an on-premise environment to the public cloud allowed one-third of the compute and storage allotted for MRMS on on-premise infrastructure to be reallocated to support critical updates to MRMS and other applications required by forecasters to support the weather and water mission.



Estimated precipitation in inches from 8 am on June 30 to 8am on July 3, 2021 over New York City produced by the operational Multi-Radar Multi-Sensor system. Image credit: NOAA Research/NSSL

1.A.2 MODELS

HYSPLIT MODEL SAVES LIVES, MONEY, AND TIME IN A RANGE OF ROUTINE AND EMERGENCY SITUATIONS

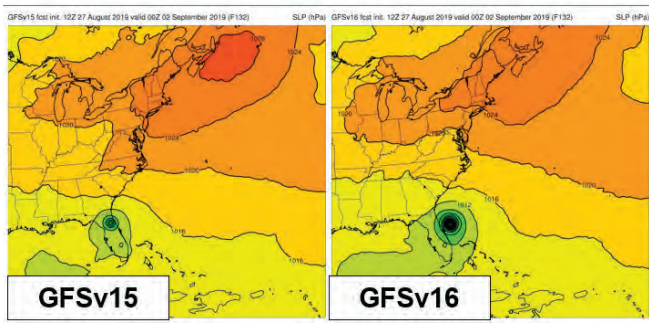
Changing weather patterns brought a devastating plague of locust swarms to northern Africa in 2020. NOAA Research was able to adapt the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model's atmospheric transport capabilities to predict the locust swarms' path of travel in order to alert areas in danger of infestation. This effort began in February 2020 to aid the Food and Agriculture Organization of the United Nations (UN FAO) in responding to the threat in Africa. In early 2021, NOAA introduced new functionality regarding time-of-arrival for the swarms and an application programming interface (API) for local agencies to run multiple swarm forecasts automatically. The HYSPLIT team continues to work with the UN FAO to develop new features and provide forecasts up to 15 days before regions experience impact. FAO forecasts enable local officials to conduct aerial spraying to reduce the impact of desert locusts, which can destroy grains, grasses and other greens that are life-sustaining foods for entire regions. Overall, the UN's HYSPLIT-enabled response preserved livelihoods of 36.9 million people and protected food security. The overall value of local surveillance, prediction, and intervention is estimated at $1.57 billion (crop and milk production saved).

ACCELERATING THE DEVELOPMENT OF FUTURE DATA ASSIMILATION INFRASTRUCTURE FOR REGIONAL AND GLOBAL FORECASTING: JOINT EFFORT FOR DATA ASSIMILATION INTEGRATION (JEDI)

The process by which observational data is brought into models is called data assimilation (DA). The Joint Effort for Data assimilation Integration (JEDI) is the next generation, unified DA framework under collaborative development between NOAA and cross-agency partners through the Joint Center for Satellite Data Assimilation (JCSDA). JEDI will allow for a faster development and research-to-operations (R2O) of advanced data assimilation and related components to meet the requirements of NOAA's Unified Forecast System (UFS). In June 2021, JCSDA made the second, public open-source release of JEDI, which featured updates to the Interface for Observational Data Assimilation. This release markedly improves JEDI's performance, allowing for efficient storage of and access to the rapidly growing volume of data as well as accommodating various file formats that JEDI receives from observation data providers. Extensive work is also being conducted on DA related to the ocean, sea ice, land and hydrology, atmospheric composition and air quality, and everything from short range weather to coupled applications for subseasonal and seasonal prediction. JEDI is well positioned to be the next generation DA system for the UFS.

NOAA UPGRADES TO THE GLOBAL FORECAST SYSTEM

NOAA upgraded its Global Forecast System (GFS) weather model to boost weather forecasting capabilities across the U.S. and the world. These advancements will improve forecasting hurricane development, modeling for snowfall location, heavy rainfall forecasts, and overall model performance. This is the first major upgrade to the Global Forecast System (GFS) for short and medium range (0-16 day) weather prediction using the new Unified Forecast System (UFS) framework. Key components of this upgrade that improves its forecast capability include doubling the vertical resolution (from the surface of the Earth to the top of the atmosphere), updated model physics, improved system for data assimilation, and the addition of new observations.

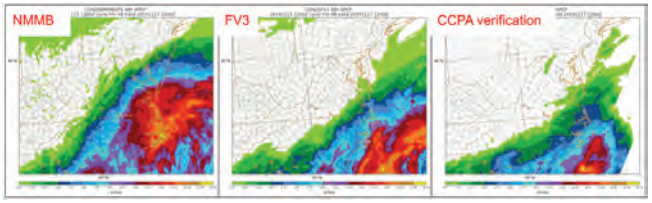


GFSv16 correctly predicted the path and strength of Hurricane Dorian (shown in green and black) keeping it away from the Florida coast while the operational GFSv15 took the storm inland with much weaker intensity. Shown in this figure is a 132-hr forecast initialized on Aug. 27, 2019, six days in advance of the event, which was used as a verfication method. Image credit: NOAA

Also, for the first time, the global wave model is now coupled with the atmospheric model to provide improved wave forecasts for the marine and coastal regions around the globe.

HIGH RESOLUTION ENSEMBLE FORECAST SYSTEM UPGRADE ADDS 12 HOURS OF ADDITIONAL LEAD TIME

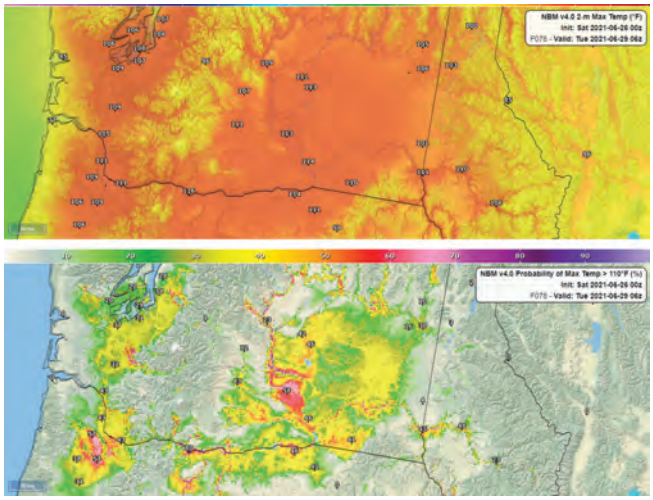
The High Resolution Ensemble Forecast (HREF), which is a collection of different regional weather forecast models called members, was upgraded in May 2021 by adding several significant new forecast products, which includes new methods of generating ensemble mean and probability products for precipitation. The HREF model membership was also changed with the upgrade, extending the forecast range for HREF from 36 to 48 hours, fully covering the day two period for the first time in operations. Forecasters looking for tools to aid in the prediction of near-term, high-impact weather events will benefit from the additional 12 hours of additional lead time that this upgrade provides. In addition to severe weather and extreme precipitation events, this system has applications in the renewable energy sector, like wind energy.



48 hour precipitation totals from the November 15, 2019 case, showing forecasts from the now retired NMMB member at left and the new FV3 member at center, and the Climatology-Calibrated Precipitation Analysis (CCPA) of observed precipitation at right. The NMMB has heavy precipitation too far to the northwest; the FV3 correctly keeps it further southeast and more in line with the CCPA.. Image credit: NOAA NWS/NCEP/EMC

NATIONAL BLEND OF MODELS (NBM) UPGRADED TO VERSION 4.0

The National Blend of Models (NBM) is a nationally consistent and skillful suite of calibrated forecast guidance based on a blend of both NWS and non-NWS numerical weather prediction model data and post-processed model guidance.The latest version of the NBM, which was implemented in September 2020, has narrowed the existing NWS product gap and has also improved existing guidance. The primary NBM improvements with this implementation centered on the elements associated with aviation weather, water resources, mariners, and tropical weather. Some examples include: (1) Significant improvements in the aviation forecast guidance routinely used in daily airport operational planning through 84 hours; (2) advancements in the area of heavy precipitation forecasts and its associated uncertainty information for Alaska, Puerto Rico, and oceanic domains; (3) the addition of statistical forecast uncertainty information for temperature forecasts for days 1-10. It is anticipated that these along with other upgrades will benefit the NWS in its mission to better support their core partners as they make decisions due to weather, water, or climate impacts.



National Blend of Models (top) high temperature forecast and (bottom) probability of high temperature exceeding 110 degrees F for southern Washington and northern Oregon issued 9 pm EDT Friday June 25, 2021, three days ahead of the actual event. Image credit: NOAA NWS Whole Story Uncertainty and Probability (WSUP) Viewer

STREAMFLOW AND STORM SURGE MODEL UPGRADES RESULT IN IMPROVED FLOOD FORECASTS

NOAA upgraded two models related to streamflow and storm surge to improve flood forecasting. These are the NOAA Water Model (NWM) and the Probabilistic Tropical Cyclone Storm Surge (P-Surge).

- The NWM simulates observed and forecast streamflow over the continental United States, taking into consideration the water cycle, its different processes, and how they fit together. The upgraded model produced a 48 percent improvement in the contiguous United States for major flood events and a notable reduction in Hawai'i-domain false alarms. The NWM upgrade expands the domain to include the Great Lakes drainage basin, and produces an operational NWM forecast for Puerto Rico and the U.S. Virgin Islands for the first time, and improves forecasts downstream of approximately 500 reservoirs.
- P-Surge is based on an ensemble of Sea, Lake, and Overland Surge from Hurricanes (SLOSH) model runs which are derived from the National Hurricane Center official advisory along with historic errors in its track, size, and intensity. The improvements to P-Surge are most pronounced between 36-60 hours prior to tropical system landfall, resulting in better overall forecasts of storm surge in the critical 48-60-hour lead times.

By leveraging the improved forecast guidance allowed by the model updates, NOAA continues to increase the accuracy and availability of mission critical services to the nation.

1.A.3 FORECASTS

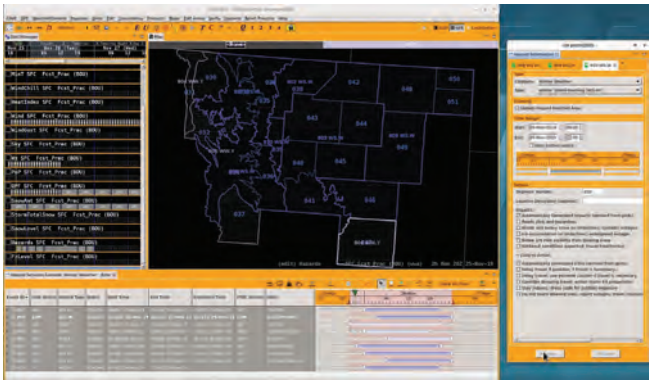
NOAA BEGINS USING PROBSEVERE TO ASSIST WEATHER FORECASTERS

Scientists at NOAA NESDIS and their partners used artificial intelligence to create an application called ProbSevere that helps forecasters provide rapid warnings for tornadoes, hail, and straight-line winds. ProbSevere gathers and integrates multiple information types, including satellite, radar, and lightning observations, identifies the pieces with the highest value for addressing severe weather, and provides forecasters with critical insights. For example,during an outbreak of severe weather over portions of southeast Texas on January 6, 2021 researchers showed that using ProbSevere in combination with radar scanning can increase forecasters' confidence in issuing warnings.

Artificial intelligence- derived information, available within the Advanced Weather Interactive Processing System, helps forecasters at NOAA NWS issue timely severe weather warnings. Image credit: NOAA NESDIS

HAZARD SERVICES WINTER WEATHER WARNING CAPABILITIES WILL DEPLOY TO NWS NATIONWIDE IN TIME FOR WINTER OF 2022-2023

Hazard Services is a software package that consolidates multiple hazard applications used by NWS forecasters into one application and modernizes how NOAA creates forecasts and communicates hazardous weather information. The easily customizable software allows for promising science and technology to be rapidly incorporated into the warning decision-making process. Hazard Services winter weather capabilities are being evaluated operationally at more than 20 NWS forecast offices in the winter of 2020-2021 and 2021-2022, and will be deployed nationwide in time for winter 2022-2023. Last winter, more than 200 winter weather watches, warnings, and advisories were issued from Hazard Services, providing timely information to NWS partners and the public days ahead of winter weather threats including blizzard conditions, heavy snow, freezing rain, and ice events.



The Hazard Services winter weather workflow being evaluated during the Thanksgiving Blizzard of 2019. Hazard Services is providing forecasters the ability to use just one software to issue warnings during winter weather events. Image credit: Vada Dreisbach, University of Colorado/ Cooperative Institute for Research in Environmental Sciences and NOAA Research/GSL

GSL balances the needs of replicating current functionality of the NWS software Hazard Services is replacing and maintaining a forward-thinking posture for the shift in paradigm Hazard Services will bring. — Nicole McGavock, Service Hydrologist - NWS Tulsa, OK (TSA)

COLLABORATIVE FORECAST PROCESS ENHANCES EXPLORATION OF WARN-ON-FORECAST SYSTEM USE FOR FORECASTING SEVERE WEATHER AND FLASH FLOODING

A snapshot of participants working a simulation together during the 2021 Warn-on-Forecast testbed experiment. Image credit: Katie Wilson, University of Oklahoma Cooperative Institute for Severe and High-Impact Weather Research and Operations/NOAA Research/NSSL

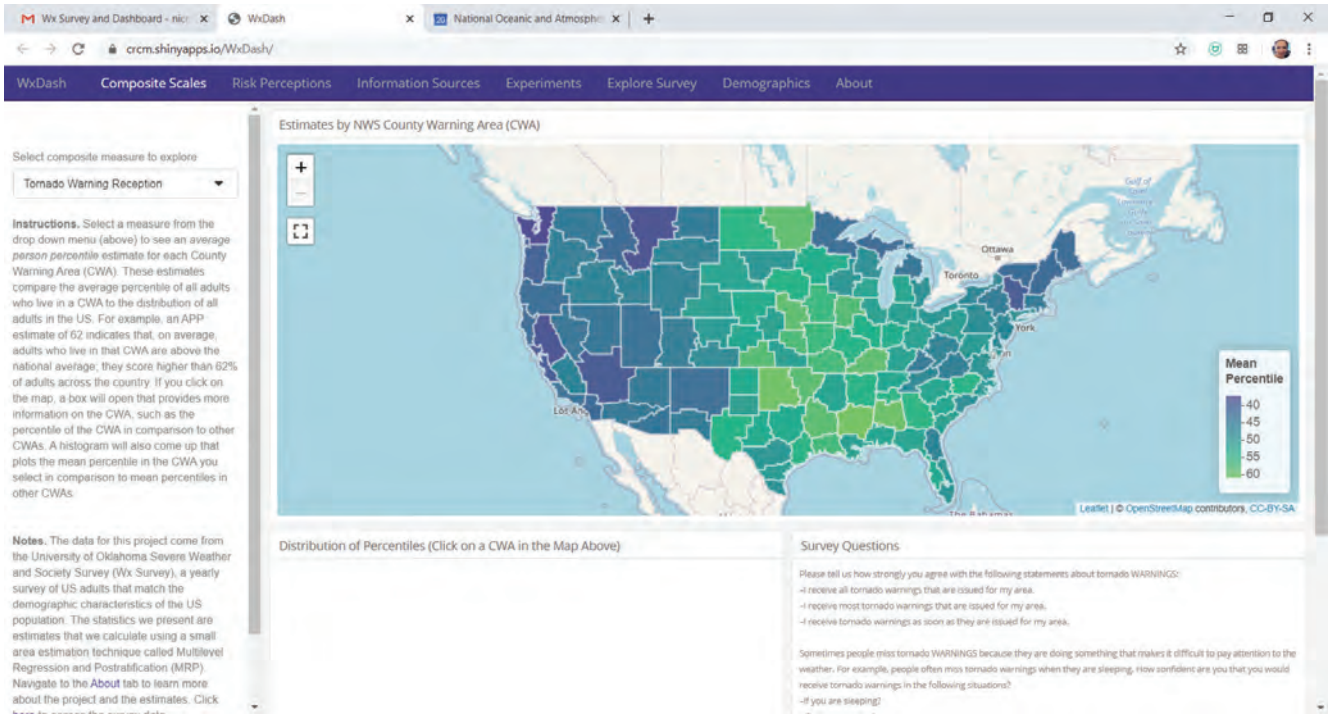
NOAA hosted the virtual 2021 Warn-on-Forecast (WoF) testbed experiment to explore how a revolutionary new computer model could help the NOAA NWS issue more specific and timely warnings for severe weather and flash flooding. During severe weather events, every half hour the experimental Warn-on-Forecast System (WoFS) creates 18 forecasts, all with slightly different inputs, to predict the movement and intensity of individual thunderstorms at the city level, several hours into the future. WoFS takes advantage of radar and satellite data in new ways, and provides a confidence estimate based on similarity between the 18 forecasts. The WoF virtual experiment broke new ground, as forecasters from NWS local offices (called Weather Forecasting Offices, WFOs) worked with two national offices to perform weather-event simulations in a cloud-based version of NWS software. During the four-week experiment, the simulations primed forecasters to discuss their expectations of how to use WoFS in current NWS operations or future operations. Insights gained will help establish strategies for using WoFS collaboratively between NWS local and national offices.

"Hands-on experience with WoFS and the chance to experiment in a no-risk environment allowed me to become more familiar with WoFS, try out ideas, and think outside the box." - Forecaster

"[The focus groups] not only provided me a chance to share my forecast process but also gain more perspective on what other national centers and WFOs (local offices) are using and doing during times of high impact weather situations and how they incorporated WoFS into their own forecast flowchart." - Forecaster

1.A.4 HUMAN BEHAVIOR

EXPANDING SOCIAL AND BEHAVIORAL DATA AVAILABILITY TO IMPROVE COMMUNICATION OF FORECAST UNCERTAINTY AND PROBABILISTIC INFORMATION



The Wx Dashboard will help NWS forecasters and partners better understand the communities they serve, by displaying results from the University of Oklahoma's Weather and Society Survey in a useful format. Image credits: Dr. Joe Ripberger/University of Oklahoma's Center for Risk and Crisis Management and NOAA

NOAA NWS has expanded the availability of the Weather and Society Dashboard (Wx Dashboard) to the NWS cloud platform. The Wx Dashboard, developed by the University of Oklahoma's Center for Risk and Crisis Management through the NOAA Joint Technology Transfer Initiative (JTTI) Program, is a dynamic interface and database of survey information reflecting the public's perception, response, and readiness to severe and tornadic events. The Dashboard enables forecasters to better understand public perception and the nuances associated with demographics so that they can best message and prepare the public to respond to severe weather events. The Dashboard will support the development of a baseline and performance metrics for messaging associated with severe and tornadic events to improve impact-based decision support services (IDSS) in saving lives and property.

