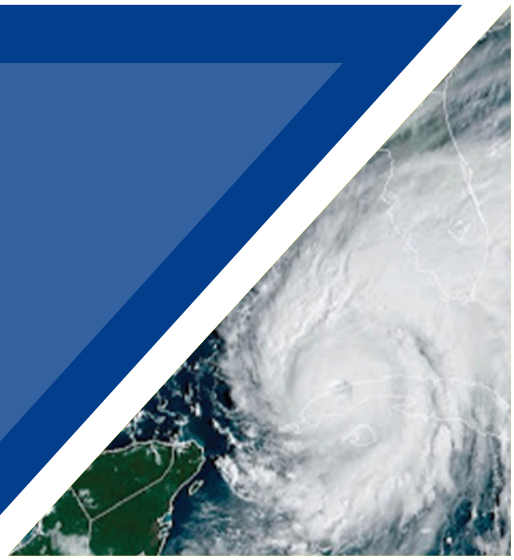
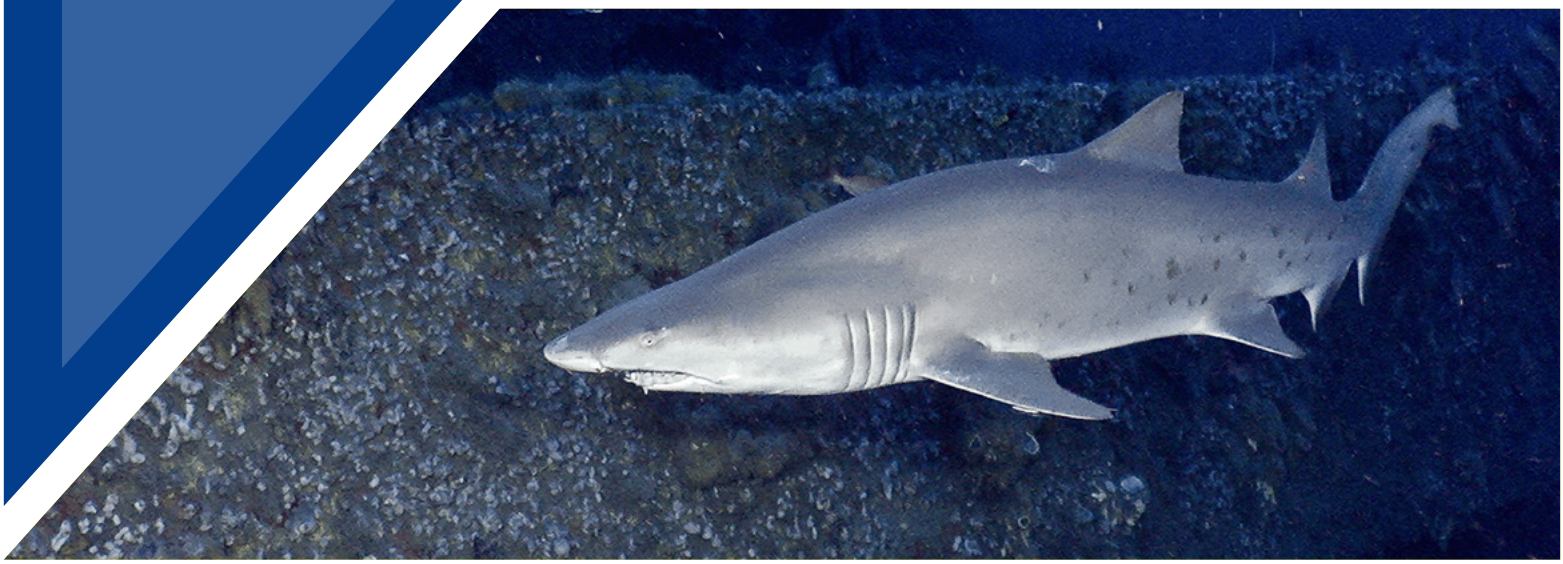
2022 NOAA SCIENCE REPORT





U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NOAA Technical Memorandum NOAA Science Council - 005

2022 NOAA Science Report

Joe Fillingham, Anita Harrington, Megan Deehan, Isha Renta, Elizabeth Gugliotti, Gary Matlock, Eric Bayler, Sarah Davis, Judy Ghirardelli, Monica Grasso, Michelle Harmon, Michael Liddel, Anthony Marshak, Felipe Arzayus, Laura Newcomb, Jeffrey Wielgus, Kristen Schepel, John Schattel, Melissa Yencho

NOAA
Silver Spring, Maryland

March 2023

noaa

NATIONAL OCEANIC
AND ATMOSPHERIC
ADMINISTRATION

NOAA Science Council

2022 NOAA Science Report https://doi.org/10.25923vsa1-gg59

Joe Fillingham, Anita Harrington, Megan Deehan, Isha Renta, Elizabeth Gugliotti, Gary Matlock, Eric Bayler, Sarah Davis, Judy Ghirardelli, Monica Grasso, Michelle Harmon, Michael Liddel, Anthony Marshak, Felipe Arzayus, Laura Newcomb, Jeffrey Wielgus, Kristen Schepel, John Schattel, Melissa Yencho

NOAA
Silver Spring, Maryland

March 2023

NOTICE

ACKNOWLEDGEMENTS

LAYOUT

Megan Deehan

DIVERSITY AND INCLUSION

Office of Inclusion and Civil Rights

SCIENCE & PLAIN LANGUAGE REVIEWS

Megan Deehan, Anita Harrington, Joe Fillingham, Isha Renta, Elizabeth Gugliotti, Maria Torres, Susan Cobb, Liz Perotti, Nicole Rice, Courtney Byrd, Clara Deck, Kristina Kiest, Adi Hanein, Barb Deluisi, Laura Chaibongsai, Rayne Sabatello, Emily Crum, Sierra Sarkis, Heather McCullough, Caitlin Valentine, Jennie Lyons, Marissa Anderson, Symone Barkley, Alejandra Enriquez, Troy Kitch, Julia Ortiz, Vickie Bowman, Linda Taylor, Christopher Vaccaro, Susan Buchanan, Maureen O'Leary, Jasmine Blackwell, Keli Pirtle, Rosemary Booth, Grace Bottitta-Williamson, Kate Naughten, Rebecca Ferro, Ryann Agbasi, Renata Lana, John Bateman, John Leslie, Marjorie Mooney-Seus, Forbes Darby, Sarah Mesnick, Teri Frady, Keeley Belva, Monica Grasso, Joseph Conran, Jeffrey Wielgus, Richard Methot, Christine Stawitz, Ole Shelton, Jameal Samhouri, Leah Crowe, David Demer, Laurie Weitkamp, Darren Wright, Jessica Schauer, Kimberly McMahon, David Dewitt, Douglas Hilderbrand, Ivanka Stajner, Fanglin Yang, Neal Dipasquale, Avichal Mehra, Jocelyn Burston, Dave Turner, Bryan Mrocska, Daniel Barrie, Monika Kopacz, Gina Eosco, Yong Wei, Mimi Hughes, Rob Cifelli, Gregory Foltz, Chidong Zhang, Hallee Meltzer, Joanne Flanders, Tane Casserley, David Wiley, Edward Myers, Andria Bilich, Katie Kirk, Hannah Brown, Bryan Costa, Matthew Poti, Randy Clark, Tim Battista, Charles Menza, Peter Etnoyer, Terry McTigue, Rance Hardison, Maggie Broadwater, Marc Suddleson, John Knaff, Jeff Key, Paul Chang, Huan Meng, Yunyue Yu, Mark Kulie, Sean Helfrich, Christopher Jackson, Rob Redmon, Shobha Kondragunta, Monica Allen