METEOROLOGY AWARDS:

AMERICAN METEOROLOGICAL SOCIETY (AMS)

Charles L. Mitchell Award – Awarded to John M. 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

Award for Exceptional Specific Prediction – Awarded to Bryan T. Smith for a highly specific and accurate prediction of a strong supercell event with long lead time that saved lives

AMS Editors Award for Weather and Forecasting – Awarded to Michael Coniglio for consistently providing high quality, constructive, and rigorous reviews that help to uphold the high standards of AMS journals committees

NATIONAL WEATHER ASSOCIATION (NWA)

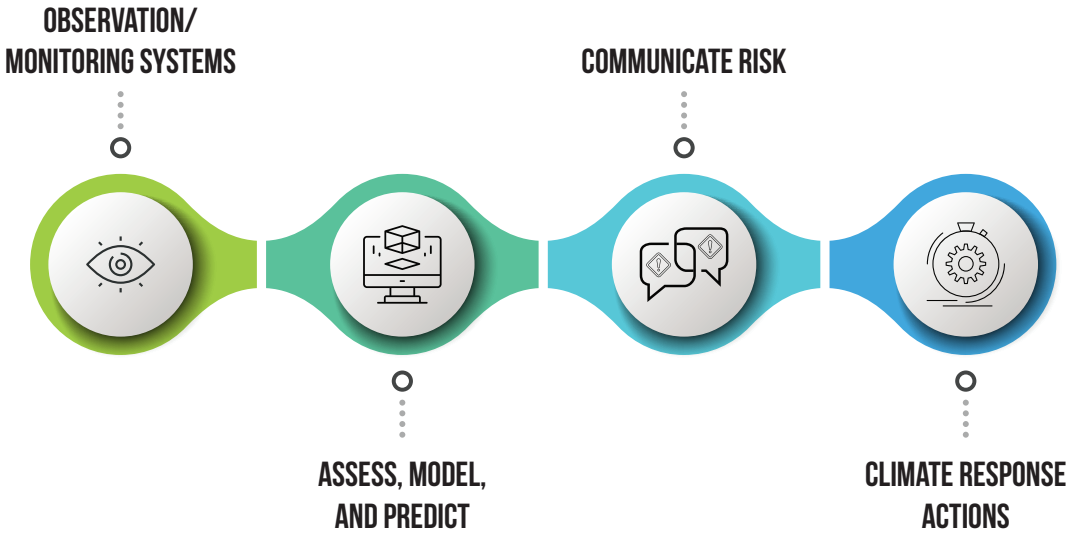
Dr. T. Theodore Fujita Research Achievement Award – Awarded to Pam Heinselman for outstanding leadership of the NOAA/NSSL Warn-on-Forecast research and development program, particularly her work in developing collaborations with the operational community that have strengthened the research-to-operations and operations-to-research pipelines

SOUTH KOREAN MINISTRY OF ENVIRONMENT

Minister's Commendation – Awarded to Hyun Cheol Kim for contributions to South Korean air quality research

1B. CLIMATE CHANGE

The Executive Order on Tackling the Climate Crisis at Home and Abroad (EO 14008) emphasizes the importance of NOAA's climate science, products, and services, which increase our understanding of the impacts of climate change and provide decision support for at-risk communities. NOAA observation and monitoring systems provide long-term data to identify trends and feedback in the climate system. NOAA models produce bulletins and outlooks of future conditions, which the public can use to assess their risk to societal impacts of climate and respond with mitigating and adaptive actions. Approaching climate science work with an environmental justice framework is key for NOAA to improve the accessibility, usefulness, and impact of the science and services.



OBSERVATION/MONITORING SYSTEMS

Long-term observations are essential for identifying climate trends. NOAA collects and assimilates long-term observations on land, in the water, and from the atmosphere and space in order to monitor the climate system and provide baseline data for models.

ASSESS, MODEL, AND PREDICT

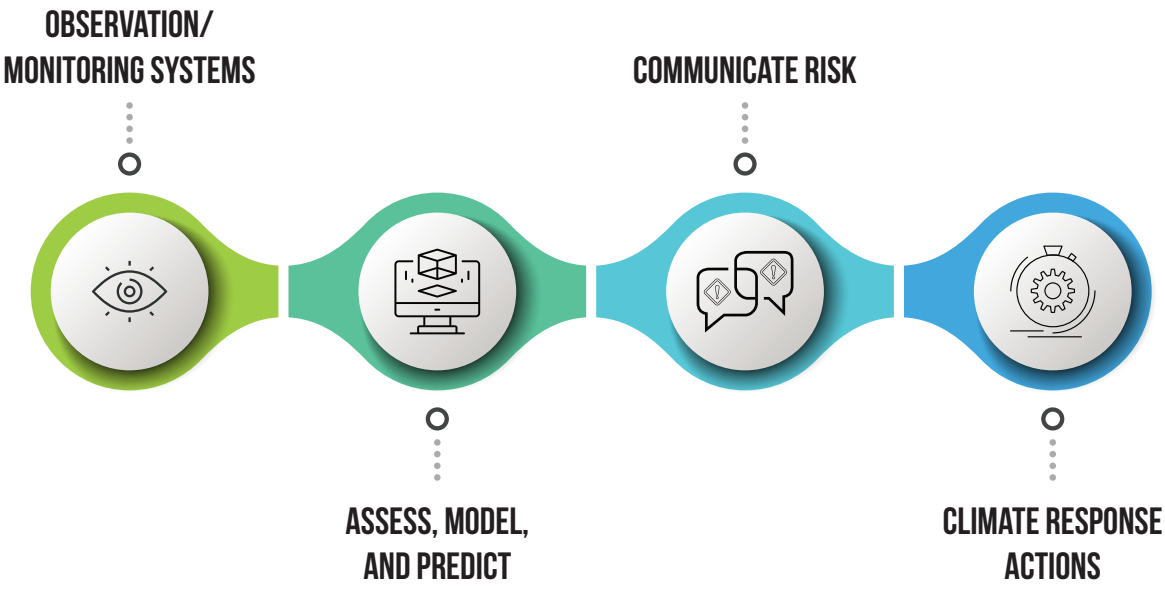
NOAA produces higher level data products from climate observations and develops models in order to assess the past, present, and future conditions of the Earth's climate system. NOAA produces forecasts, bulletins, and outlooks for informing risk assessments of hazardous climate conditions.

COMMUNICATE RISK

Forecasts of future climate scenarios are used to communicate risk to ecosystems, species, and communities and inform decision making.

CLIMATE RESPONSE ACTIONS

Members of the public can use NOAA products and services to develop and implement climate response plans and make decisions regarding adaptation and mitigation.



SPOTLIGHT

OBSERVATION/MONITORING SYSTEMS

Cities across the country and worldwide are facing increasing and inequitably distributed challenges around extreme heat, a threat that kills more Americans than any other weather event. The National Integrated Heat Health Information System (NIHHIS), an interagency initiative led by NOAA, is coordinating community science field campaigns to expose how individuals within their own cities are experiencing heat differently, and what municipalities can do to create healthy and equitable cities as the climate warms. NIHHIS conducts the campaigns through a Public-Private Partnership with CAPA Strategies, LLC (CAPA); together they have coordinated heat mapping campaigns in more than 55 U.S. cities to date. The NOAA NWS provides forecasts to help the communities plan their campaigns and NOAA NESDIS provides data hosting support. Each community has myriad partners including local government, science museums, environmental justice organizations, private sector companies, and community groups who organize and plan the campaigns locally.

ASSESS, MODEL, AND PREDICT

Once the measurements are collected by volunteers, CAPA uses machine learning (artificial intelligence) techniques to process the data and model air temperature and heat index using satellite imagery as well as other regional observations.

COMMUNICATE RISK

The maps produced provide critically needed urban heat island profiles of communities to inform heat-health risk reduction actions at the neighborhood scale..

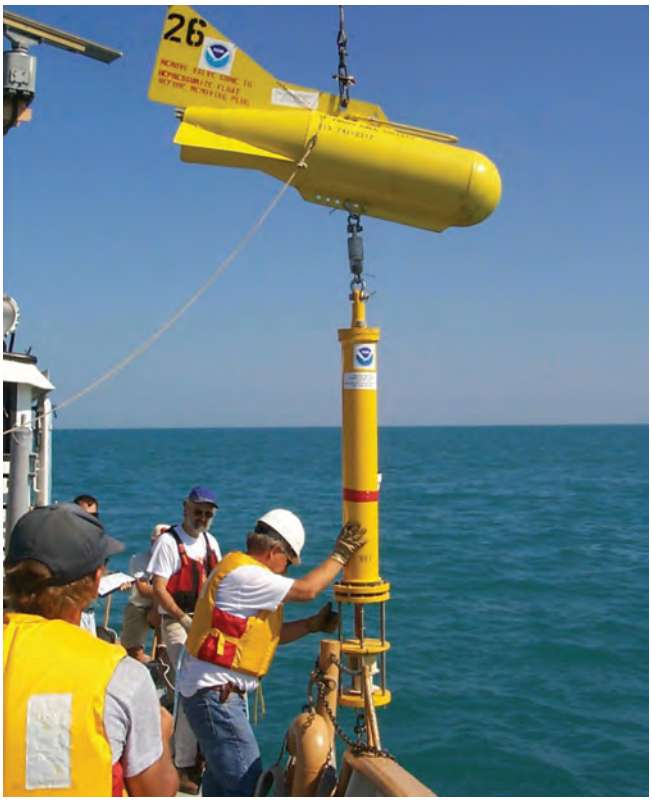
CLIMATE RESPONSE ACTIONS

Communities have used this information to increase awareness among community members and civic leaders, inform climate action and resilience planning, as well as direct additional research on effective solutions to ultimately create healthier, safer, and more resilient cities.

1.B.1 OBSERVATION/MONITORING SYSTEMS

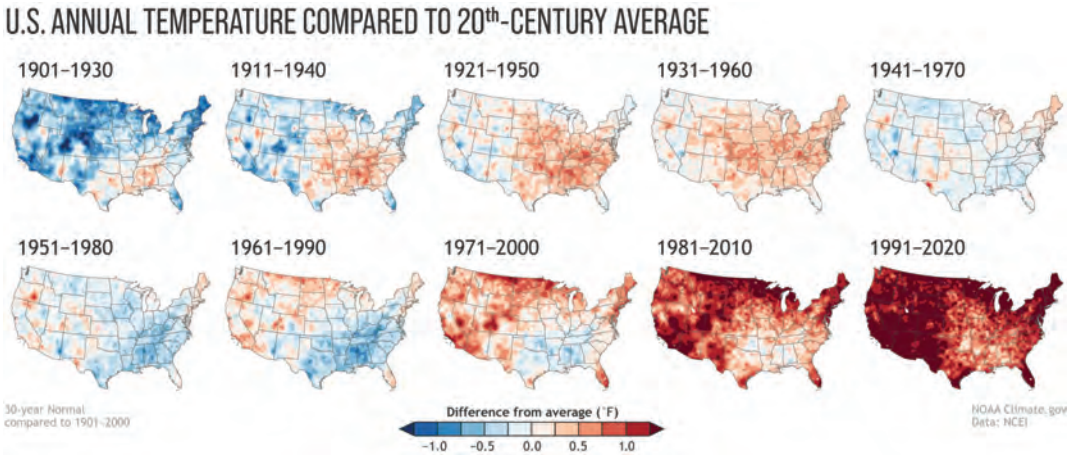
LAKE MICHIGAN'S RISING TEMPERATURE: TROUBLING CLIMATE CHANGE SIGNAL

A long-term study published by NOAA Research reveals a warming trend in Lake Michigan's deep water temperatures that foreshadows profound ecological change on the horizon. Using a unique, continuous 30-year dataset of approximately hourly deep water temperature measurements, NOAA scientists showed that Lake Michigan's seasonal mixing patterns are being affected by climate change. With increased delays in the onset of cooler autumn weather over the past three decades, the annual mixing cycle has shifted and Lake Michigan's deep waters now have shorter winter seasons. This change could eventually alter Lake Michigan's ecological productivity and disrupt the entire food web, negatively impacting fisheries and recreation. The deep water conditions of the Earth's largest lakes are a missing piece of the global climate change puzzle, and NOAA's monitoring of the Great Lakes will pave the way for understanding these changes.



NOAA GLERL scientists deploy a thermistor chain for long-term temperature monitoring in southern Lake Michigan, 1999. Photo credit: M. McCormick, NOAA Research/GLERL

NOAA RELEASES A NEW SET OF U.S. CLIMATE NORMALS FOR 1991-2020



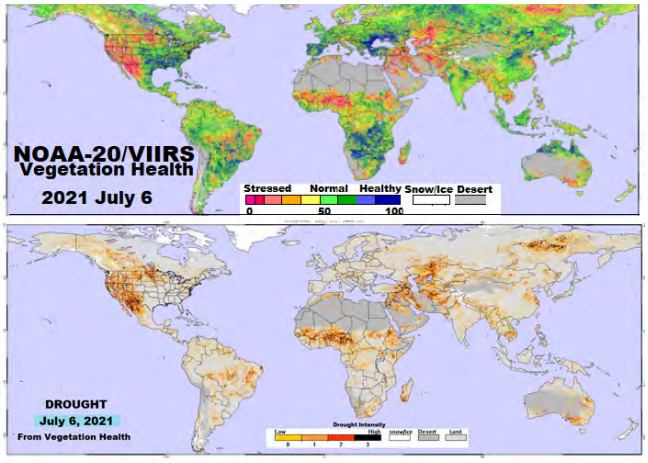
U.S. annual average temperature normals in the contiguous U.S. for 30-year periods up to the present minus the 1901-2000 20th-century average. Warming has impacted temperature normals substantially in recent periods. Maps by NOAA Climate.gov, based on analysis by Jared Rennie, North Carolina Institute for Climate Studies/NOAA NESDIS/NCEI

NOAA NESDIS released the 1991-2020 U.S. climate normals for 15,000 observation locations in May 2021. This set of temperature, precipitation, and other climate variables and statistics is used by NOAA NWS and commercial broadcast meteorologists to provide a baseline for comparing today's weather and tomorrow's forecast to the current climate.

In addition, climate normals characterize the state of the current climate and are used in decision making by both public departments and private businesses involved in many U.S. economic sectors, including energy, agriculture, construction, and general commerce. The annual, seasonal, monthly, daily, and hourly climate normals are calculated using established peer-reviewed methodologies designed by NOAA scientists to account for issues with observation quality, ensure consistency, and meet user requirements. Climate normals are a utilitarian product, but they also carry within them the fingerprints of climate change as they evolve over time, as can be seen in the rapid increases in temperatures over the last several nomals cycles.

NOAA MONITORS DROUGHT CONDITIONS FROM SPACE

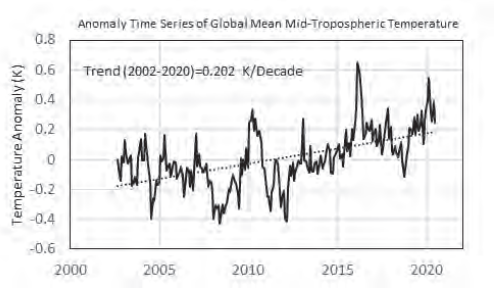
NOAA extended a data record from its new generation polar orbiting satellites to 2012-2021 and increased the ability to monitor global drought conditions. Data from the Visible Infrared Imaging Radiometer Suite (VIIRS) were used to derive weekly vegetation health, moisture condition, and thermal condition data at one-kilometer resolution (approximately 0.62 miles). NOAA scientists use these data to monitor agriculture, food security, vegetation health, crops' thermal and moisture stress, and climate change. The U.S. Department of Agriculture uses this data on vegetation health as vegetative health products can be used as proxy data for monitoring soil saturation, desertification, fire risk, land degradation, crop and pasture productivity, and more.



Vegetative health and drought information from the NOAA-20 satellite's VIIRS instrument. Image credit: NOAA NESDIS

NOAA'S IMPROVED ABILITY TO DETECT CLIMATE TEMPERATURE TRENDS

NOAA NESDIS combined observations from multiple satellites to create an atmospheric temperature time series. The accuracy of this new time series in trend detection is better than 0.02 degree Fahrenheit per decade. As a result, it may serve as a reference measurement of climate variability and trends in atmospheric temperatures. The warming rate from this time series for the atmospheric layer between the Earth's surface and 10 kilometers is 0.41 degree Fahrenheit per decade during the period from 2002 to 2020. The new time series can be used as a reference to identify errors in trend detections produced by other time series developed by different research groups. It can also be used to verify climate model simulations of atmospheric temperature trends with high accuracy.



Deseasonalized monthly global mean anomaly time series of mid-tropospheric temperatures merged from Aqua, Metop-A, Suomi NPP, and NOAA-20 satellites. Anomalies are relative to a monthly climatology of the Metop-A period from January 2008 to December 2017. Image credit: C.-Z. Zou, NOAA NESDIS/STAR

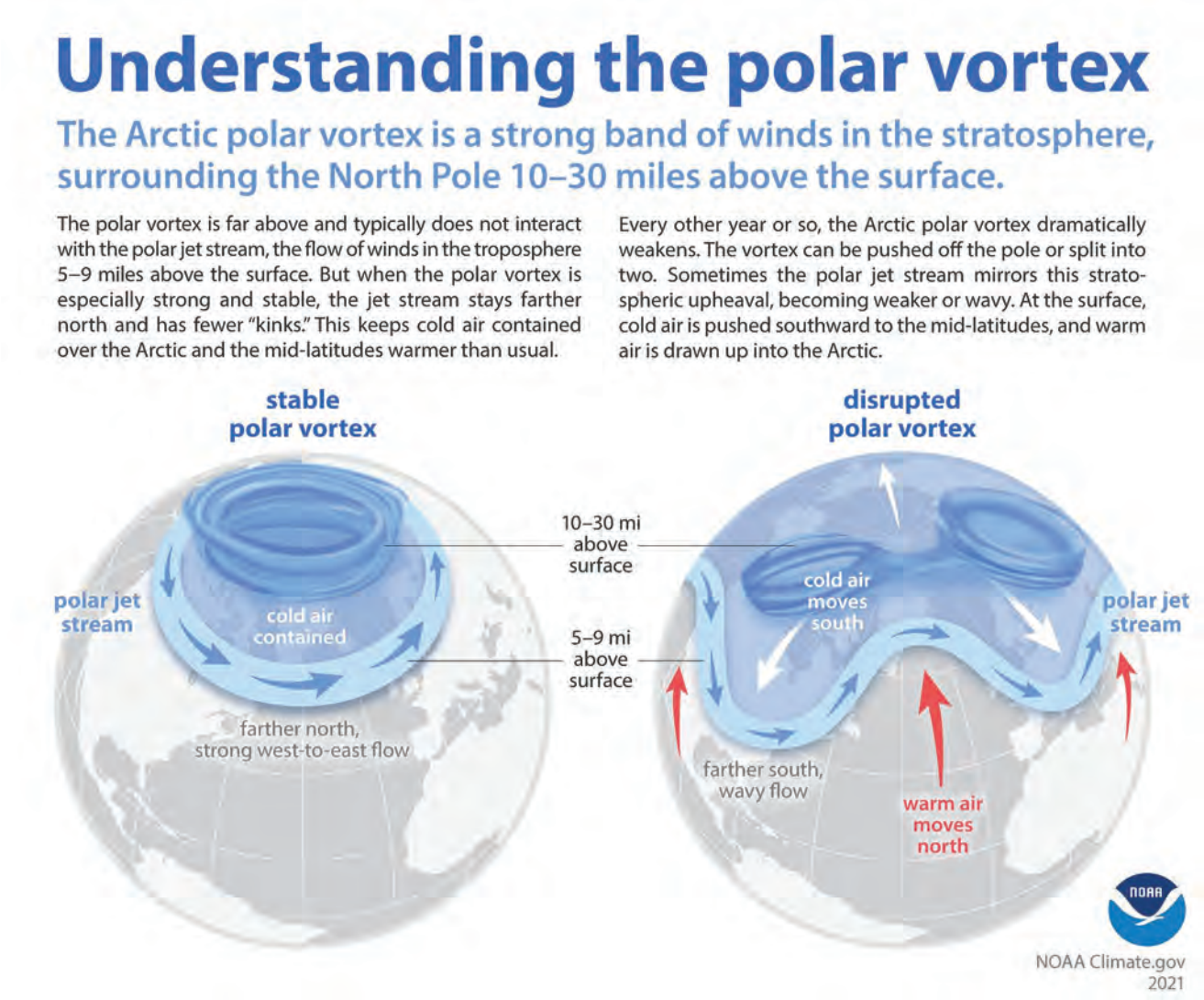
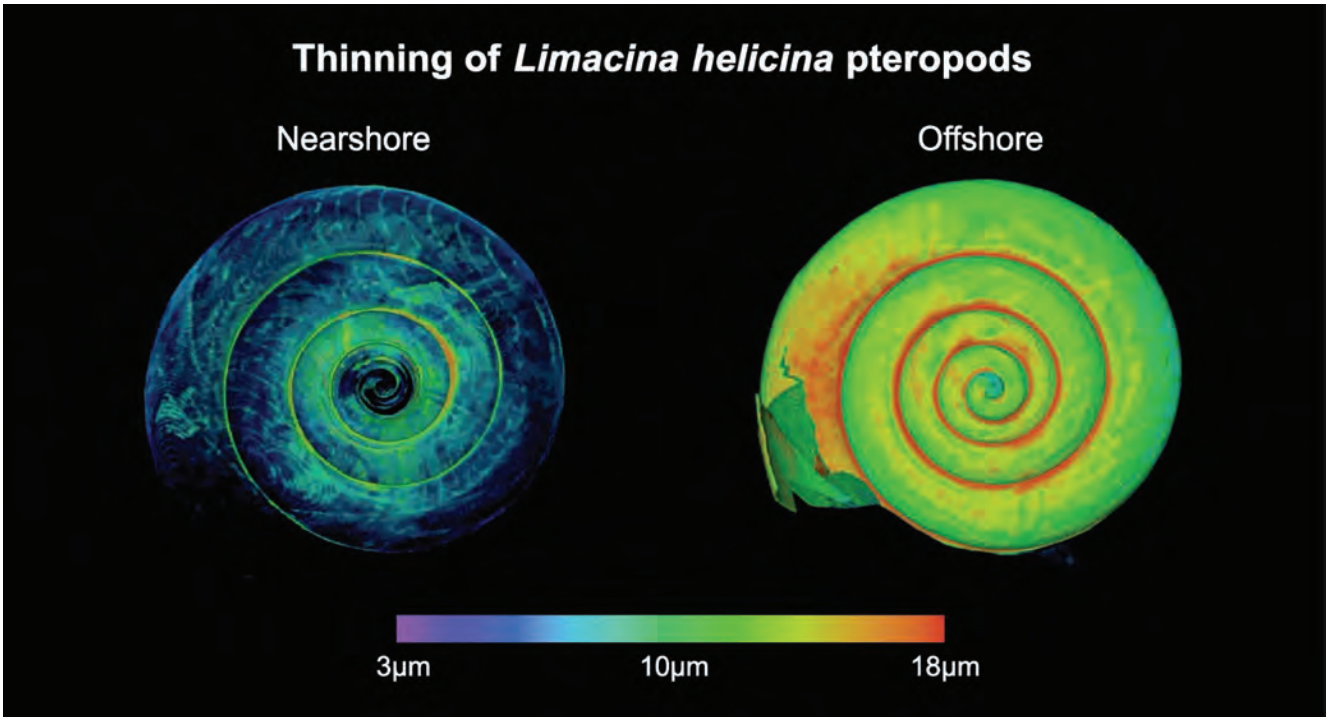