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 PHOTOS

An image of Hurricane Ian (top), NOAA Ship *Reuben Lasker* (middle), a shark swimming by the USS *Monitor* shipwreck during a survey expedition (bottom). Credit: NOAA/NOAA Fisheries/GFOE

FOREWORD

It is my honor and privilege to introduce NOAA's seventh annual Science Report. NOAA is the Nation's premier ocean, weather, atmospheric and climate agency. We have a deep commitment to science, service and stewardship. The annual NOAA Science Report began when our current Administrator, Dr. Richard Spinrad, was formerly serving as the NOAA Chief Scientist and recognized the value in sharing NOAA's research accomplishments of the past year. This report not only documents the breadth and high caliber of our research, but also emphasizes the wide range of impacts that our scientific advancements have on the lives of the American people and the World.

With climate change altering the status quo, there is a need for new and innovative science, technology, communication, and stewardship approaches. NOAA is responding to this need by advancing fundamental science, providing support for decision making, developing solutions for vulnerable communities and ecosystems, and ensuring our work represents the needs of the Nation. The scientific highlights within the report demonstrate NOAA's progress and commitment to building a Climate Ready Nation that is resilient and well equipped to deal with future climate change, integrating equity into NOAA's services and operations, and supporting the sustainable growth of the Blue Economy.

We could not continue to produce such valuable work for the American people without our international, academic, industry, interagency, state and local government, and non-governmental organization partners. These coalitions are critical for developing innovative and impactful science, and unlocking the full value of our work through effectively utilizing and leveraging our respective capabilities.

As we look to the future, NOAA will need to continue to be at the cutting edge of understanding the dynamic Earth system and predicting and projecting future changes and impacts. NOAA science will need to reduce uncertainty and improve the communication around what is to come to not only inform the management of risks across timescales, but support new innovative solutions-oriented commerce. I have no doubt that we will be able to meet these growing demands because our workforce is creative, dedicated to the mission, and contagiously enthusiastic about their work.

This report is both a showcase of our science advancements and a testament to the commitment of NOAA's workforce. Thank you to all who have contributed to NOAA scientific advancements, often only completed after years of dedication. And thank you to the writing team, who have built this document to identify and celebrate NOAA science. Thank you.

Sarah Kapnick, Ph.D.
NOAA Chief Scientist

CONTENTS

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 (R&D) for observing and understanding the complex environmental systems of our planet. This understanding provides the information and knowledge needed to inform decision-making, protect lives and property, support livelihoods, and sustain critical ecosystems.

NOAA IS A SCIENCE AGENCY

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

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.

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

The **National Marine Fisheries Service (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.

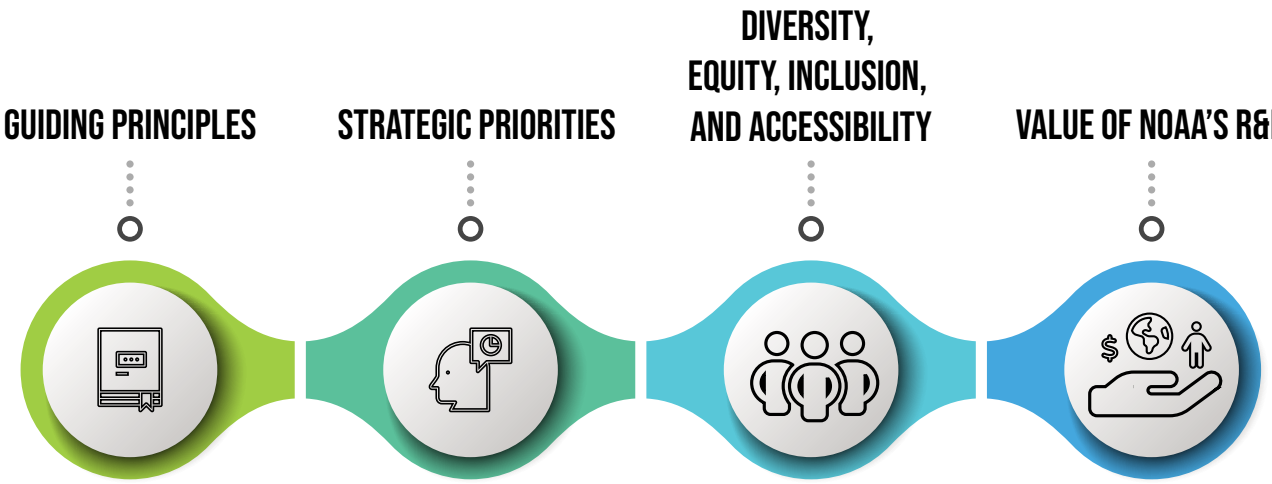
The **National Ocean Service (NOAA NOS)** is the nation's premier science agency for oceans and coasts. NOAA NOS delivers the applied science, modeling, tools and services needed to understand, predict, and respond to the challenges we face along America's 95,000 miles of shoreline and 3.5 million square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

The **National Environmental Satellite, Data, and Information Service (NOAA 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. NOAA NESDIS supports science through the Center for Satellite Applications and Research, the National Centers for Environmental Information, and the Office of Satellite and Product Operations. Through these programs, NOAA NESDIS researches, formulates, develops, validates, maintains, verifies, and sustains environmental measurements from satellites, as well as associated applications of satellite environmental observations, and maintains the quality of measurements from NOAA's operational satellites and domestic and international partners, directly enabling and supporting NOAA's environmental analysis and prediction capabilities. NOAA 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 (NOAA Research)** provides the research foundation for understanding the complex earth systems that support our planet. NOAA Research's role is to provide unbiased science to better manage the environment nationally and globally. The science and technology that NOAA Research produces and transfers to partners (in NOAA's service lines and beyond) is instrumental to preventing the loss of human life, managing natural resources, and maintaining a strong economy. NOAA Research has partnerships and platforms around the world and offices located across the country, including ten laboratories and seven program offices that support research and provide information used from the international to the local level.