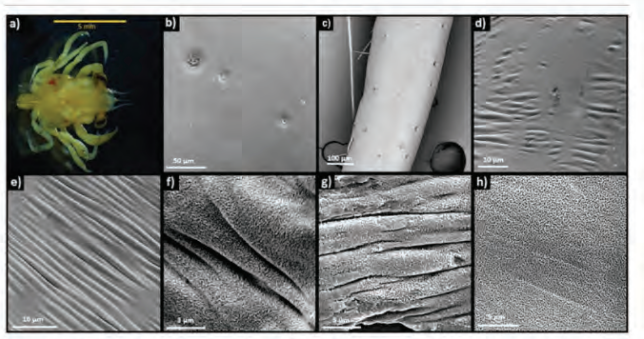
Image credit: NOAA climate.gov

The winds in the polar stratosphere are increasingly linked to weather extremes. The rapid slowdown of stratospheric winds, called a "sudden stratospheric warming" (SSW), is well-known for increasing the likelihood of cold extremes over the eastern U.S., northern Europe, and Asia during the wintertime. These events can also cause additional weather extremes, including warmer than normal temperatures in the Canadian Arctic and Middle East, and increased risk of flooding in the Mediterranean. NOAA Research is shedding light on the importance of understanding how the stratosphere influences extreme weather conditions at the surface, which may lead to being able to predict weather extremes weeks in advance, providing lead time for preparation and response.



This image depicts the difference in thickness between two specimens of the pteropod *Limacina helicina*, one collected in more acidified coastal waters, the other collected offshore, that were analyzed as part of a new study published in Science Reports. Image courtesy of Lisette Mekkes, Naturalis Biodiversity Center; used with permission

The California Current System, running along the North American west coast from south British Columbia to Baja California, is a region where seasonal upwelling brings nutrient- and carbon dioxide-rich and oxygen-poor waters to the surface. Increasing levels of carbon dioxide from upwelling and anthropogenic emissions cause a series of chemical reactions that are ultimately increasing acidity in these waters. Because the California Current System is an area with high rates of primary production by phytoplankton, air-sea carbon dioxide exchange, and carbon export to the open ocean and sediments, it is particularly susceptible to the impacts of ocean acidification and hypoxia (or low-oxygen levels). In June and July 2021, NOAA and partner scientists aboard the NOAA Ship *Ronald H. Brown* set out on the West Coast Ocean Acidification Research Cruise to characterize conditions along the West Coast of North America and continue to build a unique time-series of carbon and hydrographic measurements in areas



External carapace and pereopod exoskeleton of the Dungeness crab megalopae (a) in its undamaged form (b, c) and with dissolution presence ranging from mild (Stage 1; d) to severe (Stage 2; e, f) patterns showing similarity in the structural damages (g) or exposed crystals (h). Image from: Bednarsek et al. 2020, used with permission

expected to be highly impacted by ocean acidification. Scientists have been collecting samples from CTDs (tools that measure temperature, depth, and conductivity), collecting plankton and water samples for genomics analysis, and conducting the first systematic regional survey of methane gas coming out of the thousands of seeps along the West Coast. The comprehensive approach taken on this year's mission—combining detailed physical,

chemical and biological measurements—will not only allow scientists to better understand how the ocean is changing, but also test what new tools can be used to assess the future of these important marine ecosystems.

With data collected from this cruise and previous ocean acidification cruises in this region, scientists are documenting the changing ocean acidification conditions and how they are impacting marine ecosystems against a backdrop of multiple stressors including warming and deoxygenation. In 2016, measurements from this cruise demonstrated, for the first time, that ocean acidification along the U.S. Pacific Northwest coast is impacting the shells and sensory organs of some larval Dungeness crab, and that pteropods sampled near the coasts of Washington and Oregon had shells 37 percent thinner than those in waters further offshore.

MARINE ECOSYSTEMS ARE IMPACTED BY THE PACE OF CHANGE IN HUMAN ACTIVITIES

NOAA Fisheries scientists and partners merged data on fish behavior and demographics in a coral reef ecosystem to better understand how ecosystems respond to human activities like changing fishing practices. Their work reveals that ecosystems respond to more than just how much seafood is harvested.Because of interactions between harvested and unharvested species, ecosystems also are impacted by how quickly harvest policies change.The results of this work illustrate the importance of ecosystem-based approaches to management.

The research team was awarded the 2020 Cozzarelli Prize. This prestigious prize is given annually to six teams published in the journal Proceedings of the National Academy of Sciences whose articles made outstanding contributions to their fields. Each team represents one of the six classes of the National Academy of Sciences. Munch, Hein, and their co-authors won in the category of Applied Biological, Agricultural, and Environmental Sciences.

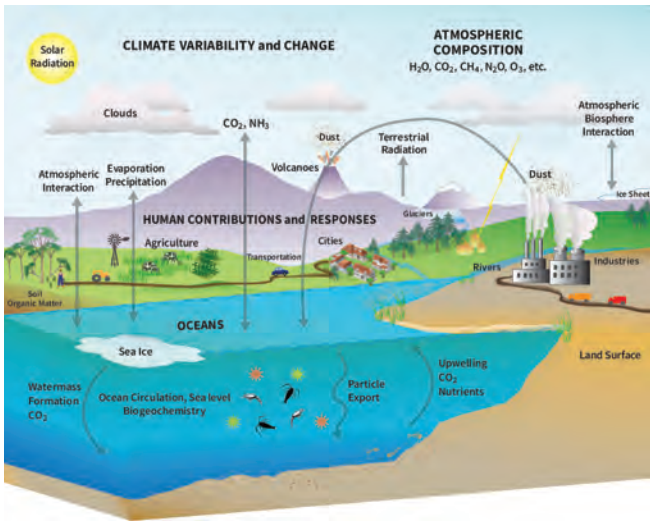
1.B.2 ASSESS, MODEL, AND PREDICT

EVALUATING IMPACTS OF CLIMATE CHANGE ON MANAGED MARINE SPECIES AND FISHING COMMUNITIES

The "Future Seas" project is a collaborative, interdisciplinary effort to explore potential impacts of climate change on U.S. West Coast fisheries and evaluate strategies for managing those impacts. The project uses a suite of models combined in a framework to explore physical changes, socioeconomic consequences, and other impacts under potential future climate scenarios and evaluate uncertainty in the models. This year, the team completed detailed projections of West Coast ocean conditions out to the year 2100 and used them to project potential climate-driven changes in the distributions and landings of Pacific sardine and albacore tuna in the California Current System. Project members from NOAA and academic partners provide information and scientific advice on climate resilience for West Coast fisheries using a management strategy evaluation framework informed by the projected changes in fish productivity and distribution.

NOAA'S FIRST COUPLED CARBON-CHEMISTRY-CLIMATE MODEL

NOAA has released its first model that captures the interactions among carbon, chemistry, and climate in order to improve the understanding of how these interact and reduce the uncertainty in future projections of climate change. The model incorporates state-of-the-art representations and interactions among atmospheric dynamics, physics and chemistry, ocean physics, biogeochemistry and ecosystems, sea ice, and land physics, biogeochemistry and ecosystems. The new model features vastly improved climate mean patterns and variability from previous chemistry and carbon coupled models.



Pictorial representation of the components of and linkages between elements that make up the new Earth System Model. Image citation: Dunne et al. (2020, JAMES, https://doi.org/10.1029/2019MS002015) Figure 1

1.B.3 COMMUNICATE RISK

COASTAL MANAGERS EVALUATE VULNERABILITY OF TIDAL MARSHES TO INFORM RESTORATION

A NOAA NOS-funded project, led by scientists at Oregon State University and the U.S. Geological Survey, enhanced an ecosystem model that projects how sea-level rise (SLR) may affect tidal marshes in the San Francisco Bay-Delta, including their long-term elevation and capacity for carbon sequestration (the process of capturing and storing atmospheric carbon dioxide). Local partners are using the results from the project to make natural resource management decisions. The San Francisco Bay National Estuarine Research Reserve is using these results to better understand impacts of SLR and other changing environmental conditions (salinity, sediment, and vegetation) on their managed wetlands. California's Delta Stewardship Council has integrated these results into their climate change planning work. In addition, the Sonoma Land Trust in California is using this information for the long term planning of the Petaluma River watershed, informing land acquisition and restoration plans. In April 2021, an NOS-led StoryMap was published that will allow coastal managers to understand the science behind SLR and visually evaluate wetland vulnerability to it, continuing to influence how marshes are managed in the region.

An example of predicted marsh changes with sea-level rise in the San Francisco Bay-Delta. Details of the WARMER model used to produce these results and additional information on the project can be found in the story map. Image credit: NOAA NOS/NCOSS

"The WARMER-2 update and its associated products have been critical to assessing risk to the California Delta's tidal wetlands and are playing a key role in the Delta Adapts Climate Vulnerability Assessment recently completed by the Delta Stewardship Council. Looking forward, the results will be an important component of developing the Adaptation Strategy for the Delta Adapts effort."—Dr. Dylan Chappel, Senior Environment Scientist with the Delta Stewardship Council

NOAA CLIMATE SCIENTISTS CONTRIBUTED TO THE 2021 IPCC REPORT

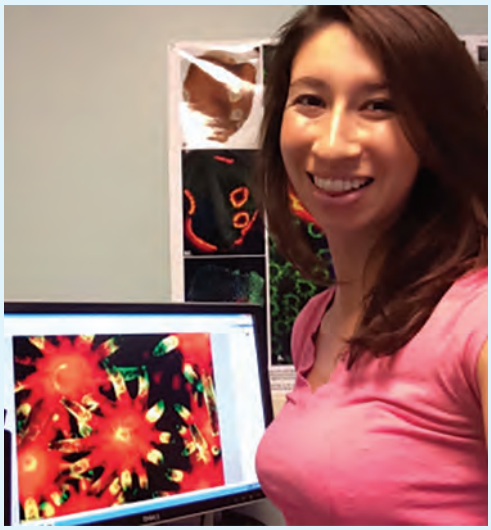
The Intergovernmental Panel on Climate Change is a body under the United Nations created to provide scientific assessments on climate change for policy makers. Their report, released every six to seven years, includes the current state of the knowledge on climate change, projections, implications, potential future risks, and adaptation and mitigation strategies. Their most recent report, released in August 2021, showcases international collaboration between more than 200 climate scientists from around 60 countries, including scientists from NOAA Research and NOAA NESDIS. Their contributions and expertise to this report is vital for our planet and helps support NOAA's leadership on addressing the climate crisis.

1.B.4 CLIMATE RESPONSE ACTIONS

TESTING INTERVENTION STRATEGIES TO ENHANCE CORAL RESILIENCE TO CLIMATE CHANGE

NOAA supports work to increase coral resilience to climate change in response to a National Academies of Sciences, Engineering, and Medicine study to review and evaluate potential novel ecological and genetic coral interventions and the resulting NOAA Action Plan on Coral Interventions. Examples include research on manipulating the symbiotic algae in corals to reduce heat stress and bleaching, advancing monitoring technologies using coral images (for example, through CoralNet as shown in the associate figure) and artificial intelligence to track corals' responses to disturbances like heat waves, and innovative rescue efforts in response to stony coral tissue loss disease. Study results are informing restoration strategies to enhance coral resilience to climate change, such as techniques to improve the tolerance of nursery-grown corals to various stressors, and where to outplant those corals on the reef so that they have the best chance of surviving and reproducing. For example, genomic analyses provide information to facilitate identification of corals that are able to withstand and recover from stressors, such as increased water temperature, and those corals could be used to grow more resilient corals in nurseries.

CoralNet is a software package that uses artificial intelligence to analyze benthic photos to classify corals. Image credit: NOAA Fisheries/PIFSC



EPP/MSI Alum Andrea Gomez. Photo courtesy of Andrea Gomez

ANDREA GOMEZ PHD.

Dr. Andrea Gomez earned her PhD in 2020 from The City College of New York as a NOAA Center for Earth System Science and Remote Sensing Technologies (CESSRST) fellow. Her research entitled "Evaluating Satellite-Based Sea Surface Temperatures and In Situ Observations, and Coral Symbioses in Southwestern Puerto Rico" sought to characterize the seasonal changes of algae symbiont identity and density using NOAA Coral Reef Watch 5km satellite-based sea surface temperatures and in-situ temperature loggers. While pursuing her PhD, Dr. Gomez completed a 12 week graduate internship with the NOAA/OAR Atlantic Oceanographic and Meteorology Laboratory entitled "Satellite Measured Sea Temperatures and Comparison with Vertical Temperature Profiles Near a Coral Reef Ecosystem in South Florida". Dr. Gomez was hired using the Conservation Corps Act of 2019 Direct Hire Authority by the NOAA/NMFS Greater Atlantic Regional Fisheries Office as a Communications Specialist in 2021.

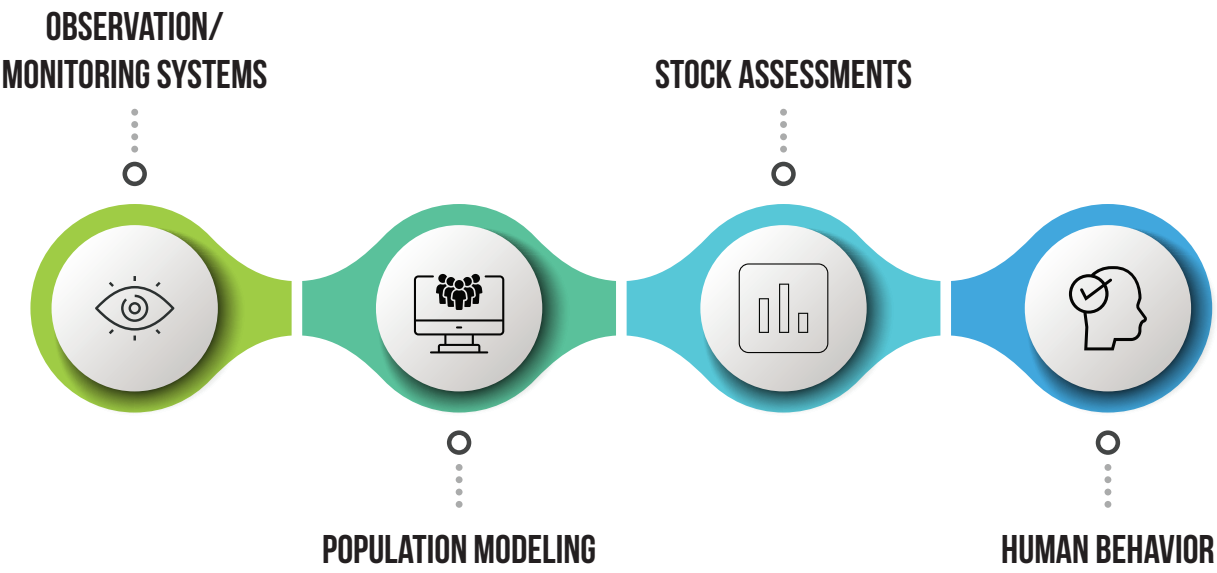
2. SUSTAINABLE USE AND STEWARDSHIP OF COASTAL AND OCEAN RESOURCES

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 2021, NOAA's scientific accomplishments for enhancing the sustainable use and stewardship of ocean and coastal resources included the following categories: coastal resilience and productive and sustainable fisheries.

2.A PRODUCTIVE AND SUSTAINABLE FISHERIES

In passing the Magnuson-Stevens Fishery Conservation and Management Act in 1976, Congress established federal management of the nation's fisheries and fostered long-term biological and economic sustainability of our nation's marine fisheries, with key objectives to prevent overfishing, rebuild overfished stocks, increase long-term economic and social benefits, and ensure a safe and sustainable supply of seafood. NOAA is responsible for the stewardship of the nation's ocean resources, including productive and sustainable fisheries. Since 2000, 45 U.S. marine fish stocks have been rebuilt, and the vast majority of the U.S. fish stocks were at sustainable population levels in 2018, with the number of U.S. fish stocks subject to overfishing near an all-time low. NOAA R&D supports these movements towards sustainable use and stewardship of our ocean and coastal resources.



OBSERVATIONS

NOAA conducts research on fish, fisheries, and protected species, including a variety of ongoing field studies and surveys. NOAA also conducts economic and socio-cultural research on the communities that depend on these resources. Climate change impacts all of these areas and is an important area of study as it relates to fish and fisheries.

POPULATION MODELING

NOAA uses models to address a range of research and management needs. Some models generate short-term projections to support management advice. Other models stimulate long-term evaluation of management strategies. Some models investigate the impacts of climate change as they relate to fish and fisheries.

STOCK ASSESSMENTS

NOAA uses stock assessments to monitor the condition of nearly 500 fish stocks and stock complexes (groups of similar stocks managed together). Stock assessments are scientific efforts that involve data collection, data processing, and mathematical modeling that estimate the health and size of a fish stock, measure how fishing affects the stock, and project harvest levels that achieve the largest sustainable long-term yield.

HUMAN BEHAVIOR

NOAA's science-based conservation and management for sustainable fisheries ensures these important resources will continue to support food and nutrition security, increase income and improve livelihoods, and promote economic growth.

SPOTLIGHT

OBSERVATIONS

NOAA Fisheries scientists collect and analyze data on Alaska Walleye Pollock. Information about the number, location, and age of pollock in Alaskan waters is collected during annual surveys using acoustic technology, midwater trawls, and bottom trawls. These data are combined with information collected by fishery observers. NOAA also conducts early life studies to understand how young pollock respond to environmental changes. This helps scientists understand and communicate future uncertainty in population size, and thus, the size of eventual fishing quotas to managers, the public, and fishery stakeholders.