The **National Weather Service (NOAA NWS)** provides weather, water, and climate data, forecasts, warnings, and impact-based decision support services (IDSS) for the protection of life and property and the enhancement of the national economy. NOAA 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. NOAA 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. NOAA 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 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. OMAO has established an Uncrewed Systems Operations Center 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.



GUIDING PRINCIPLES

Societal needs, mandates, and policies shape NOAA's R&D enterprise and ensure high-quality outputs.

STRATEGIC PRIORITIES

Strategic R&D planning drives a balanced, equitable R&D portfolio and a diverse R&D workforce.

DIVERSITY, EQUITY, INCLUSION, AND ACCESSIBILITY (DEIA)

Integration of DEIA into NOAA's core operations involves strengthening the foundation for a diverse and inclusive workforce, training and retaining the next generation of scientists, and leveraging the wealth of experiences and perspectives of NOAA's employees to support R&D, achieve mission goals, and business objectives.

VALUE OF NOAA'S R&D

The assessment of societal impacts and economic valuation of NOAA's R&D help us to better understand the "return on investment" of NOAA's R&D products, knowledge and application, and how it contributes to improving the lives of the American people.

GUIDING PRINCIPLES

HOW DOES NOAA INVEST IN RESEARCH?

NOAA's investment in R&D expands capabilities and improves the quality of NOAA's products and services for the Nation. Dynamic engagement between NOAA and its stakeholders drive the development of products, services, and new research initiatives that incorporate the needs of the people. NOAA also develops research initiatives to address legislative mandates and other requirements. By integrating internal R&D with partner efforts (including cooperative institutes, universities, other government agencies, and the private sector), NOAA can better transform concepts into the data, tools, and products and services that meet the needs of stakeholders. NOAA balances a broad research portfolio to further the NOAA mission and serve the Nation. NOAA's R&D addresses the needs of the user community while advancing fundamental scientific understanding.

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 thoughtfully 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.

NOAA maintains both internal and external research investments. Some NOAA programs invest the majority of their R&D funding internally at laboratories and science centers with federal employees and other NOAA programs invest the majority of their funding with external R&D partners such as universities, industry, and other research institutions. In many cases, NOAA programs distribute their R&D investments across both internal and external efforts.

NOAA partnerships, vital to the agency's R&D success, 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, external grant programs, contracts, and Cooperative R&D Agreements with the private sector.

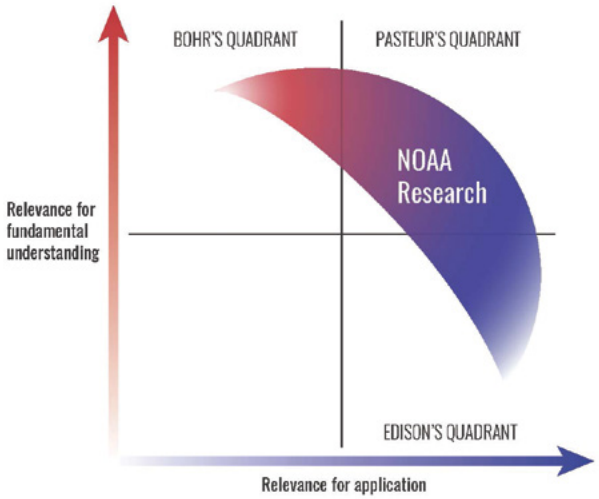


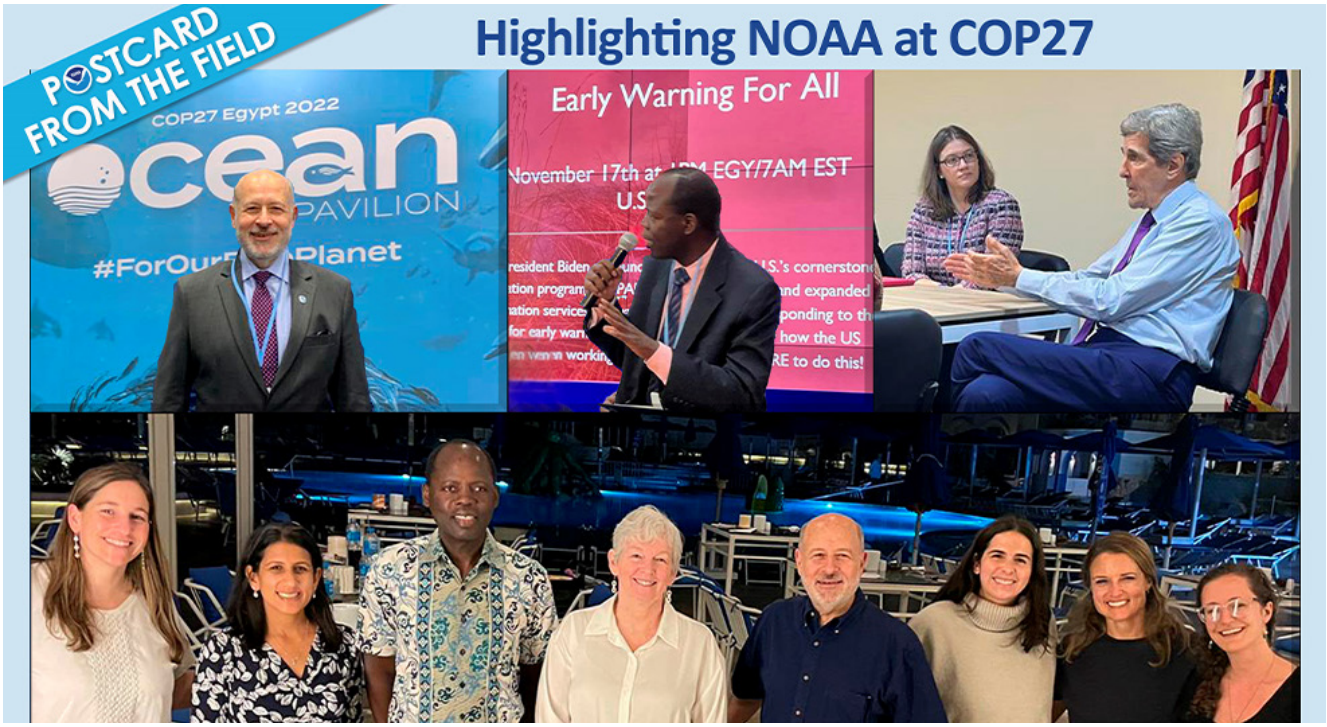
Figure 1. Donald Stokes proposed the above chart in his 1997 book *Pasteur's Quadrant: Basic Science and Technological Innovation*. This chart portrays that, while some research largely focuses on fundamental understanding (Bohr's quadrant upper left) or application (Edison's quadrant, lower right), 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) 216-115B: Research and Development in NOAA [NOAA, 2022] when formulating, directing, and evaluating all agency research:

- Mission alignment
- Transition readiness (NAO 216-105B, [NOAA, 2022])
- 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 leadership and staff are shown in NOAA's *Postcard From the Field* at the 27th United Nations Climate Change Conference (COP27) in Egypt in November 2022. Throughout COP, NOAA highlighted how they are collecting and using climate data to equitably strengthen community resilience, building a Climate Ready Nation, incorporating Indigenous and local knowledge into climate adaptation and mitigation plans, and supporting universal access to near-real-time ocean data to underpin climate action, among many other initiatives. Credit: NOAA

SCIENTIFIC INTEGRITY

NOAA's Scientific Integrity Policy (NAO 202-735D-2 [NOAA, 2021]), exists 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 the 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 principal science asset, our employees.