POPULATION MODELING

Data on the age of pollock in Alaskan waters informs age-structured modeling of populations.

STOCK ASSESSMENTS

NOAA creates Stock Assessment and Fishery Evaluation (SAFE) reports to summarize the best available scientific information concerning the past, present, and possible future condition of stocks, marine ecosystems, and fisheries that are managed under federal regulation, including the walleye pollock fishery.

HUMAN BEHAVIOR

These SAFE reports provide information to the North Pacific Fishery Management Council for determining annual harvest levels from each stock; documenting significant trends or changes in the resource, marine ecosystems, and fishery over time; and assessing the relative success of existing state and federal fishery management programs.

2.A.1 OBSERVATIONS

LOCAL COMMUNITIES CONTINUE KEY FISHERY SURVEYS DURING PANDEMIC

NOAA Fisheries regularly relies on community partners as part of sampling and survey efforts, but these partnerships took on new significance in 2020 as they ensured that critical work continued during the global pandemic. In the Pacific Islands, for example, NOAA relied on a 10-year cooperative research partnership with the local Hawaiian fishing community to continue the Bottom Fishery-Independent Survey in Hawai'i. By maintaining this continuous data stream for the Main Hawaiian Islands Deep 7 Bottomfish Stock Assessment, managers will be able to set sustainable commercial catch limits for the fishery. In Alaska, where salmon are woven into the fabric of life and culture, and have been harvested by indigenous people for more than a thousand years, NOAA's partnership with the Yukon Delta Fisheries Development Association ensured that an important time series of Chinook salmon data collected since 2014 was maintained. When COVID-19 restrictions prevented NOAA researchers from conducting fieldwork in Alaska during the summer of 2020, local fishermen from the villages of Emmonak and Alakanuk stepped up to make certain the research continued.

From left to right: Technicians Kaitlyn Hanson and Jeniah Alstrom measure juvenile salmon and record lengths. Photo credit: Courtney Weiss/Yukon Delta Fisheries Development Association

"GREAT RED SNAPPER COUNT" DETERMINES ABUNDANCE OF RED SNAPPER IN GULF OF MEXICO

Red snapper is a highly-prized species that contributes economically to communities across the Gulf of Mexico. At the direction of Congress, NOAA competitively selected and funded an external, university-based research team of 80 scientists to conduct independent red snapper data collections, surveys and assessments — including the use of tagging and advanced sampling technologies — from 2017-2019. In 2021, the Sea Grant-supported Great Red Snapper Count released its findings that there are more than 110 million red snapper in the U.S. waters of the Gulf of Mexico, a count that greatly surpasses previous population estimates of about 36 million red snapper. The greater estimate is mostly attributed to a major new discovery of fish caught over the uncharacterized open bottom habitat in the Gulf. This new absolute abundance estimate holds the potential to change the way the Gulf of Mexico fishery is managed by both federal and state officials.

PARTNERSHIP PROVIDES UPDATED SPATIAL DENSITY AND DISTRIBUTION MODELS FOR CETACEANS AND SEA TURTLES IN THE GULF OF MEXICO

Gulf of Mexico Marine Assessment Program for Protected Species (GOMMAPPS) is a four-year partnership between the Bureau of Ocean Energy Management, NOAA Fisheries, U.S. Geological Survey, and U.S. Fish and Wildlife Service that provides improved information on abundance, distribution, and habitat use of cetaceans (dolphins and whales), seabirds, and sea turtles in the northern Gulf of Mexico. NOAA Fisheries conducted three vessel surveys covering oceanic waters and three aerial surveys over the continental shelf in 2017 and 2018, and completed the data analyses this year. The surveys resulted in updated abundance estimates for 25 cetacean stocks and four sea turtle species and improved precision and accuracy compared to prior estimates. Additionally, the survey data were combined with earlier data to develop models of spatially-referenced species counts with environmental predictors describing oceanographic conditions. Findings suggest seasonal and interannual variability in abundance and potential shifts in spatial distribution associated with changes in ocean conditions for some species, highlighting the importance of understanding the underlying dynamics in oceanographic conditions and their impacts on spatial distribution and abundance. Resource managers can use these model outputs to assess and manage human impacts on protected and endangered species, which is particularly valuable given potential offshore wind energy and aquaculture development and ongoing oil and gas development.

A NOAA Twin Otter aircraft used to conduct aerial surveys. A visual observer collects data and Atlantic spotted dolphins (Stenella frontalis) sighted from an aerial survey. Photo credit: NOAA Fisheries (Permit #14450).

RESEARCH INFORMS MANAGEMENT OF RARE GULF OF MEXICO WHALE

With a very small population size, the Rice's whale is one of the rarest whales on the planet, designated as endangered in 2019. Previously thought to be members of the Bryde's whale species, recent genetic and morphological data now identify the filter-feeding Rice's whales as a separate species. A NOAA-led research team is working to learn more about the whales' movement, habits, and feeding patterns to identify critical habitat and recovery planning efforts. Recent research has revealed that the whales spend most of their daylight hours in a constant diving and feeding pattern; and then rest just below the surface most of the night. The Rice's whale feeds on dense aggregations of fish that form just above the bottom during daylight hours, and may be selectively feeding on one or two fish species. The presence of upwelled water near the bottom, along with seasonal inputs of high productivity shelf water into the habitat, are likely important factors in maintaining enough prey to support the energetic requirements of the whales.

NOAA Fisheries researchers and collaborators described a new species of baleen whale from the Gulf of Mexico. Photo credit: Laura Dias, NOAA Fisheries (NMFS Permit #21938)

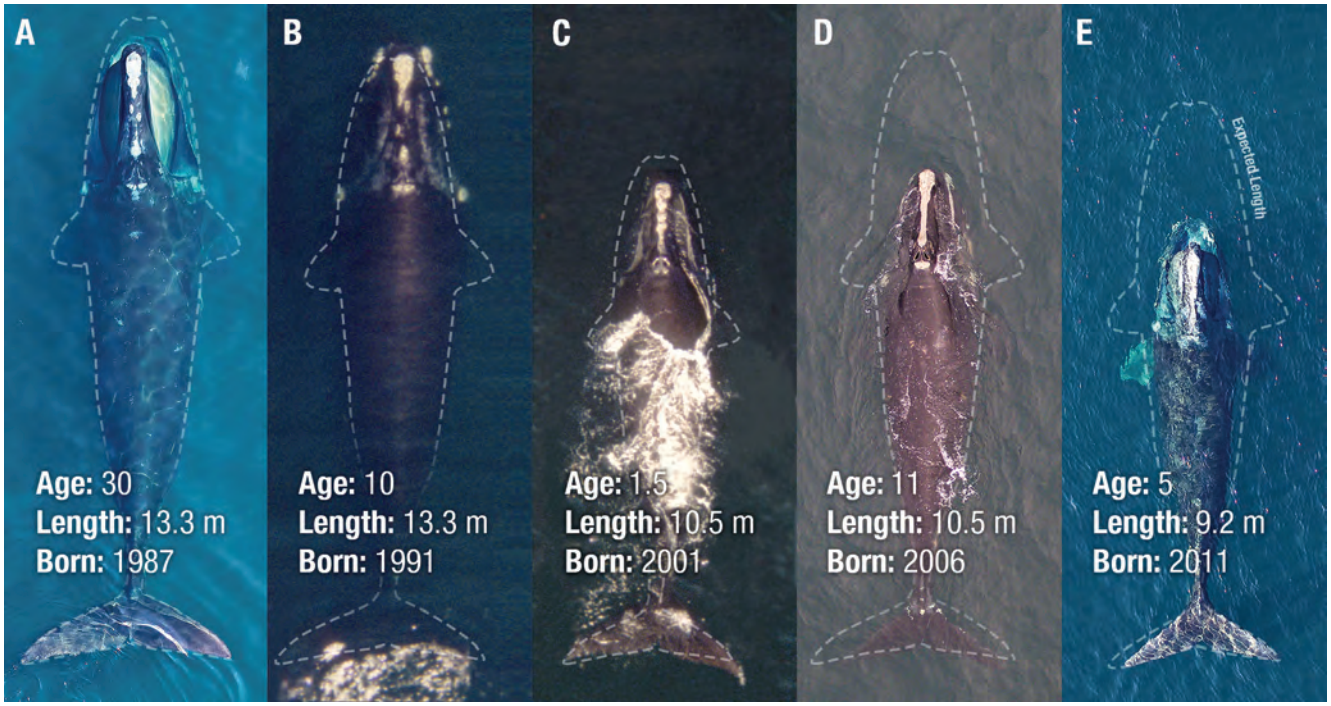
EPP/MSI Alum Ammar Hanif. Photo courtesy of Ammar Hanif

AMMAR HANIF PHD

Dr. Ammar Hanif earned his Ph.D. in Marine Estuarine Environmental Science at the University of Maryland Center of Environmental Science - Institute of Marine & Environmental Technology. As an EPP/MSI Living Marine Resources Science Center fellow, Dr. Hanif completed research focused on using molecular techniques and bioinformatics as tools to study the marine environment and answer ecological questions. During his Ph.D. studies, Dr. Hanif completed a 12-week graduate internship with the NOAA/NMFS Northeast Fisheries Science Center where he studied the diet of Atlantic menhaden using DNA barcoding. Dr. Hanif joined NOAA's National Centers for Coastal Ocean Science, HABs Monitoring and Reference Branch as a federal employee in 2021.

2.A.2 POPULATION MODELING

CRITICALLY ENDANGERED NORTH ATLANTIC RIGHT WHALES GETTING SMALLER

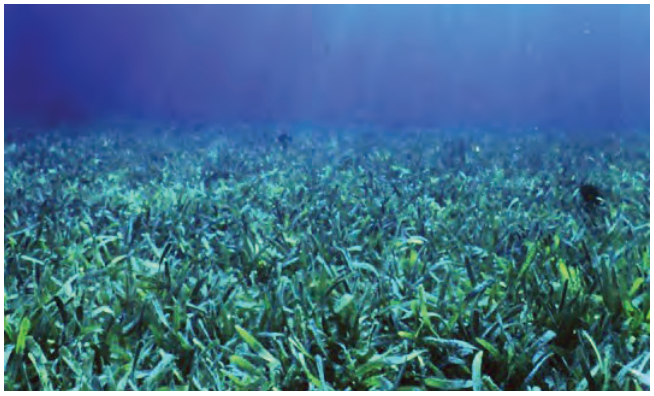


A photo illustration compares the body lengths of North Atlantic right whales, including two stunted whales born in 2006 and 2011. The dotted lines show the expected length of right whales of the same age if they had been born in 1981 with no history of entanglements, or entanglements of their mothers. The whales were photographed from crewed aircraft in earlier years and, later, by drone. Figure design by Madeline Wukusick. Photo credits: John Durban, Holly Fearnbach, Michael Moore, Carolyn Miller, Wayne Perryman, and Morgan Lynn (NOAA Fisheries Permits #17355 and #21371)

NOAA researchers found a North Atlantic right whale born today would be expected to reach a full-grown length of about three feet shorter than one born in 1981. This change in size has been linked to entanglements in fishing gear and other factors (for example, vessel noise and shifting availability of the tiny copepods that are the whales' primary prey) stunting the growth of this critically endangered species, which currently numbers less than 400 animals. These smaller whales are vulnerable to other threats, such as decreased resilience to climate change and perturbations on and near feeding and breeding areas, which adds further stress to the imperiled species.

FISH PRODUCTION CALCULATOR: A TOOL FOR MANAGING SALT MARSH AND SEAGRASS HABITATS

A great number of fish and invertebrates that are born and survive each year depend on the existence and health of coastal vegetated habitats like salt marsh and seagrass. That's why NOAA Fisheries and The Nature Conservancy developed an interactive management tool that provides estimates of how many juvenile fish, crabs, and shrimp are produced within specific nursery habitats in the northern Gulf of Mexico. The



Seagrass in Florida Keys National Marine Sanctuary. NOAA and The Nature Conservancy's Fish Production Calculator allows for estimates of fish production in seagrass and salt marsh habitats. Photo credit: Paige Gill

user-friendly tool draws on habitat valuation research, which uses models to estimate fish production in a particular type of habitat—allowing managers to better understand the value of a defined area of habitat for its role in growing fish. More specifically, managers can use the tool to answer questions about how species populations would be affected if a habitat was lost or restored. That information in turn helps NOAA and our partners focus conservation efforts to better achieve coastal habitat and fisheries management goals.

"We're very excited about this research and how it informs marine resource management decisions," said Janet Coit, Assistant Administrator for NOAA Fisheries. "This user-friendly tool helps NOAA and our partners gain a better understanding of where to focus conservation efforts to achieve coastal habitat and fisheries management goals."

INNOVATIVE SONAR TECHNOLOGIES HELP SCIENTISTS TRACK COMMERCIALLY VALUABLE FISH STOCKS IN ALASKA

With crewed research surveys limited by the global pandemic, NOAA Fisheries relied on next-generation technology in 2020 to help ensure that critical data were still collected. NOAA researchers worked with partners to use uncrewed surface vehicles known as saildrones to make acoustic-based abundance estimates for use in the stock assessment of Alaska walleye pollock, the nation's largest fishery. In a first-of-its-kind study, scientists also recovered data from four acoustic sensors mounted on the seafloor used to track seasonal movements of pollock across the U.S.-Russia international boundary in the eastern Bering Sea. The data will assess the degree to which the population migrates across the border, a major source of uncertainty in the management of this trans-boundary stock. This cost-effective technology also included sensors to monitor currents and ocean conditions,

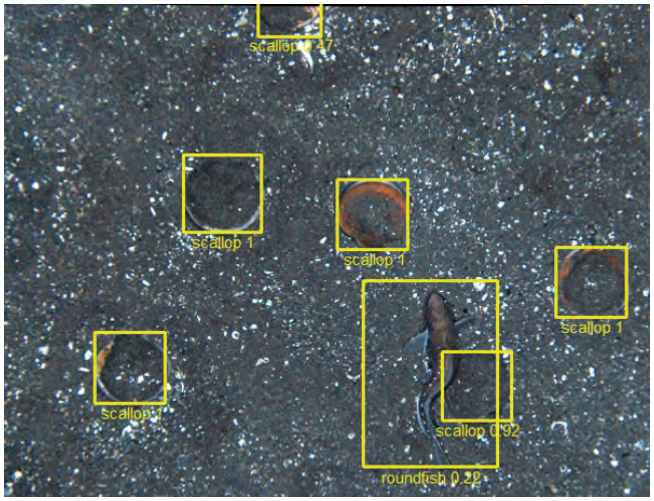
Deploying the echosounder to monitor pollock movements in the Bering Sea. Photo credit: Leah Zacher, NOAA Fisheries

which will be linked to fish migratory behavior. While not a replacement for crewed research surveys that also collect biological data, these technological solutions improve the resiliency of NOAA Fisheries' science efforts and support NOAA's strategy to expand the use of emerging science and technologies to advance our research mission.

2.A.3 STOCK ASSESSMENTS

COMPUTERS NOW "SEE" ANIMALS ON THE OCEAN BOTTOM

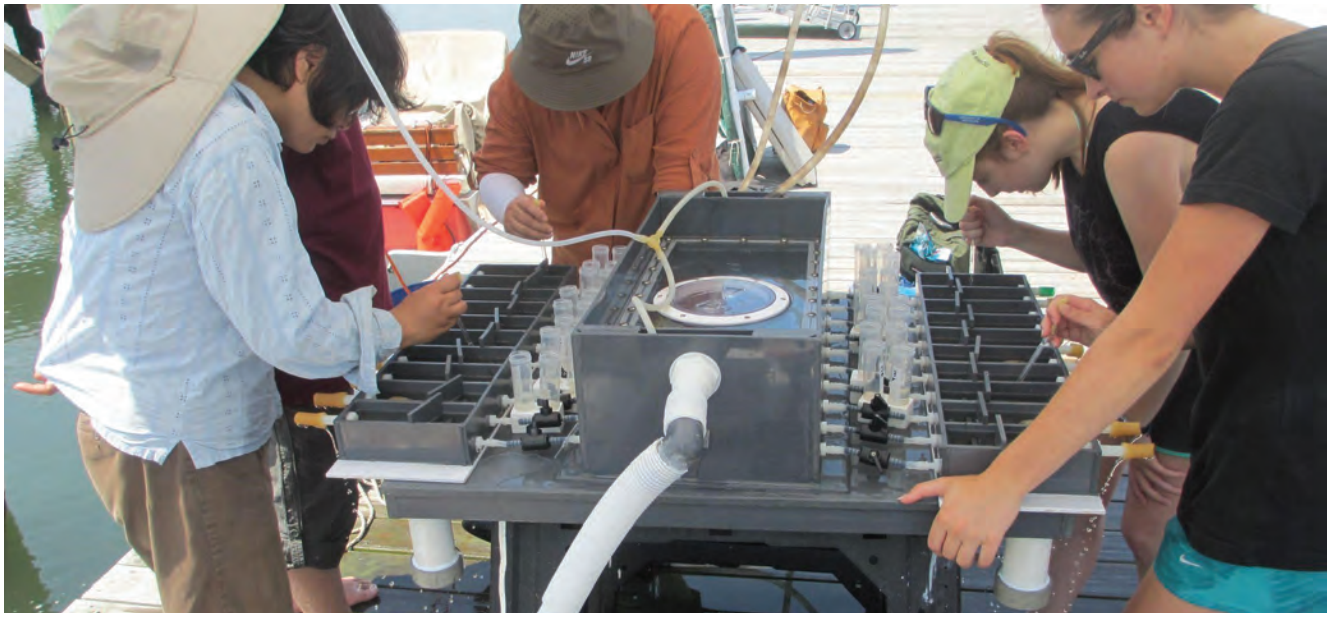
NOAA Fisheries researchers are using machine learning software to teach computers how to identify sea life in millions of images of the ocean floor. Using this technology, the 2021 northeast sea scallop survey was able to identify sea scallops and various categories of fish, crabs, and whelks, in near real-time from images collected by a towed sampling device called the HabCam. The automated image detection uses VIAME, the world's first advanced automated image analysis software for the marine environment, developed through a NOAA Fisheries strategic initiative. The researchers have now turned their sights to integrating these data from VIAME into sea scallop stock assessments, which support one of the nation's most valuable sustainable fisheries. They are also working to make automated image detection a regular part of survey operations because survey operations traditionally have relied on scientists and volunteers to identify target species in a small percentage of the images gathered during the survey. Machines can help identify sea life in the images faster and more efficiently, which improves population data for sea scallops.



Example of an HabCam image annotated by VIAME sea scallop and fish detectors. Image credit: NOAA Fisheries

2.A.4 HUMAN BEHAVIOR

HOW MUCH IS A CLAM WORTH TO A COASTAL COMMUNITY?



Field experiments to measure feeding and nutrient uptake by shellfish in the Greenwich watershed in 2015. Photo credit: NOAA Fisheries

Scientists have long known that shellfish improve water quality by filtering excess nitrogen and other nutrients from the water, but less is known about the economic value they bring to coastal communities. Now a new study estimates that oyster and clam aquaculture provides $2.8–5.8 million in excess nitrogen removal services to the coastal waters of Greenwich, Connecticut. Researchers used a transferable replacement cost method, which puts a dollar value on ecosystem services by estimating what it would cost for people to provide the same services. In the case of Greenwich, the community would have had to fund wastewater treatment improvements, septic systems upgrades, and better stormwater management, for example, to achieve the same water quality benefits provided by nearby shellfish aquaculture. The interdisciplinary study was conducted by shellfish biologists, economists, and modelers from NOAA and Stony Brook University. This cost estimation method can be applied to other coastal communities.

"Shellfish provide water quality benefits that coastal residents and visitors may not fully appreciate on a day-to-day basis. Our findings show that shellfish populations grown for harvest may complement land-based nutrient management approaches as part of the portfolio of solutions for excess nitrogen in our coastal waters." – Anthony Dvarskas, co-lead of the study and an assistant professor at Stony Brook University.

2.B COASTAL RESILIENCE

NOAA-LED CEOS COAST RECOGNIZED AS "CONTRIBUTIONS TO THE OCEAN DECADE" FOR ITS COASTAL APPLICATIONS

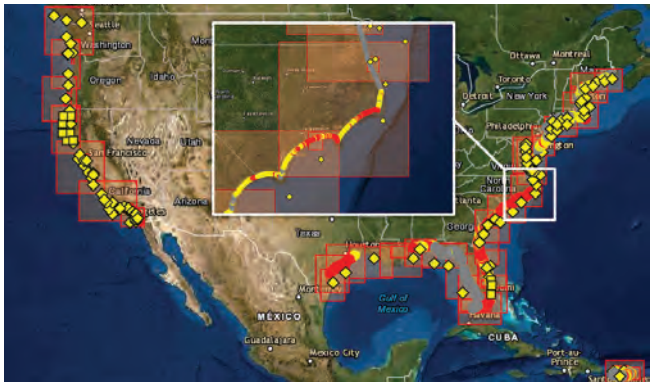
Coastal hazards like flooding and inundation, and water quality and associated impacts to ecosystem health and productivity, represent great challenges for society. To address these, the Committee on Earth Observation Satellites (CEOS) formed the COAST (Coastal Observations, Applications, Services and Tools) team in 2019. COAST, co-chaired by NOAA, uses data and resources from all contributing international space agencies to develop products useful from geographical regions to the entire globe. In 2021, CEOS COAST plans to develop products in the areas of bathymetry, coastal mapping, coastal eutrophication, turbidity/sedimentation, flooding and inundation, and oceanography for two-to-three target regions: the Chesapeake Bay, the Bay of Bengal, and the west coast of Africa. CEOS COAST also plans to develop products for the Caribbean, Pacific small island nations, and the La Plata Estuary. In October 2021, CEOS COAST and the Group on Earth Observation co-hosted a virtual global showcase to demonstrate capabilities to potential users, who can then co-design or co-develop new or improved data-driven satellite products to better inform regional decision-makers. The Intergovernmental Oceanographic Commission recognized CEOS COAST as a Contribution to the United Nations Decade of Ocean Science for Sustainable Development.

"It gives me a great pleasure to inform you of the endorsement of your Decade Action entitled 'No.121 - Committee on Earth Observation Satellites - Coastal Observations, Applications, Services, and Tools (CEOS COAST)', which you submitted in response to the Call for Decade Actions No. 01/2020 as a contribution to the UN Decade of Ocean Science for Sustainable Development. I thank you very much for your engagement and commitment to the Ocean Decade. The endorsement of your programme is a milestone in your involvement in the Ocean Decade. … On behalf of the entire Ocean Decade Team, please accept my heartfelt congratulations on the endorsement of your Decade Action. Together, let us work towards the ocean we want!" — Vladimir Ryabinin, Executive Secretary, IOC

FIRST EVER NATIONAL RIP CURRENT MODEL LAUNCHES

In February of 2021, NOAA launched the first ever national rip current forecast model. The model predicts the likelihood of hazardous rip currents every kilometer along the coast, every hour, up to six days out. Rip currents cause approximately 100 deaths in the U.S. each year. With improved accuracy, resolution, and lead-time, the new model has the potential to reduce the number of drownings and save lives. The model is operated by

A photo of a rip current highlighted by harmless green dye. Photo credit: NOAA



The Nearshore Wave Prediction System coverage for the continental U.S., with an inset box showing hazardous rip current likelihood for the North Carolina coast. Alongshore color denotes rip current likelihood from low (gray) to high (red). Image credit: NOAA

NOAA NWS as a component of the Nearshore Wave Prediction System. NOAA NOS scientists developed the model and published their associated research in 2013. Following a multi-year assessment of its performance, NOAA staff deployed the model at numerous locations across the coastal U.S.

FIELD-BASED DEPLOYMENTS FOR ASSESSING IMPACTS OF CHEMICAL SPILLS

NOAA NOS designed, engineered, and validated a system of field-deployed mesocosms (outdoor experimental systems) for NOAA's use in assessing oil or other chemical spill impacts. The system will serve as a rapid-response tool for determining chemical effects on fish and invertebrates, and addresses a critical need to collect data immediately after a spill. The team researched and tested different enclosure designs to select a preferred model based on performance, durability, ease of use, and portability. The preferred design was tested using two common estuarine organisms (grass shrimp and mummichogs) in the laboratory and in field locations in the Southeastern and Gulf Coasts. A StoryMap was also created that describes the purpose, design, construction, and usage of the systems.

Checking mesocosm performance in Leadenwah Creek near Charleston, South Carolina. Photo credit: Blaine West, NOAA NOS/NCCOS

IMPROVED RESPIRATORY ILLNESS HAZARD FORECASTS FOR GULF OF MEXICO RED TIDE

Blooms of *Karenia brevis,* a type of algae that produces potent neurotoxins, often gets into particles in the air. When the toxin is inhaled, it causes respiratory irritation in healthy people, and may severely impact people with asthma and other respiratory conditions. Many people tend to avoid beaches during these blooms (commonly known as "red tides,") resulting in negative economic impacts on local businesses. As these blooms are patchy and winds that carry toxins onshore are variable, communities need access to high resolution information that describes where and when respiratory irritation may occur. NOAA NOS has substantially improved the spatial and temporal resolution of its predictions, as well

as how often these forecasts are produced. With its partner, the Gulf of Mexico Coastal Ocean Observing System (GCOOS), NOAA is producing and posting forecasts of respiratory irritation every three hours, currently at 6-12 beaches in each county along the Gulf of Mexico and east coast of Florida.

AN EARLY WARNING SYSTEM FOR PSEUDO-NITZSCHIA HABS ON PACIFIC NORTHWEST OCEAN BEACHES

Timely harmful algal bloom (HAB) bulletins for the Pacific Northwest — the result of a NOAA NOS-funded pilot and promising results from state shellfish toxin testing in Washington state — helped the Quinault Indian Nation and Washington Department of Fish and Wildlife (WDFW) decide to allow limited razor clam digs in spring of 2021. This decision resulted in the first instance of public access to this prized shellfish resource since the fall of 2020, when all clamming beaches in Washington and Oregon were closed due to a HAB event. Over the span of 27 digging days, the Quinault Department of Fisheries estimated tribal members harvested more than 266,000 lbs. of razor clams with more than $590,000 paid to commercial diggers while a separate subsistence harvest filled many tribal freezers and pantries with the shellfish prized for home consumption. WDFW estimated 27,850 participants enjoyed recreational razor clam digging at one beach in six days. Each Pacific Northwest HAB Bulletin combines expert analysis of data on real-time ocean conditions, algae and algal toxin abundance both in offshore hotspots and near clamming beaches, and forecast model output to provide advance warnings of toxic *Pseudo-nitzschia* HAB events that support targeted shellfish management decisions.

Digging for razor clams at low tide. Photo credit: David J. Ruck, NOAA

2021 EPP/MSI Graduate Fellow Shanelle Haughton. Photo courtesy of Shanelle Haughton

SHANELLE HAUGHTON

Shanelle Haughton is a Ph.D. student at the University of Maryland Eastern Shore graduate program in Marine Estuarine Environmental Science, a participant in the NOAA Living Marine Resources Cooperative Science Center, and a member of the 2021 EPP/MSI Graduate Fellows inaugural class. Her current research is evaluating the physiological and immune responses of Tanner crabs to *Hematodinium* infection using tools like immunological assays, gene expression analysis, and bioinformatics. She completed a graduate internship in 2019 entitled "Understanding *Hematodinium sp.* in Alaskan crabs: new hosts, improved detection and health effects in a changing ocean" with the NOAA/NMFS Alaska Fisheries Science Center (AFSC). In 2022, Shanelle will begin a required 1 year fellowship with the NMFS AFSC in Seattle, Washington.

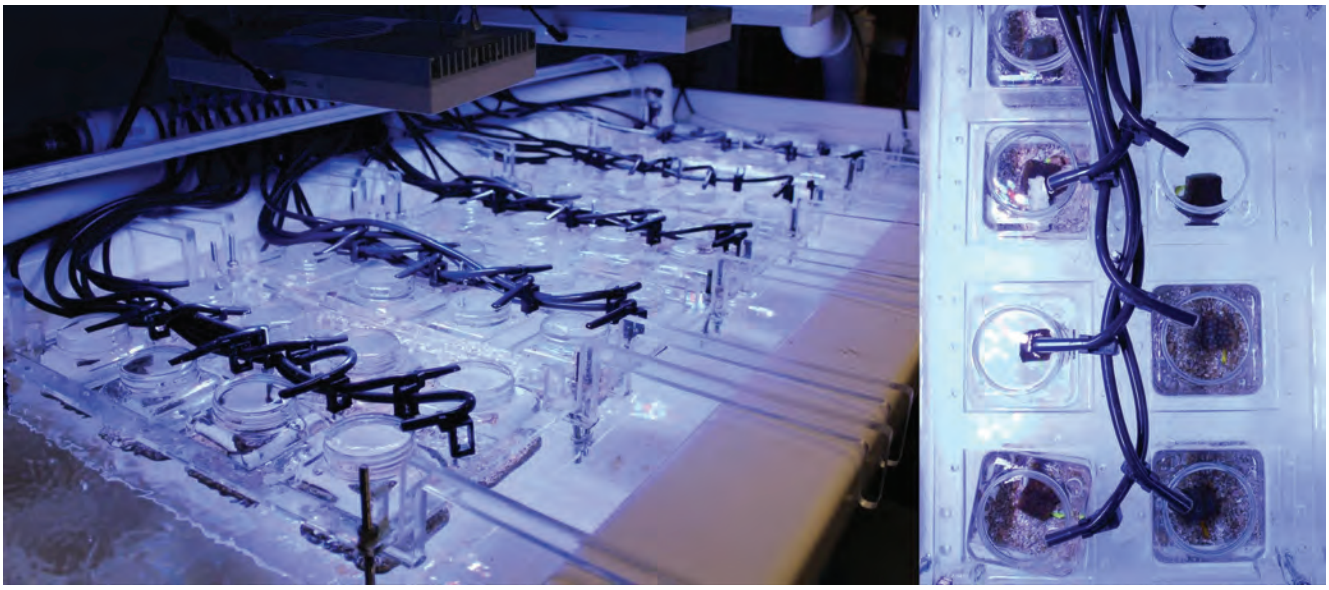
RESTORE COUNCIL MONITORING AND ASSESSMENT PROGRAM: A COMPREHENSIVE MONITORING NETWORK

The Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act (RESTORE Act) was signed into law on July 6, 2012 as a result of the Deepwater Horizon Oil Spill. The RESTORE Act established the Gulf Coast Ecosystem Restoration Council, which developed strategies and projects within a comprehensive plan to restore the Gulf ecosystem and economy. The RESTORE Council Monitoring and Assessment Program, administered by NOAA and the U.S. Geological Survey, developed foundational components for a Gulf of Mexico–wide monitoring network to support the Council in making science-based decisions and evaluating restoration effectiveness. The team assembled programmatic metadata for 544 Gulf of Mexico water quality and habitat monitoring and mapping programs into a database that was the foundation for a web-accessible data discovery and visualization tool. This centralized information provides the best available monitoring information for RESTORE Council restoration activities and supports broader Gulf of Mexico restoration, monitoring, and research communities.

IMPROVED GEOSPATIAL TOOLS FOR THE ALASKA SHELLFISH MARICULTURE INDUSTRY AND COASTAL COMMUNITIES

Alaska communities face ongoing and increasing climate change-driven threats for public health and shellfish mariculture operations from *Vibrio* (bacteria causing food-borne illness) and paralytic shellfish poisoning caused by harmful algal blooms (HABs) of *Alexandrium* phytoplankton species. To help communities and state public health and resource managers assess risks for shellfish consumption and more efficiently target *Vibrio* and HAB toxin monitoring efforts, NOAA NOS developed pilot Alaska *Vibrio* and HAB risk assessment products from high resolution satellite sea surface temperature imagery. The web-based, geospatial tools build on previous NOAA Alaska research and monitoring efforts to identify *Vibrio* species and quantify relationships between water temperature and *Alexandrium* blooms. The pilot risk assessment products are being provided to and tested by state and federal agencies, Alaska Native tribal, shellfish farmer, community harvester, and academic stakeholders, including through the multi-agency Alaska HAB Network. NOAA NOS will refine the product in response to user feedback.

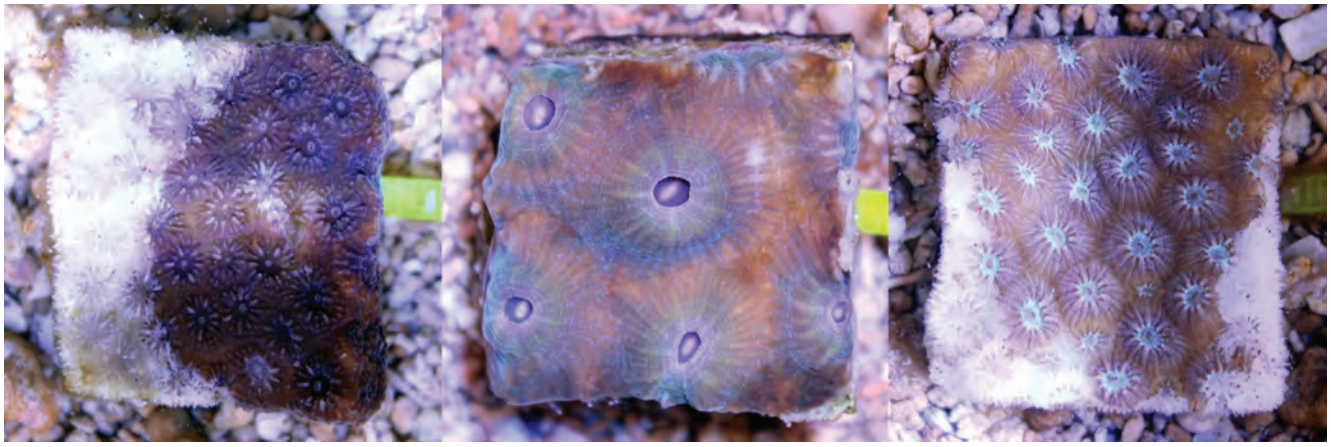
RESEARCH AND PREPARATION FOR STONY CORAL TISSUE LOSS DISEASE



Experimental apparatus used to identify reef sediments as an SCTLD vector, with coral fragments in individual cups. Photo credit: Michael Studivan/University of Miami-Cooperative Institute for Marine and Atmospheric Studies, NOAA Research/AOML

Stony coral tissue loss disease (SCTLD), a new outbreak which causes rapid death in roughly half of all Caribbean coral species, including endangered and rare species, has spread throughout the Florida Reef tract and to 20 Caribbean countries and territories. Since 2014, this coral disease has expanded throughout the western Atlantic, including to the U.S. Virgin Islands and Puerto Rico, and recently emerged in the Dry Tortugas as of May 2021. However, it has yet to be detected in the remote reefs of the Flower Garden Banks National Marine Sanctuary (FGBNMS; Gulf of Mexico) or in the Indo-Pacific region. Given the proliferation of this disease, NOAA is performing work to find solutions and minimize damage to coral reefs.

- NOAA has partnered with regional organizations to develop a cooperative network among 20 Caribbean countries and territories that works to build disease response capacity and to share information on the status of the disease and lessons learned on efforts to address it. In Florida, the U.S. Virgin Islands, and Puerto Rico, partners from federal, state, and local agencies, nongovernmental organizations, universities, and members of the community are collaborating in response. Scientific activities have included compiling a case definition, more than 100 environmental and epidemiological studies, development of gear disinfection protocols to prevent further spread, the development and application of specially designed treatments to save diseased corals, rescue efforts to preserve genetic diversity, and coral propagation and outplanting trials to guide future restoration efforts. Building on knowledge gained within the Florida Keys, FGBNMS established a comprehensive SCTLD prevention and response plan. The plan includes prevention, education, preparedness, early warning, response, and intervention strategies, which could prevent disease spread within the sanctuary and allow for a rapid and effective response should the need arise. NOAA has released a strategy for the response to SCTLD. The high-level strategy provides a framework and focus for ongoing efforts to slow the spread of the disease across the Atlantic and Caribbean regions and to prevent and prepare for the possible spread of the disease into the FGBNMS and the Indo-Pacific region in support of resilient coastal ecosystems, communities, and economies nationwide. The strategy will inform a national



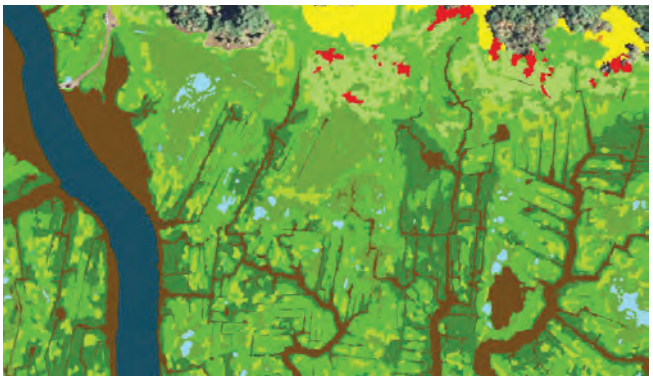
Corals that were infected with SCTLD using inoculated sediments. Photo credit: Michael Studivan/University of Miami-Cooperative Institute for Marine and Atmospheric Studies, NOAA Research/AOML

implementation plan to understand, respond to, and mitigate the disease.

- Scientists at NOAA Research have tested different disease treatment options and conducted experiments to identify the pathogen responsible for SCTLD. Experiments this year identified reef sediments as a potential way SCTLD can spread among corals. Researchers demonstrated that disease-inoculated sediments were able to transmit SCTLD to healthy corals, in some cases as quickly as 24 hours. These findings suggest that transport of reef sediments (for example, through port dredging and ship's ballast water transfer) may negatively impact coral reefs in Florida and beyond. Efforts are ongoing by NOAA researchers to attempt to identify the SCTLD pathogen from samples collected during this and other lab experiments using molecular techniques.

ADVANCING COASTAL MAPPING AND MANAGEMENT THROUGH ARTIFICIAL INTELLIGENCE

NOAA NOS is developing the next generation of land cover data for the coastal U.S. Scientists are using artificial intelligence and machine learning algorithms in a cloud-based environment to create highly detailed land cover and habitat datasets. The new datasets are developed from imagery that is 900 times more detailed than past data in order to better support local and site-specific management. These serve not only as proof-of-concept demonstrations, but are also informing coastal management decisions at regional and local levels. The state of New Hampshire, for instance, is using salt marsh habitat data generated by NOAA land cover data (available from the NOAA Digital Coast website) to better inform marsh resilience assessments, as well as aid in the state's comprehensive marsh management planning.



Saltmarsh habitat data (2013) for New Hampshire. High-resolution data from NOAA's Coastal Change Analysis Program (C-CAP) makes it possible to assess marsh resilience at the parcel scale. Image credit: NOAA

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

Earth observations, models, technology, 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 2021, NOAA's scientific accomplishments for building a robust and effective research and development enterprise projects for the following categories: data observation and assimilation, technology, and valuation.

3.A DATA OBSERVATIONS/ASSIMILATION

MACHINE LEARNING APPLICATIONS FOR AUTONOMOUS SURFACE VESSELS IN OCEAN MAPPING

In fiscal year 2021, the NOAA - University of New Hampshire' Joint Hydrographic Center (JHC) and Center for Coastal and Ocean Mapping (CCOM) achieved significant improvements in the use of data fusion and telemetry for the operation of uncrewed vessels for hydrographic survey and ocean mapping. They also used simulation to explore the application of machine learning algorithms to these tasks. The JHC/CCOM team developed a software framework that integrates a number of sensors on the uncrewed vessel, including cameras with machine learning algorithms; swath mapping echo-sounders that provide three-dimensional information about the water depth; marine radar that can locate targets around the vessel; a laser-based system that produces high-resolution images of items near the vessel, and other sensors that monitor engine functions and vehicle health. The software also integrates information from the Automatic Identification Service (AIS) based on identifiers carried on, and broadcast by, most vessels. The software condenses this information, which is passed through limited bandwidth telemetry links to provide a "picture" of what is around the vessel. This picture allows the remote operator to guide the uncrewed vessel, ensuring its safe operation. Future applications of this work would reduce reliance on human operators, allowing the uncrewed vessel to make unsupervised decisions for safe operation.