NOAA's Scientific Integrity Policy, along with its accompanying Procedural Handbook, establishes 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.

NOAA'S PRIORITY OBJECTIVES

The NOAA Fiscal Year 2022-2026 Strategic Plan, Building a Climate Ready Nation, identifies NOAA's three overarching priorities objectives, strategies, and outcomes through 2026 within three goal areas:

1. Building a Climate Ready Nation by establishing NOAA as the primary federal authoritative provider of climate information and services in the whole-of-government response to tackling the climate crisis;
2. Integrating equity into our core operations; and
3. Promoting economic development while maintaining environmental stewardship with a focus on advancing the New Blue Economy.

Secretary of Commerce Gina Raimondo visited NOAA headquarters in Silver Spring, MD. She met with NOAA leaders, received briefings, and spoke with NOAA employees. Photo credit: David L. Hall, NOAA

STRATEGIC R&D PRIORITIES

The NOAA Research and Development Vision Areas: 2020-2026, aligned with the NOAA Strategic Plan, identifies NOAA's R&D priorities. The Vision provides direction on NOAA's R&D and enables proactive actions to align NOAA's resources, budget, and functional activities to achieve stated goals. Research and development are cornerstones of NOAA's wide-ranging scientific assessments, forecasting capabilities, advancement of environmental sensors and technologies, and engagement with stakeholders and international organizations. These vision 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 carrying out the objectives in the Vision Areas and the NOAA Strategic Plan, NOAA 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 (AI) analytics for next-generation Earth science; and
6. Adopting and using information technology cloud services.

NOAA Center for AI and AI project images around NOAA. Image credit: NOAA

THE FUTURE OF AI USES AT NOAA

NOAA and the international earth science community have been challenged to establish a community-driven definition of AI-ready open environmental data to unlock the full potential of AI application development. The community's working definition for AI-ready data is open environmental data that is well documented, with proper quality information, and is findable, accessible, interoperable, and reusable for diverse AI applications. Expanding the adoption and uses of AI and machine learning involves the need for case-based metrics, measures of discoverability, and assessment tools to facilitate quick and reliable user evaluation of data applicability for each case.

In conjunction with this preliminary standard, NOAA's Center for AI is spearheading a second co-productive training initiative that develops curation tools to capture community-generated, interactive learning materials. These tools and materials promote environmental data science, expand AI and machine learning knowledge at all levels of understanding, and improve access to NOAA data and products. NOAA's Center for AI is coalescing these tools into Learning Journeys, which are short instructional modules that match any user's or interested learner's needs and skill levels. By standardizing AI-readiness and providing training tools, NOAA is working to guide trustworthy, responsible, and ethical AI and machine learning applications to support social environmental justice and incorporate broad stakeholder input. NOAA's Center for AI community of practice has grown to 600+ members, providing an opportunity for collaboration among diverse groups including NOAA, other governmental agencies, industry, and non-governmental agencies.

REFERENCES:

NOAA (2016a), NOAA Administrative Order 216-115A - Research and Development in NOAA, National Oceanic and Atmospheric Administration, Washington, D.C.

NOAA (2016b), NOAA Administrative Order 216-105B - Policy on Research and Development Transitions, National Oceanic and Atmospheric Administration, Washington, D.C.

NOAA (2018), NOAA by the Numbers, p. 3, National Oceanic and Atmospheric Administration, Washington, D.C.

NOAA (2021), NOAA Administrative Order 202-735D-2 - Scientific Integrity, National Oceanic and Atmospheric Administration, Washington, D.C.

Stokes, D. E. (1997), Pasteur's quadrant: Basic science and technological innovation, Brookings Institution Press.

DIVERSITY, EQUITY, INCLUSION, AND ACCESSIBILITY

VISION AND PLAN

NOAA's overall vision for Diversity, Equity, Inclusion, and Accessibility (DEIA) is an environment in which NOAA leverages DEIA to achieve mission goals and business objectives while also maximizing the potential of individuals within the organization.

NOAA's developing DEIA Strategic Plan describes how NOAA envisions, defines, assesses, values, and commits to diversity, equity, inclusion, and accessibility. A comprehensive plan and implementation, with actions and metrics, will assist NOAA in collaboratively achieving the goals.

ADVANCING DEIA

NOAA recognizes that diversity is about more than race and gender and strives to foster an inclusive culture for everyone by advancing our DEIA initiatives, programs, and groups hosted by the 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 by promoting diversity, equity, inclusion, and accessibility - resulting in a more productive, professional environment that champions mission achievement.

In 2022, OICR hosted ten Special Emphasis Program Observances events, with an average of over 270 attendees at each event. NOAA also served as a sponsor for three national DEIA-related conferences in Fiscal Year (FY) 2022: The Federal Asian Pacific American Council Conference; Federally Employed Women Science, Technology, Engineering, and Mathematics Day; and the Federally Employed Women National Training Programs Conference. Additionally, NOAA hosted the attendance of several employees at the Global ERG Summit for Employee Resource Groups (ERGs), Business Resource Groups, Diversity Councils, and other Affinity Groups, where the Generations with Genius, the Accommodating Differently Abled People Team, and Women of NOAA ERGs all received a Diversity Impact Award for their work in advancing DEIA in NOAA.

STRENGTHENING THE FOUNDATION

The Majority staff of the Committee on Science, Space, and Technology analyzed workforce data for seven science agencies within the Committee's jurisdiction: National Science Foundation, National Aeronautics and Space Administration, Department of Homeland Security Science and Technology Directorate, National Institute of Standards and Technology, NOAA, Department of Energy, and Environmental Protection Agency (Report).

The Majority staff reported on the following statistics:

- NOAA's workforce declined by 8.6% from FY 2009-2020;
- And the NOAA Science, Technology, Engineering, and Mathematics, or STEM, workforce declined by 1.6% during this time
- At the end of FY 2020 NOAA employed roughly 8.5 male engineers for every 1 female engineer
- While STEM employment among minority groups at NOAA increased by 13.6% from FY 2016 - 2020, only 0.4% were Black/African

American

- NOAA's STEM workforce experienced large declines in several critical scientific occupations, including fish biologists (8.1% decline), oceanographers (9.0% decline), and wildlife biologists (30.4% decline)

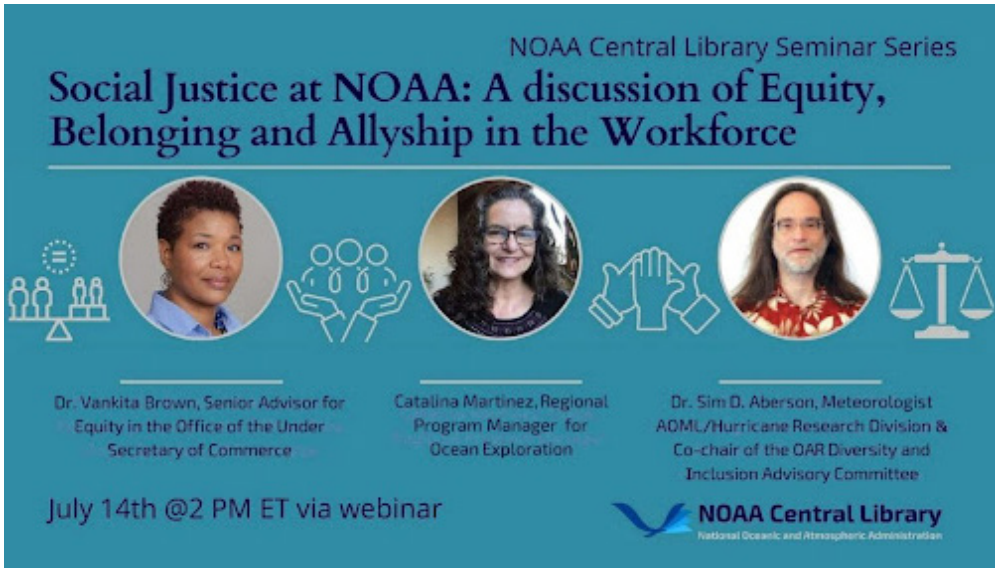
As a result of this report, the NOAA Science Council identified best practices for hiring and retaining underrepresented groups and addressed other workforce challenges.

To begin addressing these challenges, the NOAA Science Council organized a seminar series aimed at educating hiring managers and NOAA staff on these best practices. The seminar series took place over the Spring and Summer in 2022 and focused on accessing the NOAA STEM talent pool, advancement, retention, allyship, belonging, and equity. These recorded seminars featured panelists across each line office and led to insightful and engaging conversations with viewers.

OICR developed NAO 215-4 to advance NOAA's goal of a fully inclusive workplace by clarifying roles and setting expectations for respecting gender identity that applies to all employees, contractors, fellows, interns, and grantees.

The Office of Human Capital Services drafted a NOAA-specific operational plan for recruiting, hiring and retaining persons with disabilities and developed a reasonable accommodation webinar for employees on the Commerce Learning Center. The NOAA employees who took this training increased from 86 individuals in 2020 to 275 in 2021 (219% attendance increase).

NOAA has also made advancements in having a workforce that represents individuals with targeted disabilities. In 2021 representation was at 2.65%, 0.65% above the federal goal established by the Equal Employment Opportunity Commission. In FY21, the representation of Hispanics, White Females, African Americans, American Indian or Alaska Natives Females and two or more races in NOAA's workforce were below the civilian labor force. NOAA recognizes that there is still ample work to be done to address deficiencies in DEIA within the agency and going forward in 2023, will continue to make efforts and support initiatives to progress and improve diversity and inclusion in the work environment.



To better integrate diversity, equity, and inclusion into NOAA's hiring process, the NOAA Science Council, The Office of Education, and the NOAA Central Library created a series of webinars in March, May, and July 2022. The seminar topics included accessing the NOAA STEM talent pool, advancement, retention, allyship, belonging, and equity. Recordings of these seminars can be found on the NOAA Central Library's YouTube Channel. Credit: NOAA

DEIA AND THE DEVELOPMENT OF THE NEXT GENERATION

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 those from diverse backgrounds. OEd-supported programs play an essential role in contributing to NOAA's DEIA goals.

The Educational Partnership Program with Minority-Serving Institutions supports the education, training, professional development, and graduation of post-secondary students at NOAA-supported minority-serving institutions, where most of the student population are traditionally underrepresented and historically excluded communities. NOAA funding also assists research capacity development in STEM, social science, and policy fields at Minority Serving Institutions that are aligned with NOAA mission fields.

The 2022 class of EPP/MSI scholars during their scholarship orientation. From left to right, Christian Schnell, Courtney White, Martin Gonzalez, Alison Novara, Ingrid Martinson, Kiah Matthews, Michaela Wong, Hailey Poole, Richarde Graham II, and Alexandria Tennant. Photo credit: Elvis Efamba/Office of Education

NOAA'S DEIA COMMITMENT

NOAA commits to providing our workforce and job applicants with a full and fair opportunity for employment, career advancement, and access to resources and programs and recognizes that diversity is about more than race and gender, and we strive to foster an inclusive culture for everyone. NOAA values the unique differences and shared values of each member of the NOAA team.

NOAA is committed to incorporating the principles of DEIA as a core value. Empowering our workforce through DEIA initiatives allows the capability to understand and respond effectively to the workforce's needs and mission.

DEIA IS A CORE VALUE OF NOAA R&D

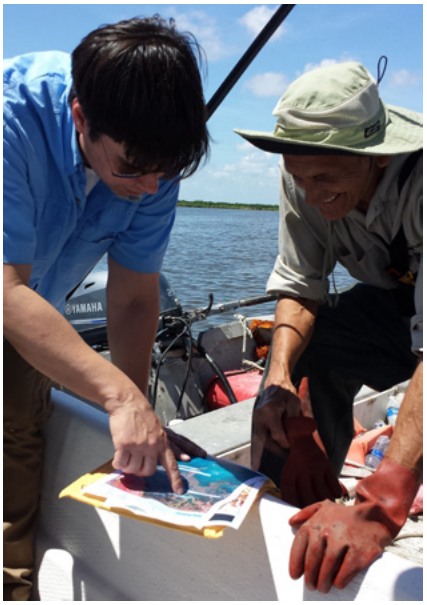
It is imperative that NOAA's R&D portfolio prioritizes DEIA to successfully address the needs of the public. Through working to build a diverse workforce and network of partners, incorporating traditional ecological knowledge, and increasing the accessibility of NOAA research to all, NOAA is not only strengthened as an agency, but is better positioned to meet our R&D mission.

The following impactful R&D projects, critical to achieving NOAA's mission, highlight DEIA as a core NOAA value.