The University of New Hampshire's Bathymetric Explorer and Navigator (BEN) uncrewed surface vehicle launched from NOAA Ship *Fairweather*. Photo credit: Christina Belton, NOAA

INVESTIGATING CHANGES IN THE ARCTIC OCEAN AND SUBPOLAR SEAS

NOAA NESDIS partnered with scientists at the Cooperative Institute for Satellite Earth System Studies (CISESS) to better understand ocean circulation and waves in the Arctic ocean and investigate changes in sea ice thickness. To do this, they are using ocean heights measured from satellite radar altimeters. This effort hopes to make navigating maritime waters safer and support the blue economy. Researchers who study the polar

climate system may find this work particularly valuable. The team found an increasing trend in winter storminess in the Bering Sea during the last two decades. These winter storms produce extremely high wave conditions that are a hazard to navigation and pose disruptions to the fishing industry.

NOAA IS CREATING SYNTHETIC APERTURE RADAR APPLICATIONS TO IMPROVE ICE MODELING

NOAA NESDIS, responding to requests from U.S. National Ice Center, NOAA NWS, and other sea ice community scientists, is creating high-resolution sea ice drift data products from satellite-based synthetic aperture radar (SAR) instruments. SAR is an active radar satellite instrument that transmits microwave pulses that bounce off the Earth's surface. The radar signals are then processed into imagery that can be used to derive features such as wind speeds, oil spills, sea ice and ship detection. For this project, researchers use pairs of SAR images from the Sentinel-1 and RADARSAT-2 satellites and the RADARSAT Constellation Mission to identify the movement of ice features. Ice motion data, received in specific formats, are necessary for NOAA to improve ice modeling and forecasting. Better ice models and forecasts help the commercial fishing and maritime transport industry make decisions, which impacts the blue economy. In 2021, this product began supplying images of the Arctic region four times per day.

NOAA UPGRADES ITS DROUGHT PRODUCT SYSTEM, LEADING TO IMPROVED EVAPOTRANSPIRATION DATA

Evapotranspiration data are needed to validate predictions from weather, climate, and hydrological models while evaporative stress index products are useful for drought monitoring. The NOAA NESDIS GOES Evapotranspiration and Drought product system (GET-D) generates an evapotranspiration data product, a measure of how much water from land surface and plants transfers to the atmosphere, every day and an evaporative stress index every one or more weeks. In 2021, the GET-D was upgraded with new data streams (Advance Baseline Imagers data and microwave observations of land surface temperature) from GOES-16/17 for all-weather conditions. This update improves the spatial resolution of the products from eight km (approximately five miles) to two km (approximately one and one-fourth mile) spatial resolution, which gives users more detailed information on drought locations. The GET-D software is being tested on NOAA servers for potential operational transfer.

Trends in very high and phenomenal sea state in the Bering Sea in winter. Two independent measurements show an increase in storminess in the Bering Sea over the last 16 years. Graphic credit: Sinead Louise Farrell, Kyle Duncan and John M. Kuhn, "Altimetry of the Arctic Ocean and Subpolar Seas Ocean Surface Topography Science Team Report: 2016-2020"

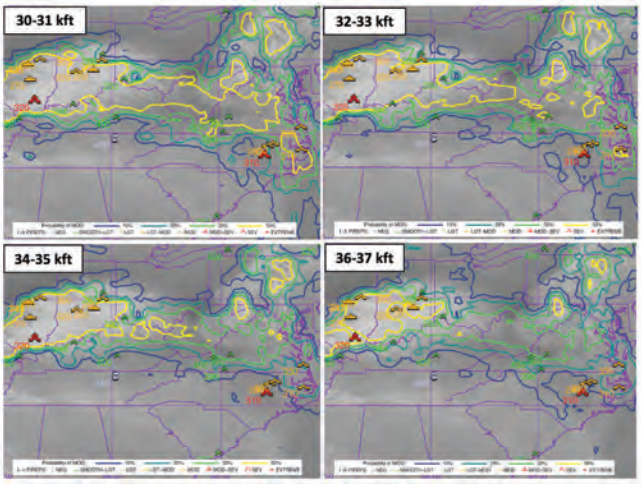
DETERMINING THE ROTATION OF THE MARIANA TECTONIC PLATE

GPS equipment, with charter boat in background, at the island of Asuncion. Photo credit: Jim Harrington, NOAA NOS/NGS

In a few years, NOAA NOS will modernize the National Spatial Reference System, which is the coordinate system (latitude, longitude, elevation, etc.) used by every federal agency as well as a large majority of state and local agencies so that geospatial information aligns consistently. The update will include the definition of a plate-fixed reference frame (a method of keeping latitude and longitude constant in the presence of tectonic plate rotation) for Guam and the Commonwealth of the Northern Mariana Islands, called the Mariana Terrestrial Reference Frame of 2022 or MATRF2022. To define such a frame, the rotation of the Mariana tectonic plate must be determined relative to an established, plate-independent frame. Very few studies of the Mariana plate have ever been performed, and most are only relative to other plates. To address this situation, NOAA NOS performed a complicated GPS survey of geodetic control points on numerous islands on the plate. Comparing this survey with a previous GPS survey allowed NOAA NOS to define the rotation of the plate. This estimate of the plate's rotation was the most accurate and data-rich estimate ever performed for this small tectonic plate and will serve as the underlying model for MATRF2022. The results were published in a NOAA technical report in August 2020.

NOAA ENHANCES NOWCASTING OF AVIATION TURBULENCE

NOAA scientists improved a product that estimates the probability of turbulence at aircraft cruising altitude. To do this, they created a new algorithm that integrates GOES-16 satellite imagery from the Advanced Baseline Imager with numerical forecast models. The product can now estimate turbulence at multiple flight levels and is 50 percent more accurate than the previous year's product. It also offers a new depiction of turbulence around convective storms and clear-air events. This product is now distributed to NOAA NWS aviation forecast offices where it is used as a decision aid to warn pilots of areas of otherwise unexpected turbulence, and in severe cases, reroute aircraft from those areas of danger.



Four layers of the turbulence probability product are shown with pilot reports of turbulence ("peak" symbols, with altitude to their lower-left). This is from an outbreak of turbulence across the eastern U.S. on March 11, 2021, at 6 p.m. ET. The NWS forecaster who prepared this demonstration graphic, Sean Campbell in Leesburg, Virginia noted, "The best detectability where the severe turbulence was reported in eastern North Carolina was in the 30-31,000-foot layer, the exact level of the product." Image credit: NOAA NWS

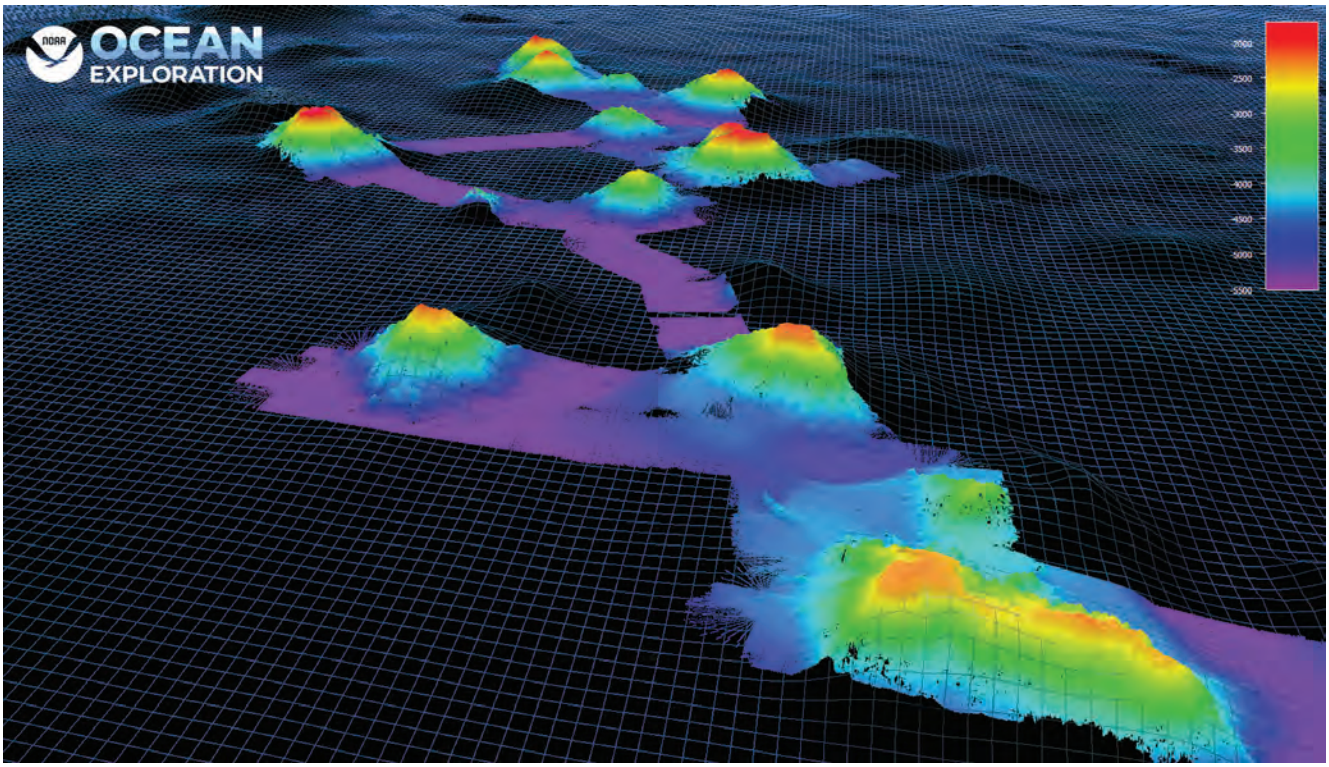
EPP/MSI Alum Ishrat Jabin. Photo courtesy of Ishrat Jabin.

ISHRAT JABIN

Ishrat Jabin is a Management and Program Analyst with the OAR Office of Science Support. She is a graduate of the NOAA Center for Earth System Sciences and Remote Sensing Technology where she received a MS degree in May 2021. Ishrat became eligible for federal jobs through NOAA's Conservation Corps Act of 2019 Direct Hire Authority, after successfully completing her 12-weeks long graduate internship at (OSS) under the mentorship of Drs. Laura Newcomb and Meka Laster. Ishrat believes that her internship helped her gain this job opportunity. "This opportunity provided my NOAA mentors the chance to learn first-hand about my strengths, work ethics and technical competence." Ishrat said, "NOAA played a pivotal role in shaping my career. Without the EPP/MSI funding and the CESSRST support system, I wouldn't have been able to pursue a master's degree. This opportunity helped me hone my skills in data science and GIS that I was to apply in NOAA mission enterprise research and professional development training."

3.B TECHNOLOGY

NEW STATE-OF-THE-ART MULTIBEAM ECHOSOUNDER INCREASES NOAA OCEAN EXPLORATION'S SEAFLOOR MAPPING CAPABILITIES ABOARD THE NOAA SHIP OKEANOS EXPLORER



New bathymetry data of the New England Seamounts collected with the EM 304 MK II model during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamount Chain (EX-21-04) expedition, overlaid on the Global Multi-Resolution Topography Data Synthesis grid. Image credit: NOAA Ocean Exploration

In collaboration with partners in industry and academia, NOAA has completed the phased upgrade of the Kongsberg EM 302 deepwater multibeam sonar. Deepwater multibeam sonars use hundreds of beams of sound to detect seafloor depth up to 10,000 meters below the vessel. This upgrade marks the first complete system of its kind, allowing NOAA to remain at the forefront of technological developments and pave the way for the broader ocean mapping community. With an increased national focus on seafloor mapping, exploration, and characterization, this system and the testing completed by NOAA Research will lead to increased efficiencies in mapping coverage and data resolution. Specifically, this system enhances the ability to address poorly understood areas within U.S. waters and beyond, and builds towards the goals of the National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone, also known as NOMEC, and the international effort Seabed 2030, which focuses on mapping the world's oceans by the year 2030. With this new system, NOAA Research anticipates it will surpass two million square kilometers of seafloor mapped with NOAA Ship *Okeanos Explorer* by the end of the 2022 field season.

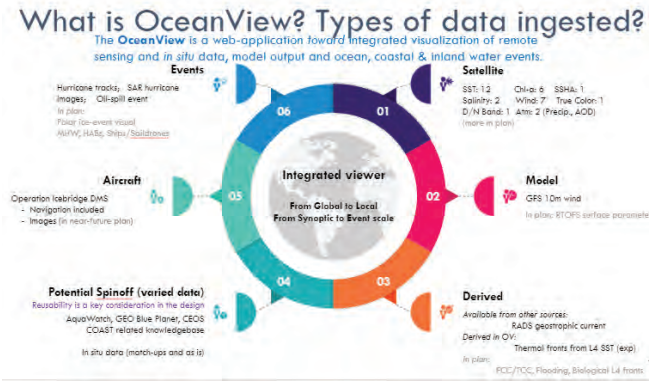
ADVANCING THE USE OF ARTIFICIAL INTELLIGENCE TO PROCESS MARINE MAMMAL CALLS

NOAA's marine mammal acoustics experts and their partners have developed a new program to automatically identify marine mammal calls using artificial intelligence. Known as INSTINCT (Infrastructure for Noise and Soundscape Tolerant Investigation of Nonspecific Call Types), the program can be applied to large archives of calls recorded in different noise conditions. For example, NOAA deployed the program to investigate a recently discovered and rare call type that may be used by critically endangered North Pacific right whales. Researchers positively detected more than 9,000 examples of the call type while searching more than 80 mooring years of data. The automated analysis was completed in a fraction of the time that manual analysis requires, reducing the researchers' workload by 96 percent and increasing the efficiency and timeliness of NOAA products and services.

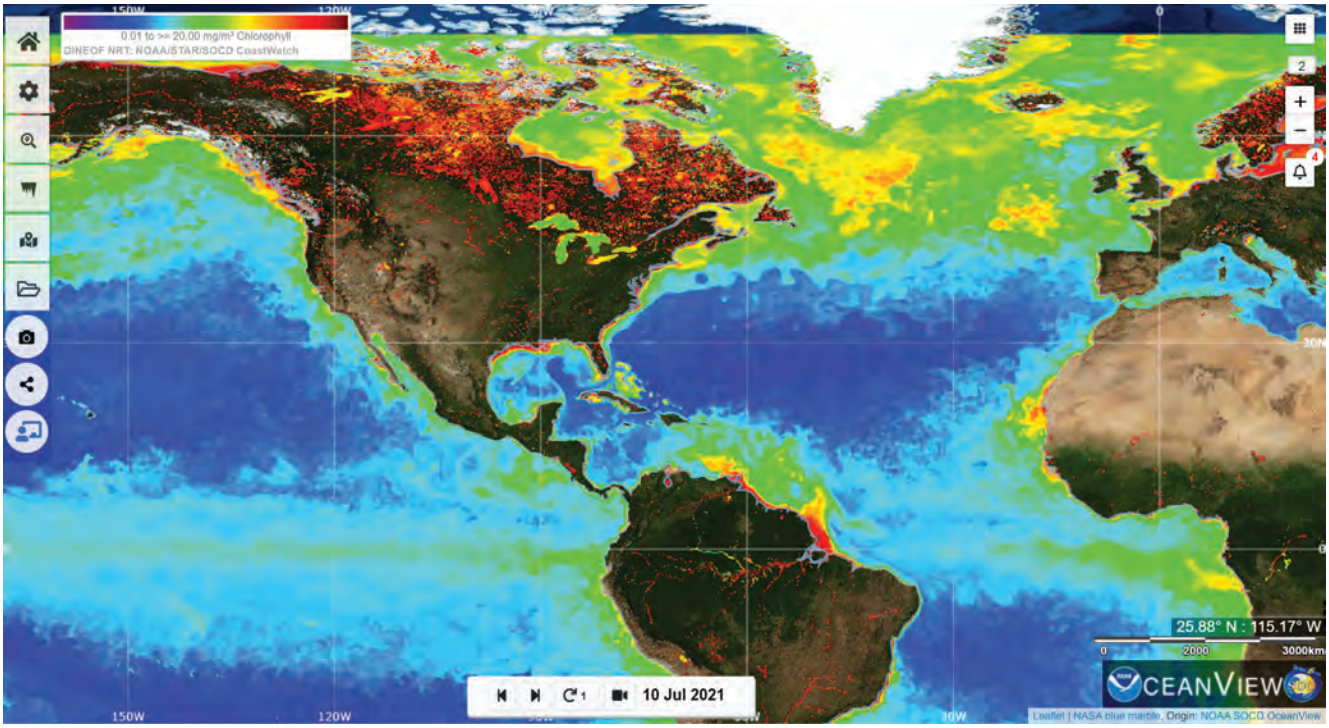
The endangered North Pacific right whale is one of the rarest of all marine mammal species. Photo credit: Brenda Rone, NOAA Fisheries

OCEANVIEW TOOL RELEASED - NEW TECHNOLOGY TO SUPPORT INTEGRATED VISUALIZATION OF WATER EVENTS

OceanView helps users quickly access diverse time and space data types to easily and holistically assess change in water bodies from both a general view and an event-scale perspective. This tool is a web application that integrates remote sensing visualizations, on-site data, model output, and ocean, coastal, and inland water events. For example, a fisheries biologist could access available 2019-2021 OceanView data for the coastal U.S. Pacific Ocean and quickly surmise if marine heatwaves, upwelling events, HABs, or oil spills may have influenced west coast annual sardine landings in those years and whether deeper investigation would be worthwhile. By incorporating data and products from both NOAA and non-NOAA sources — spanning multiple satellites, airborne and field platforms, and environmental modeling output — OceanView 1.0 is useful to the satellite remote sensing community, fisheries and endangered species biologists, sanctuary, estuarine reserve, parks and marine protected area managers, coastal resilience and watershed/floodplain specialists, as well as broader users both within and beyond NOAA. OceanView will continue to add more data and information of interest to a



OceanView (OV) data currently and potentially available to users. SST=sea surface temperature, Chl-a=chlorophyll a, SSHA = sea surface height anomaly, D/N = day/night, SAR=Synthetic Aperture Radar, AOD = aerosol optical depth, MHW= mean high water, HABs=harmful algal blooms, DMS=Data Management System, RADS=Radar Altimeter Database System, L4=level 4, FCC=false color composite, TCC=true color composite, GFS = Global Forecast System, CEOS COAST= Committee on Earth Observation Satellites Coastal Observations, Applications, Services, and Tools. Image credit: NOAA OceanView



Satellite derived chlorophyll (ocean color) in the OceanView 1.0 portal. Green to red areas indicate areas of high ocean chlorophyll content at the surface, while darker blue areas indicate areas with lower surface primary productivity. Image credit: NOAA OceanView

broad spectrum of users. NOAA NESDIS publicly released OceanView 1.0 in May 2021, after incorporating user feedback from February 2021.