COLLABORATIVE MAPPING WITH THE POINTE-AU-CHIEN INDIAN TRIBE SUPPORTS LOCAL ADAPTATION PLANNING IN COASTAL LOUISIANA

Louisiana Sea Grant's partnership with the Pointe-au-Chien Indian Tribe on a map-based decision support tool is advancing short and long-term resilience planning to the impacts of climate change in coastal Louisiana with the Tribe's priorities in mind. Rapid coastal land loss and projected sea level rise are putting unprecedented stress on vulnerable communities in coastal Louisiana. Tribes and other indigenous communities often have a strong connection to a place that helps inspire innovative ideas, promoting greater sustainability of vulnerable ecosystems and the communities that depend on them. Better inclusion of the indigenous community's knowledge into applied research is necessary to make sure their way of knowing is recognized, understood, and valued in environmental management applications.

The research team utilized interviews, focus groups, and participant observation to collect traditional ecological knowledge-based information with participating Tribe members. Interactive maps were developed that reflect local perceptions of landscape features within the Tribe's ecosystem-dependent livelihood base that contribute most to the community's physical vulnerability to coastal hazards. These maps are a resource that the Tribe is using to inform its short and long-term resilience planning and help communicate their priorities to gain support for local restoration and protection projects.



Matthew Bethel and Emary Billiot in Billiot's boat near the Pointe-au-Chien Village recording traditional ecological knowledge-based observations on maps for the collaborative project Photo credit: Corey Miller

Aerial view of Pointe-au-Chien Indian Tribe project collaborators taking researchers down Bayou Pointe-au-Chien to share traditional ecological knowledge about the place. Photo credit: Louisiana Sea Grant

THE OLYMPIC COAST AS A SENTINEL: AN INTEGRATED SOCIAL-ECOLOGICAL VULNERABILITY ASSESSMENT

In a major collaborative effort, partners from the Hoh Tribe, Makah Tribe, Quileute Tribe and Quinault Indian Nation who rely on the Olympic Coast resources, co-developed goals, priorities, and provided socio-economic information critical to assessing their community's vulnerability to ocean acidification. The Olympic Coast in the Pacific Northwest of the U.S. is currently experiencing the effects of ocean acidification, which is a change in ocean chemistry when the ocean absorbs carbon dioxide from the atmosphere that increases acidity of seawater and can pose risks to marine life and Native American tribal communities who depend on them. Harvest and use of local marine species are central to the well-being of coastal tribes for their livelihoods, food security, identity and cultural practices. Understanding impacts to marine life and tribal communities will help promote community-driven strategies to decrease societal impacts and build resilience to ocean change, improving the tribes' abilities to prepare for and respond to ocean acidification. This NOAA supported collaboration brought together Olympic Coast Treaty Tribes, Washington Sea Grant, scientists and coastal managers to better prepare for ocean change and support tribal community well-being. Learn more about the project and partners at the project website.

"Indigenous communities have been ocean observers since time immemorial," said Dr. Jan Newton, lead Principal Investigator at the University of Washington's Applied Physics Lab and the Washington Ocean Acidification Center. "They are explicitly place-based and take a holistic and integrative way. It has been a way to gain a partnership with people with that appreciation and are on the frontlines of ocean acidification and climate change. [Their] knowledge of how ocean acidification will affect different resources is critical."

Offshore rocks and spray along Washington's Olympic coast. Photo credit: Lt Jon Andvick, NOAA Corps, and crew and officers of NOAA Ship Fairweather

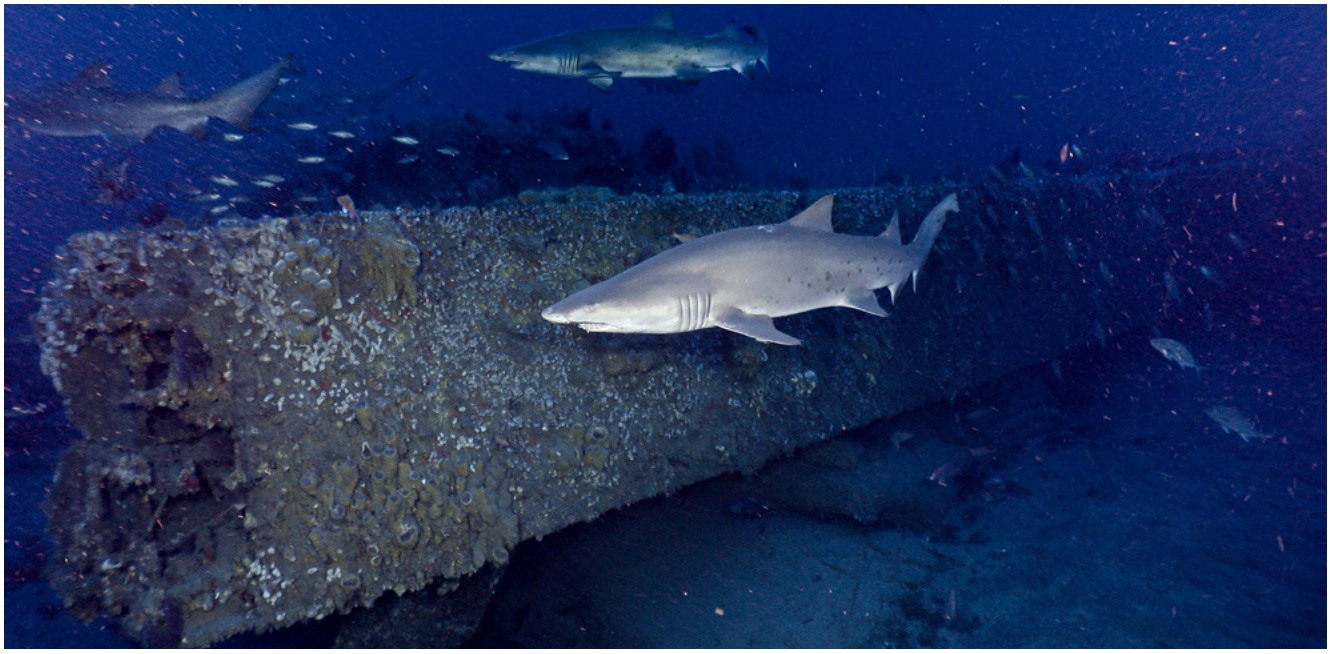
This anchor was one of two found among the remains of what is likely the 19th century whaler *Industry*, discovered and explored in February 2022 in the Gulf of Mexico. Photo credit: NOAA Ocean Exploration, 2022 ROV and Mapping Shakedown

NOAA HELPS DISCOVER 207-YEAR-OLD WRECK OF A WHALING SHIP IN GULF OF MEXICO THROUGH TELEPRESENCE

On February 25, 2022, NOAA Research, partners from SEARCH Inc., and the Bureau of Ocean Energy Management discovered the remains of what was likely the brig *Industry*, a 207-year-old whaling ship, at the bottom of the Gulf of Mexico. Discovery of the remains of the 64-foot long, two-masted wooden ship opens a window into a little-known chapter of American history when free descendants of enslaved African and Native Americans served as essential crew for the whaling industry. The discovery of this lost ship provides insights into the lives of Black and Native American mariners and their communities and how they succeeded as captains and crew members in the nascent American whaling industry and were able to prosper in the ocean economy despite facing discrimination and other injustices both at sea and on land. With guidance provided through satellite connection from partner scientists on shore, a team aboard NOAA Ship *Okeanos Explorer* piloted a remotely operated vehicle (ROV) to explore the seafloor at a suspected location first spotted by an energy company in 2011 and viewed briefly by an autonomous vehicle in 2017. The ability to lead the exploration and documentation of the wreck via satellite as "scientists ashore" is a key and important aspect of NOAA's "telepresence" model of deep-ocean exploration. Informed by extensive research on *Industry* and the video from the ROV, a team of shoreside scientists have now confirmed that the wreck is most likely the brig *Industry*. This discovery allows for the exploration of the history of this whaling crew and highlights the power of telepresence technology.

VALOR IN THE ATLANTIC TELEPRESENCE EXPEDITION SHARES THE EXCITEMENT OF OCEAN DISCOVERY AND RESEARCH IN REAL-TIME

The NOAA Ship *Nancy Foster* hosted the 2022 Valor in the Atlantic Telepresence Expedition showcasing the excitement of ocean discovery and research in real-time. The successful expedition was a partnership between NOAA's Office of National Marine Sanctuaries and the Global Foundation for Ocean Exploration. Field teams from NOAA's Monitor National Marine Sanctuary, NOAA's National Centers for Coastal Ocean Science, and North Carolina's Office of State Archaeology conducted the first in-depth, multidisciplinary survey of the iconic Civil War ironclad USS *Monitor* since NOAA and the U.S. Navy recovered the warship's famous gun turret in 2002. NOAA is increasing access to special places in remote areas by using ROVs, to document and live-stream dives and surveys of the *Monitor* and other shipwrecks off the North Carolina coast. The live-stream webcast showcased these nationally significant historic sites and the surprisingly diverse biological communities and abundance of fish occupying the reef and wreck sites while bringing the excitement of exploration and the wonders of these ocean treasures to life for students, educators, scientists, and the public worldwide.



Sand tiger sharks inspect *Monitor's* bow on an expedition with Monitor National Marine Sanctuary and the Global Foundation for Ocean Exploration. Photo credit: NOAA/Global Foundation for Ocean Exploration

UNDERSTANDING THE VALUE OF NOAA R&D

NOAA aims to produce R&D that yields useful applications and improves our fundamental understanding of the world. NOAA's R&D activities integrate social, behavioral, and economic sciences, contributing value to the U.S. economy and guiding important decisions that impact stakeholders and the natural environment. Value can be found in knowledge and products derived from NOAA's R&D that influence human behavior, such as hazardous

weather forecasts and risk communication that helps save lives, and aiding the management of natural resources that are valuable themselves, such as coral reefs that support the Blue Economy.

The following projects assess societal impacts of NOAA's R&D through economic valuation to better understand the "return on investment" of NOAA's R&D for the American people.

VALUING THE MARINE ECONOMY

NOAA and the Bureau of Economic Analysis jointly released an update to the official U.S. Marine Economy Satellite Account (MESA), which measures how dependent our nation's economy is on resources stemming from the ocean, coasts, and major water bodies such as the Great Lakes. The results show the marine economy accounted for 1.7% or $361.4 billion of current-dollar U.S. gross domestic product (GDP) in 2020 and 1.7%, or $610.3 billion, in total sales. This release shows the impact of the 2020 economic downturn for the first time - due to COVID-19, real (inflation-adjusted) GDP for the marine economy decreased 5.8% from 2019 to 2020. The account captures information from 2014 to 2020 and improves estimations from the previous modeling by using time-series input data, refining estimates for the construction and utilities sectors, and expanding the scope of activities in the professional and technical services sector. NOAA's products and services are key for the sustainable growth of the US marine economy, from fisheries management to providing information for shipping and ports. The MESA also accounts for new and upcoming sectors indicating potential growth in demand for NOAA's products and services.

GEOXO ECONOMIC ASSESSMENT

In 2021, NOAA's Performance, Risk, and Social Science Office (PRSSO) initiated a study of the potential benefits to society of NOAA's next generation geostationary satellite program (GeoXO). The current GeoXO plan includes instruments that will provide data needed to improve a wide range of NOAA's ocean, weather, climate, and air quality products. NOAA analyzed and described the full scope of beneficial societal outcomes and the processes by which improved observations lead to improved information and, in turn, societal outcomes. The team identified 175 use cases where GeoXO data are expected to provide benefits that will be realized by protecting life, increasing safety, increasing economic productivity, and reducing economic losses. This work consists of nine economic studies that assess all or part of the benefits of 44 of the 175 use cases, comparing the sum of those benefits to the full cost of GeoXO. Lower bound estimates of benefits range between 314% to 452% of GeoXO costs. Upper bound estimates range from 380% to 547% of costs which indicates that the sum of economic benefits from GeoXO far exceed the full cost of GeoXO.

SPACE WEATHER VALUE ASSESSMENT

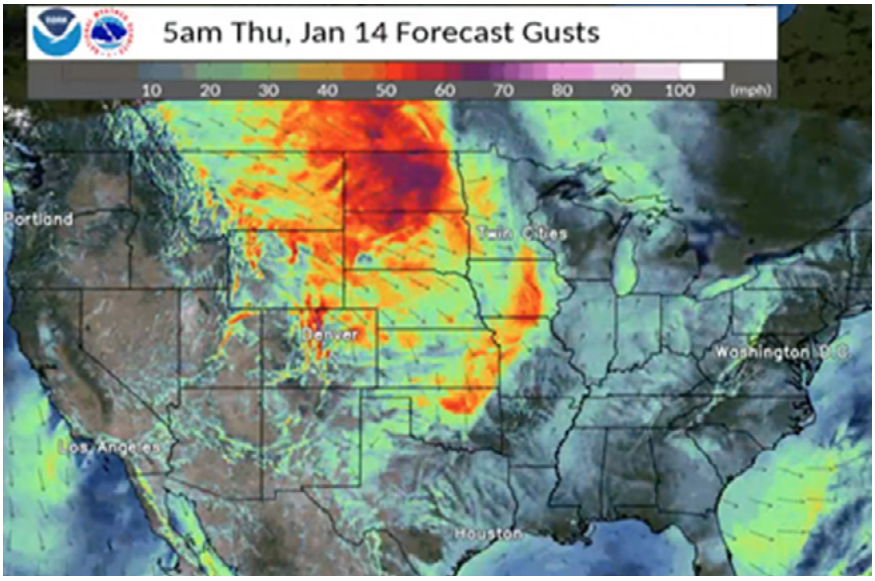
NOAA maintains the capability to monitor a variety of Space Weather phenomena such as solar flares, coronal mass ejections, high-speed solar wind, solar energetic particles, and magnetic field variations. Solar weather events can affect a variety of important industries including, but not limited to, aviation, electric power grid, satellite operations, aviation operations, the global navigation satellite system, and related emergency services. NOAA is formulating the next generation of space weather monitoring and infrastructure. As part of the formulation process, PRSSO in coordination with NOAA NWS, are developing a study to assess the potential benefits of these new space weather observations. The Space Weather benefit study will help inform the final configuration of NOAA's next generation suite of space weather sensors and will also support budget prosecution by Office of Management and Budget and Congressional staff.