"Overall, I like it and think it provides a lot of useful functionality through a pretty intuitive interface. So many congratulations on developing a very nice and useful data Web-Visualization tool!" – Vardis M. Tsontos, NASA Jet Propulsion Laboratory

2021 EPP/MSI scholar Tehani Malterre. Photo courtesy of Tehani Malterre

TEHANI MALTERRE

A 2021 EPP/MSI Undergraduate Scholar, Tehani is a junior Global Environmental Science student at the University of Hawai'i at Mānoa. In 2020, Tehani completed a 6 week internship at the NOAA Inouye Regional Center through her participation in the Hollings Preparation Program. During this experience she created an interactive virtual reality tour of the Center which incorporated aspects of NOAA operations and Hawaiian cultural knowledge. Tehani was awarded the EPP/MSI Undergraduate Scholarship in 2021 and conducted a virtual summer internship with the NOAA Office of National Marine Sanctuaries entitled, "Sanctuary Community Profile: Olympic Coast National Marine Sanctuary (OCNMS)". During this internship she compiled socio-economic, cultural, and ecosystem services data in support of future policy and decision-making processes for OCNMS. For the summer of 2022, Tehani will be working with the South Slough National Estuarine Research Reserve (NERR) on a project that will be looking into habitat suitability for culturally important plants utilizing indigenous knowledge and GIS as part of a wider estuary restoration project. Upon completion of her education, Tehani is planning for a career in the fields of conservation, restoration, and ecology in Hawai'i.

VIRTUAL DISCOVERY OF NEW SPECIES OF COMB JELLY NEAR PUERTO RICO

A NOAA Fisheries research team described *Duobrachium sparksae,* a new species of ctenophore, or comb jelly. The discovery was made at a depth of nearly 4,000 meters during an underwater expedition led by NOAA Research. A remotely operated vehicle captured a high-definition video of the new species off the coast of Puerto Rico. No physical samples were collected, so the high-definition videos are now registered as part of the Smithsonian Institution National Museum of Natural History Collection.

NOAA VIRTUAL LABORATORY MOVED TO THE CLOUD

NOAA's Virtual Laboratory (VLab) in the AWS Cloud. Image credit: NOAA

The NOAA Virtual Lab (VLab) provides an environment where collaboration and innovation among geographically diverse NOAA scientists and developers can thrive. The VLab is a service and an IT framework which enables NOAA employees and their partners to share ideas, collaborate, engage in software development, and conduct applied research. The VLab enables NOAA to reduce the time and cost of transitions of innovations to enterprise operations, minimize redundancy and leverage complementary, yet physically separated, skill sets, forge scientific and technical solutions based on a broad, diverse consensus, and promote a NOAA culture based on collaboration and trust. On May 21, 2021 the VLab began operating in the Amazon Web Services (AWS) Cloud. VLab was moved from on-premise systems to the Cloud in a disciplined, secure, and sustainable manner to support development, testing, training, and operations. This move will reduce costs and support better scientific solutions, accelerated research-to-operations, streamlined development and demonstrations, and more effective and efficient operations.

VLab Director Ken Sperow said that, "The VLab's move to the cloud represents a critical step forward in meeting the diverse collaboration needs of the VLab users, both today and in the future. The stability, performance, and flexibility of the cloud will enable the VLab to be agile, leveraging DevOps practices. We look forward to exploring more innovative ways of streamlining R2O and collaborating within NOAA."

3.C VALUATION/COMMUNICATION

LEVERAGING RISK COMMUNICATION SCIENCE ACROSS U.S. FEDERAL AGENCIES

Many U.S. federal agencies apply principles from risk communication science across a wide variety of hazards. In so doing, they identify key research and practice gaps that, if addressed, could help better serve the nation's communities and greatly enhance practice, research, and policy development. NOAA scientists published a peer-reviewed paper that provides a set of best-practices from five government agencies for effective risk communication and building science capacity across the federal government. The authors determined the best-practices by collaborating in an interagency work group on social and behavioral science. The results of this work can help governments strengthen their risk communication, which will assist them in achieving their missions to protect lives and improve myriad outcomes population-wide.

CLOSING THE LOOP ON AN APPARENT VIOLATION OF THE MONTREAL PROTOCOL: EMISSIONS OF CFC-11 ARE BACK ON THE DECLINE

In the year immediately following the NOAA discovery of a substantial violation of the Montreal Protocol on Substances that Deplete the Ozone Layer, updated measurements show a dramatic reversal and a sharp decline in global emissions of the ozone-depleting gas CFC-11. The new data confirm that the international response to NOAA's initial finding of the apparent violation, by the United Nations Environment Programme, the World Meteorological Organization, and the Parties to the Montreal Protocol and its U.S. delegation that includes U.S. Environmental Protection Agency (EPA) and State Department employees, has resulted in rapid and substantial emission reductions. The analysis, published in back-to-back papers in Nature in February of 2021, also indicated that emission declines in eastern China were responsible for most (60 percent) of the global emission decline from 2018-2019. As a result of this fast action, the health effects expected to arise from enhanced ultraviolet radiation associated with these illicit CFC-11 emissions (for example, cancer incidence and mortality, and cataracts) are predicted to be substantially less than if those emissions had continued, according to the EPA.

ECONOMIC ASSESSMENT OF GEOXO IDENTIFIED BENEFICIAL SOCIETAL OUTCOMES

In 2021, NOAA Office of Performance, Risk & Social Science (PRSSO) initiated a study of the potential benefits to society of NOAA's next generation geostationary satellite program (GeoXO). As configured in current plans, the GeoXO instruments will provide data needed to improve a wide range of NOAA's weather, climate, water quality, and air quality products. NOAA analyzed and described the full scope of beneficial societal outcomes and initiated the development of value chains to explain how the data are used to improve NOAA products whose use generates societal benefits in specific case studies. The team has identified more than 150 value chains, each representing a discrete pathway through which GeoXO data will provide benefits that will be realized by protecting life, increasing safety, increasing economic productivity, and reducing economic losses. For example, NOAA PRSSO conducted an analysis to assess whether the benefits outweigh the costs for including a proposed infrared hyperspectral sounder (HSS) on GeoXO. In a geostationary orbit, the HSS provides low-latency profiles of atmospheric wind, water vapor, and temperature, which will enhance situational awareness for operational meteorologists and provide better data for numerical weather and water prediction models. Three case studies were conducted which showed that the benefits associated with this instrument are likely to substantially outweigh the costs. The GeoXO working group completed a report detailing these findings as part of the mission planning efforts and future studies for producing a comprehensive estimate of benefits are planned.

EPP/MSI Alum Jonathan Wynn Smith. Photo courtesy of NOAA

JONATHAN WYNN SMITH, PHD

Dr. Jonathan Wynn Smith was first introduced to the Educational Partnership Program with Minority Serving Institutions (EPP/MSI) as an undergraduate scholar in 2001. He went on to earn a MS degree in meteorology from Penn State University and a PhD in Atmospheric Sciences from the Howard University Program in Atmospheric Science (HUPAS). His dissertation examined ozone production over the Equatorial Atlantic Ocean as a result of lightning-induced nitrogen oxides from convection over West Africa. Jonathan was recently hired as a Research Physical Scientist at OAR Geophysical Fluid Dynamics Laboratory where he will continue working on atmospheric chemistry in Earth system models. As a researcher Jonathan has served as a radiosonde and ozonesonde operator on several field campaigns, including NOAA Aerosols and Ocean Science Expeditions (AEROSE). His research interests include lightning, atmospheric chemistry transport, and tropospheric ozone generation.

THE FIRST OFFICIAL MARINE ECONOMY SATELLITE

Image credit: NOAA

NOAA and the Bureau of Economic Analysis jointly released the U.S. first official Marine Economy Satellite Account (MESA), which measures how dependent our nation's economy is on the ocean, coasts, and major water bodies such as the Great Lakes resources. To create the account the team used methodology that is consistent with international practices. The account improves on a prototype from 2020 by generating inflation-adjusted values, using time-series input data, refining estimates for construction and utilities sectors, and expanding activities in the research and education and professional and technical services sectors. The results show that America's marine economy contributed about $397 billion to the nation's gross domestic product in 2019 and outpaced the nation's economy as a whole. Businesses included in the report also generated a total of $665.7 billion in sales and supported 2.4 million jobs in 2019. The MESA emphasizes the importance of the marine economy, which NOAA continues to support through science, service, and stewardship, and provides data to decision makers about how to plan for the future.

BIBLIOMETRICS

This chapter represents a rigorous assessment of NOAA's scholarly research output between 2016 and 2020. 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 bench-marking 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 2016 and 2020, with approximately 82 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. Geosciences
7. Fisheries
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

EScholarly 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 2016 and 2020 and indexed in the InCites dataset as of August 27, 2021. 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 2016 and 2020.

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 four most 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 2020 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 2016-2020

10,332 Total Publications

112 *h*-index

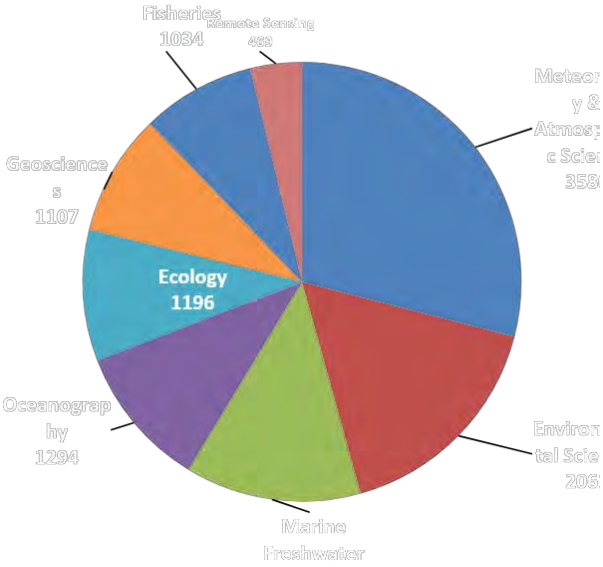
142,926 Sum of Times Cited

90.3% % of Articles Cited

18.02% of Articles in Top 10% by citation

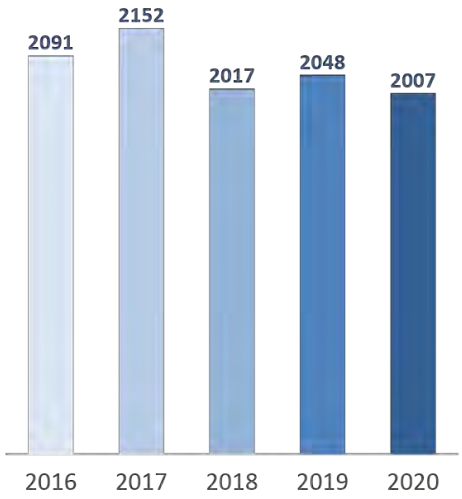
A "NOAA article" is defined as a peer-reviewed publication indexed in the Web of Science (WoS) Core Collection and identified by WoS indexers as having one or more authors who list their affiliation as National Oceanic and Atmospheric Administration. This report analyzes articles that fit this criteria and were published between 2016 and 2020 and indexed in the InCites dataset as of August 19, 2021. As an organization, NOAA has an *h*-index of 112 meaning that of the 10,332 articles published by NOAA authors in the period this report reflect, 112 have been cited at least 112 times.

Top Research Areas



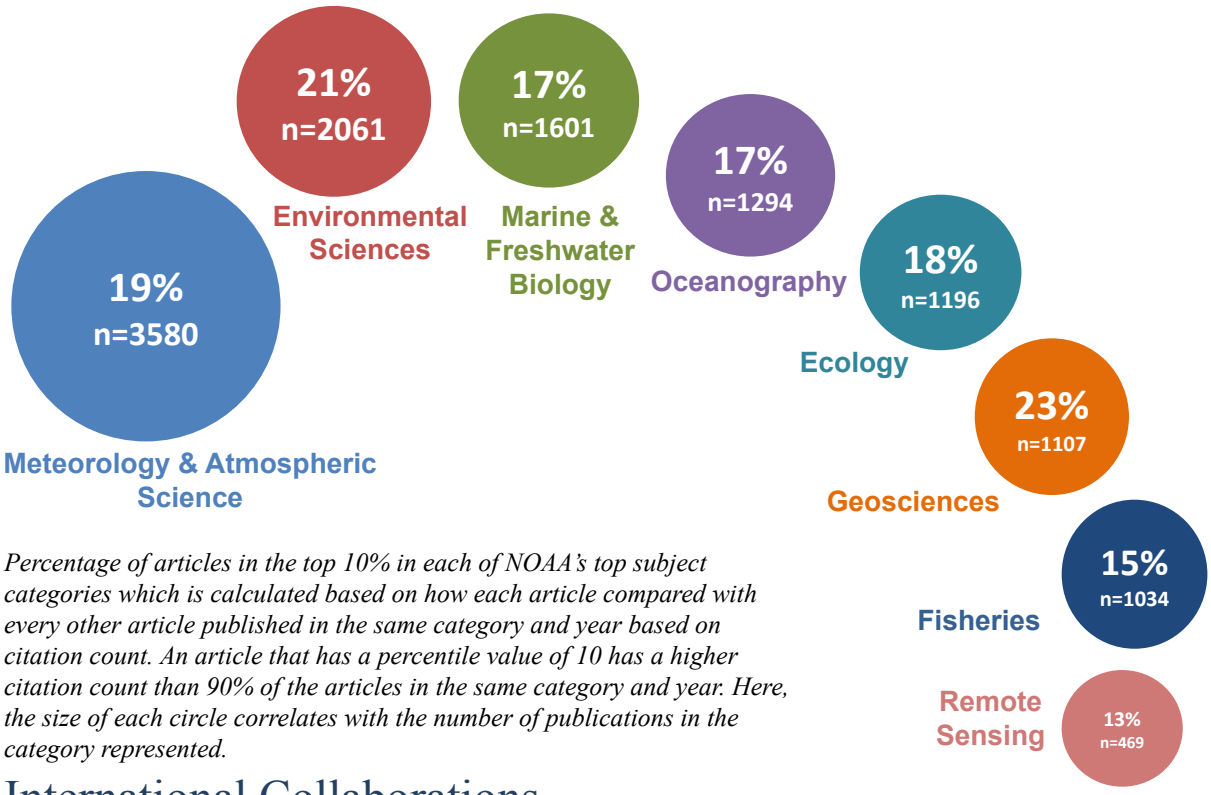
82% of NOAA articles fall within these eighth subject categories. Subject categories are defined, and assigned to articles, by Web of Science based on the journal in which each article was published. A single article may be assigned to multiple subject categories.

Articles per year



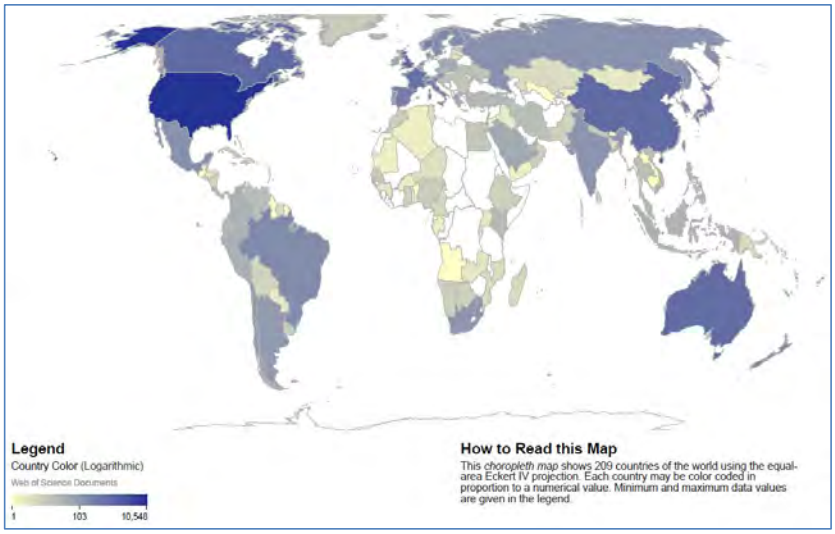
Non-cumulative number of NOAA articles published per year. On average NOAA authors have published 2,063 articles annually between 2016 and 2020.

Percentage of Articles in Top 10% by Citation



Percentage of articles in the top 10% 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% 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



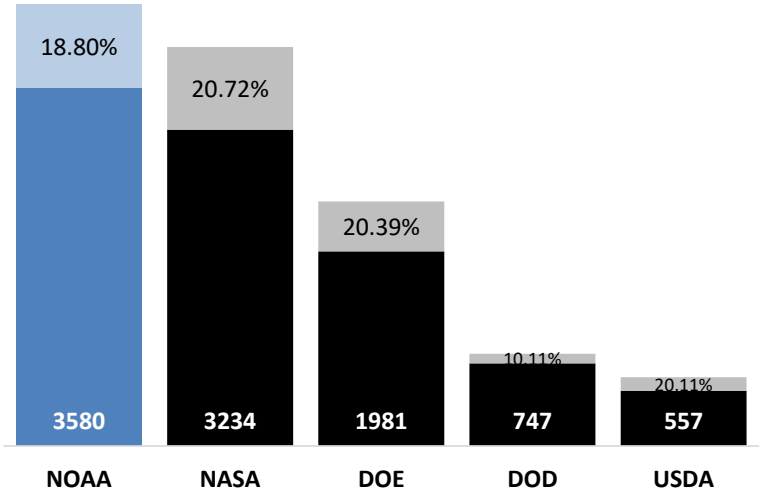
NOAA authors have collaborated with authors at **2,716** institutions in **174** countries and territories.

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 2016 and 2020, NOAA published an average of 716 articles per year in the field of meteorology and atmospheric sciences, resulting in a total of 3580 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.

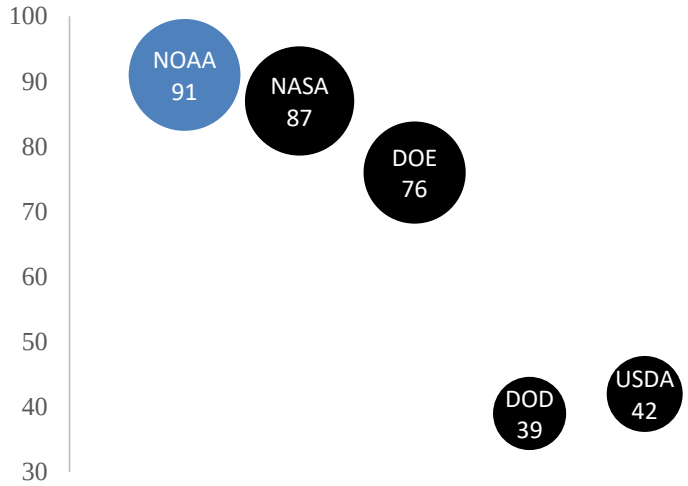
Top Journals where NOAA Publishes

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

Highly Cited NOAA Articles

- Huang, et al. 2017. Extended Reconstructed Sea Surface Temperature Version 5 (ERSSTv5): Upgrades, Validations, and Intercomparisons. J Climate.
- Le Quere, et al. 2018. Global Carbon Budget 2018. Earth System Science Data.
- Newman, et al. 2016. The Pacific Decadal Oscillation, Revisited. J Climate.

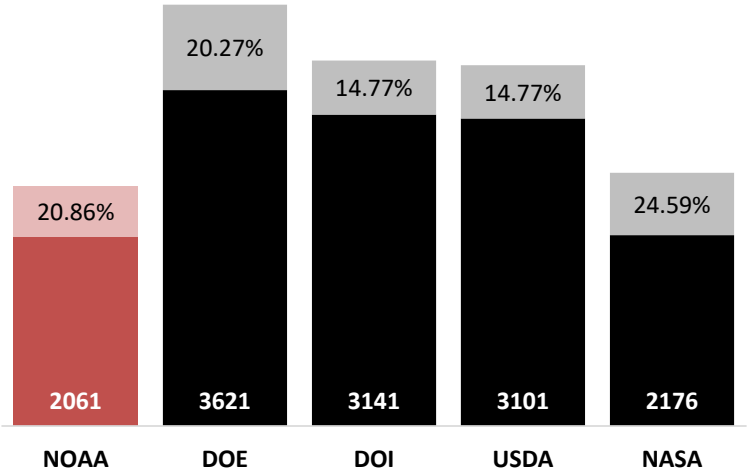
H-Index



Within the field of meteorology and atmospheric sciences, NOAA has an *h-index* of 91 - meaning that 91 of these articles have been cited in the peer-reviewed literature at least 91 times

Environmental Sciences

Total Number of Articles by Agency



Between 2016 and 2020, NOAA published an average of 403 articles per year in the field of environmental sciences, resulting in a total of 2,061 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in environmental sciences.

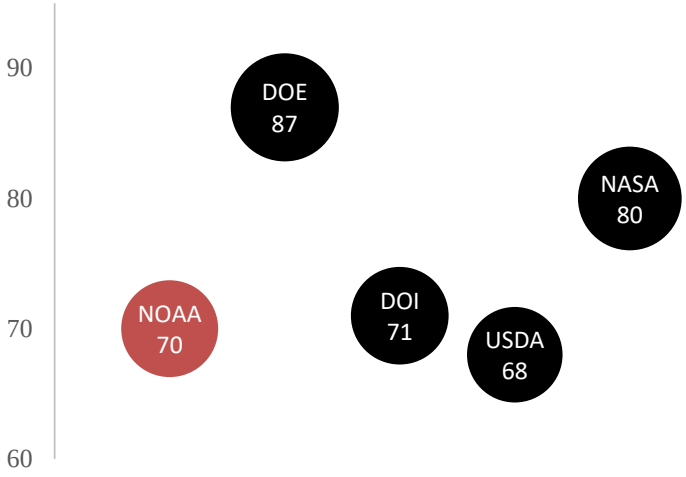
Top Journals where NOAA Publishes

- Atmospheric Chemistry and Physics
- Remote Sensing
- Frontiers in Marine Science
- Environment Science & Technology
- Atmospheric 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.
- Jung, et al. 2018. Validation of ATR FT-IR to indentify polymers of plastic marine debris, including those ingested by marine organisms. Marine Poll Bull.

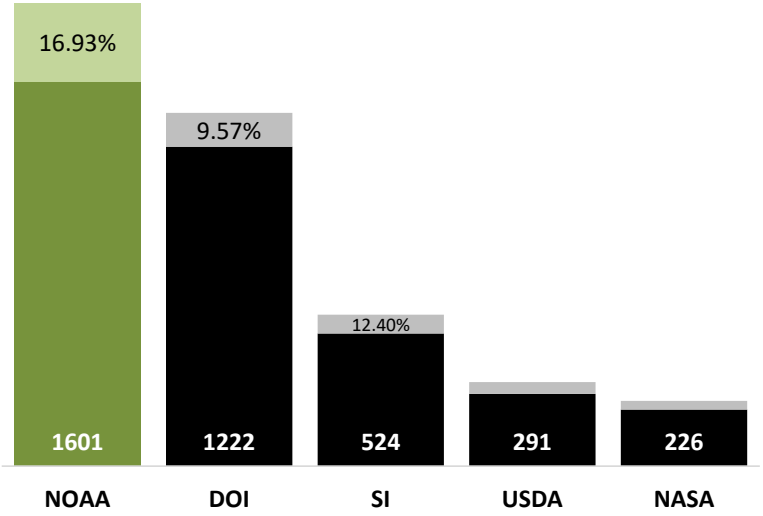
H-Index



Within the field of environmental sciences, NOAA has an *h-index* of 70 - meaning that 70 of these articles have been cited in the peer-reviewed literature at least 70 times.

Marine & Freshwater Biology

Total Number of Articles Per Agency



Between 2016 and 2020, NOAA published an average of 320 articles per year in the field of marine & freshwater biology, resulting in a total of 1,601 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in marine & freshwater biology.

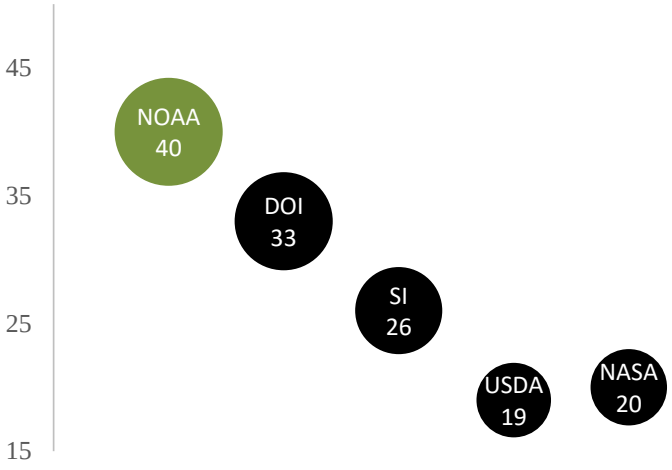
Top Journals where NOAA Publishes

- Frontiers in Marine Science
- Marine Ecology Progress Series
- ICES Journal of Marine Science
- Can Journal of Fisheries & Aquatic Science
- Marine Mammal Science

Highly Cited NOAA Articles

- Jung, et al. 2018. Validation of ATR FT-IR to indentify polymers of plastic marine debris, including those ingested by marine organisms. Marine Poll Bull.
- Berdalet, et al. 2016. Marine harmful algal blooms, human health and wellbeing. J Marine Bio Assoc UK.
- Nixon, et al. 2016. Shoreline oiling from the Deepwater Horizon oil spill. Marine Poll Bull.

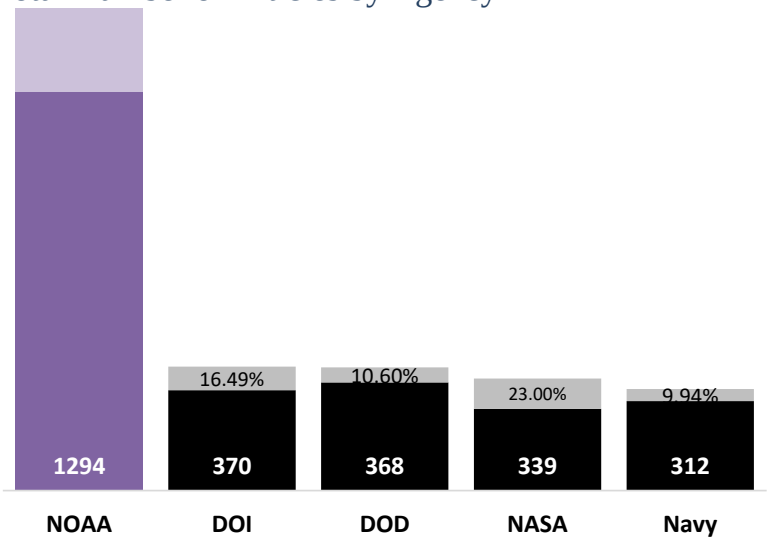
H-Index



Within the field of marine & freshwater biology, NOAA has an *h-index* of 40 - meaning that 40 of these articles have been cited in the peer-reviewed literature at least 40 times.

Oceanography

Total Number of Articles by Agency



Between 2016 and 2020, NOAA published an average of 259 articles per year in the field of oceanography, resulting in a total of 1,294 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in oceanography.

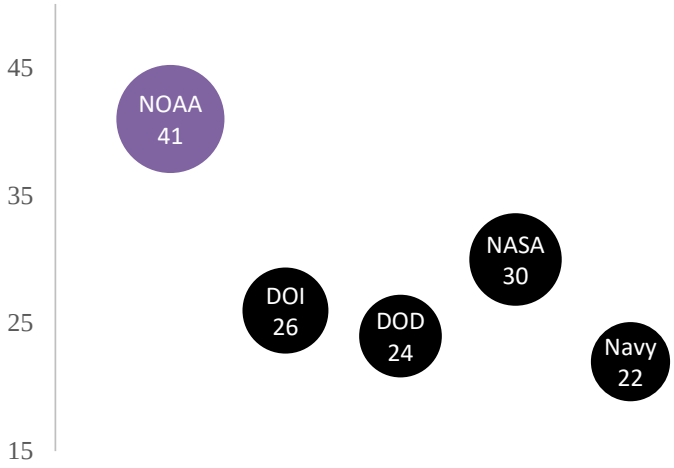
Top Journals where NOAA Publishes

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

Highly Cited NOAA Articles

- Saba, et al. 2016. Enhanced warming of the Northwest Atlantic Ocean under climate change. JGR – Oceans.
- Tsujino, et al. 2018. JRA-55 based surface dataset for driving ocean-sea-ice models (JRA55-do). Ocean Modelling.
- Johnson, et al. 2017. Biogeochemical sensor performance in the SOCCOM profiling float array. JGR – Oceans.

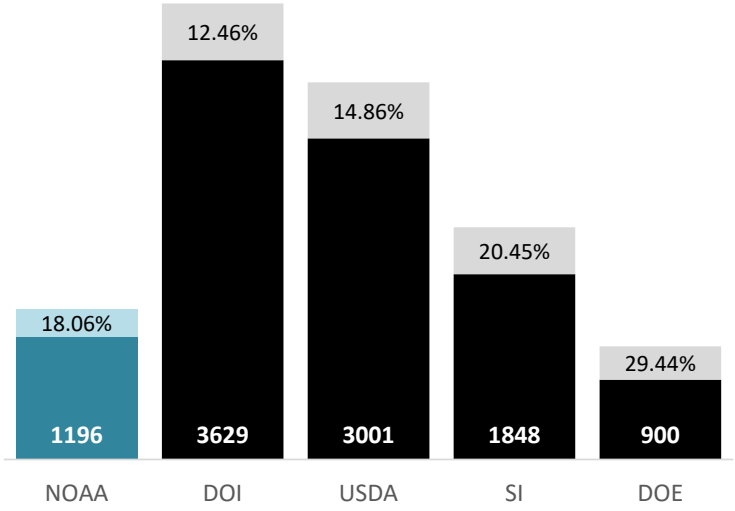
H-Index



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 2016 and 2020, NOAA published an average of 239 articles per year in the field of ecology, resulting in a total of 1,196 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in ecology.

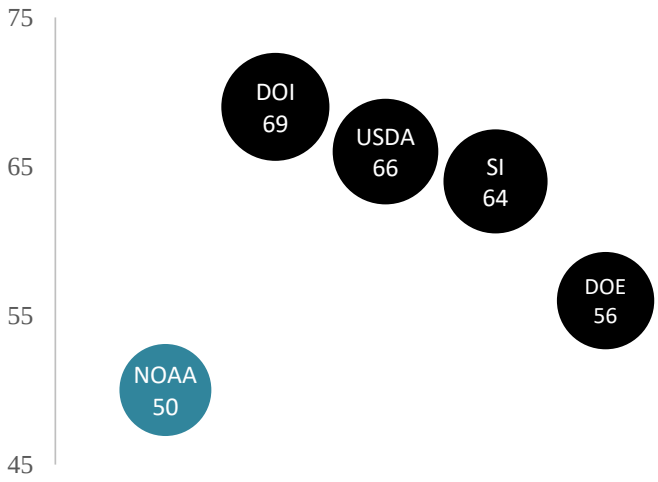
Top Journals where NOAA Publishes

- Marine Ecology Progress Series
- Ecosphere
- Ecology and Evolution
- Global Change Biology
- Environmental Biology of Fishes

Highly Cited NOAA Articles

- Heymans, et al. 2016. Best practice in Ecopath with Ecosim food-web models for ecosystem-based management. Eco Modelling.
- Gentry, et al. 2017. Mapping the global potential for marine aquaculture. Nature Ecology & Evolution.
- Howard, et al. 2017 Clarifying the role of coastal and marine systems in climate mitigation. Frontiers in Eco & the Environ.

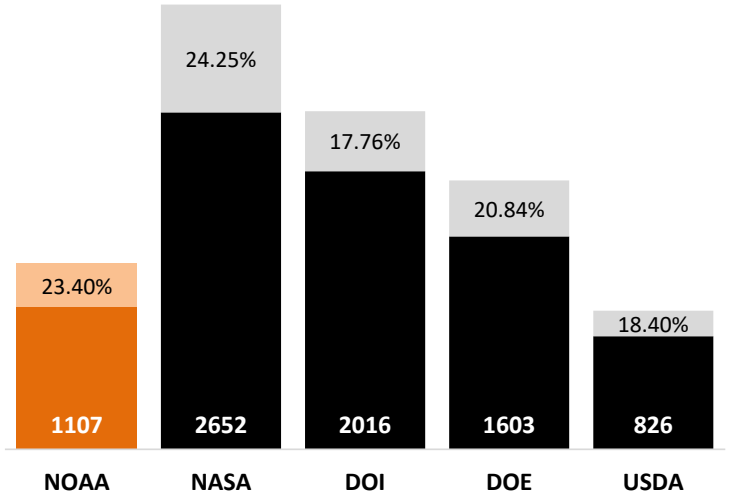
H-Index



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.

Geosciences

Total Number of Articles by Agency



Between 2016 and 2020, NOAA published an average of 221 articles per year in the field of geosciences, resulting in a total of 1,107 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in geosciences.

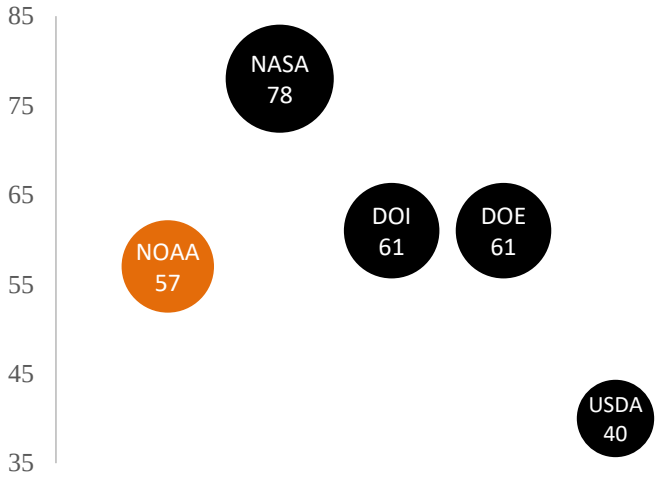
Top Journals where NOAA Publishes

- Geophysical Research Letters
- Remote Sensing
- Geoscientific Model Development
- Global Biochemical Cycles
- Journal of Hydrology

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.
- Le Quere, et al. 2018. Global Carbon Budget 2018. Earth System Science Data
- Nisbet, et al. 2016. Rising atmospheric methane: 2007-2014 growth and isotopic shift. Global Biochem Cycles.

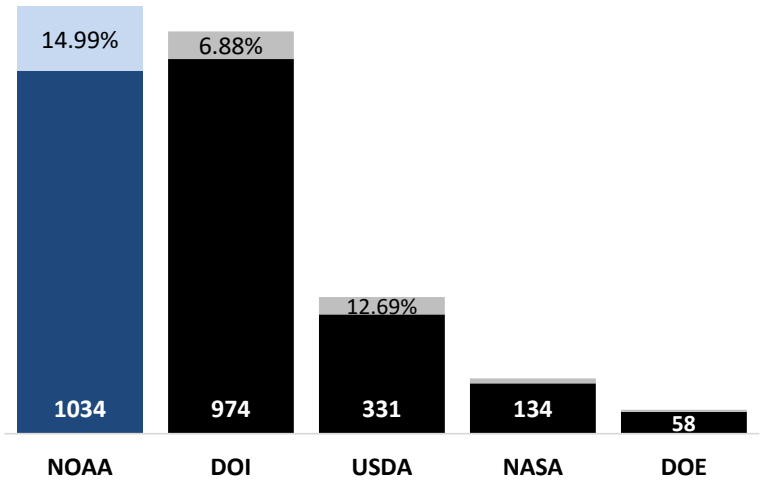
H-Index



Within the field of geosciences, NOAA has an *h-index* of 57 - meaning that 57 of these articles have been cited in the peer-reviewed literature at least 57 times.

Fisheries

Total Number of Articles by Agency



Between 2016 and 2020, NOAA published an average of 207 articles per year in the field fisheries, resulting in a total of 1,034 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in fisheries.

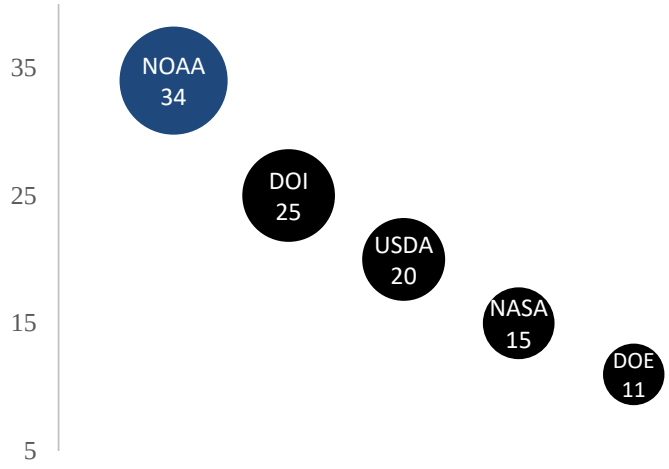
Top Journals where NOAA Publishes

- ICES Journal of Marine Science
- Can Journal of Fisheries & Aquatic Science
- Fisheries Research
- Fishery Bulletin
- Fisheries Oceanography

Highly Cited NOAA Articles

- Collie, et al. 2016. Ecosystem models for fisheries management: finding the sweet spot. Fish & Fisheries.
- Hyder, et al. 2018. Recreational sea fishing in Europe in a global contextParticipation rates, fishing effort, expenditure, and implications for monitoring and assessment. Fish & Fisheries.
- Frose, et al. 2017. Estimating fisheries reference points from catch and resilience. Fish & Fisheries.

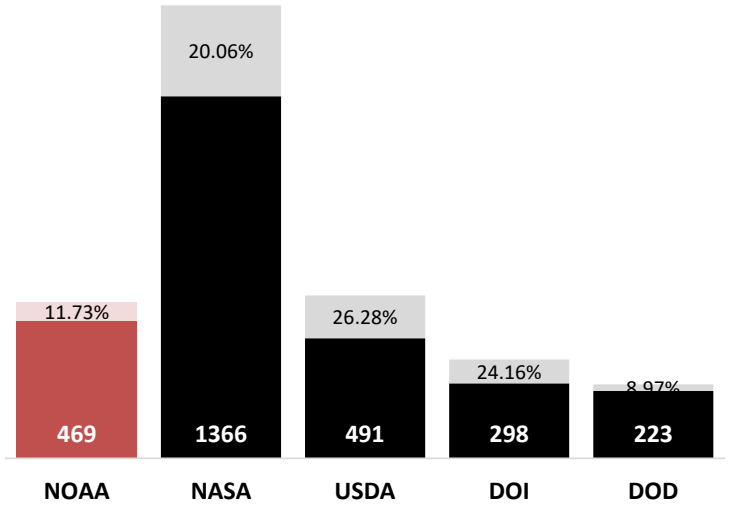
H-Index



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.

Remote Sensing

Total Number of Articles by Agency



Between 2016 and 2020, NOAA published an average of 94 articles per year in the field of remote sensing, resulting in a total of 469 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in remote sensing.

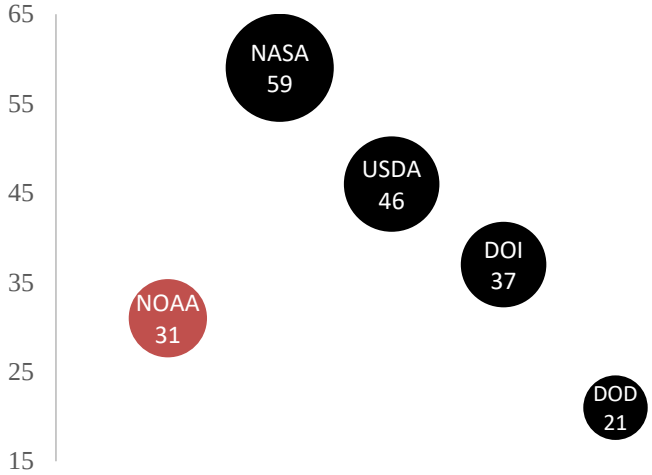
Top Journals where NOAA Publishes

- 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.
- Elvidge, et al. 2017. VIIRS night-time lights. Intl J Remote Sensing.
- Chan, et al. 2018. Development and assessment of the SMAP enhanced passive soil moisture product. Remote Sensing of Environment.

H-Index



Within the field of geosciences, NOAA has an *h-index* of 31 - meaning that 31 of these articles have been cited in the peer-reviewed literature at least 31 times.