A wind turbine at the National Wind Technology Center in Colorado. Photo credit: NOAA/Cooperative Institute for Research in Environmental Sciences

NOAA WIND FORECASTS RESULT IN $150 MILLION IN ENERGY SAVINGS EVERY YEAR

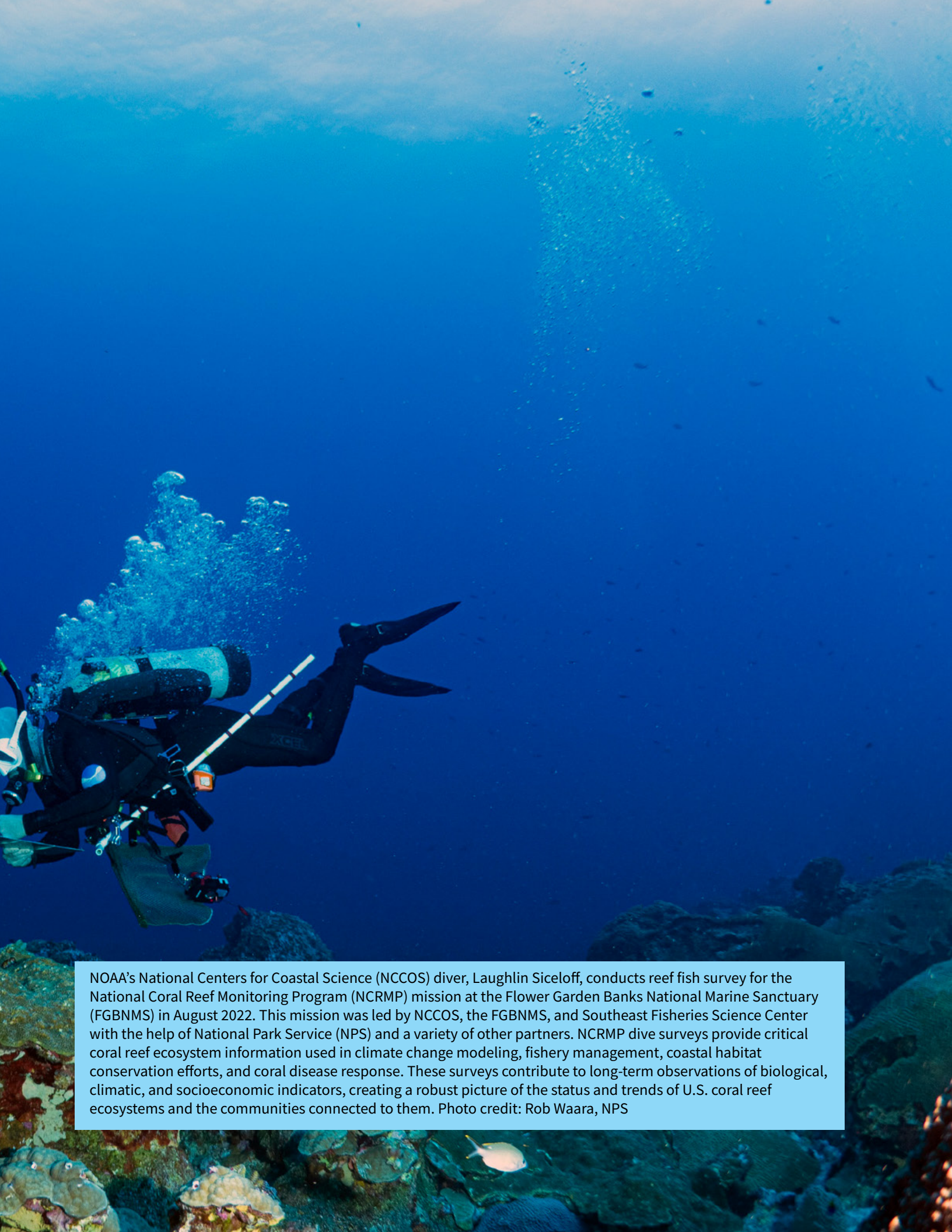
As electricity providers increasingly add renewable energy to their portfolio, a new study shows that more accurate wind forecasts generated by a NOAA weather model is saving the utilities, and hence the consumers, a lot of money. To quantify this economic benefit of more accurate wind speed forecasts, NOAA Research compared the older and newer versions of NOAA's High Resolution Rapid Refresh weather model, which provides 48 hour forecasts with updates every hour for every part of the United States. Utilities need accurate wind forecasts in order to gauge electricity production and to determine when they need to generate or purchase energy from other sources when winds abate. Poor forecasts can cost a utility a lot of money, and those costs are then passed on to consumers while accurate forecasts result in substantial savings. However, it is not always clear what those savings are. The

High Resolution Rapid Refresh model generates predictions of wind speed and wind direction at different levels of the atmosphere, including at the height of wind turbines, which energy and utility companies can use to gauge how much energy their turbines will produce. NOAA Research and Colorado State University research team calculated that increasingly accurate weather forecasts over the last decade have netted consumers over $150 million per year in energy savings.



This map depicts a visualization of the High Resolution Rapid Refresh wind forecast for January 14, 2022. A new study by NOAA and Colorado State University quantifies for the first time the economic value of accurate wind forecasts to electricity generation. Image credit: NOAA Global Systems Laboratory

SCIENCE HIGHLIGHTS



NOAA's National Centers for Coastal Science (NCCOS) diver, Laughlin Siceloff, conducts reef fish survey for the National Coral Reef Monitoring Program (NCRMP) mission at the Flower Garden Banks National Marine Sanctuary (FGBNMS) in August 2022. This mission was led by NCCOS, the FGBNMS, and Southeast Fisheries Science Center with the help of National Park Service (NPS) and a variety of other partners. NCRMP dive surveys provide critical coral reef ecosystem information used in climate change modeling, fishery management, coastal habitat conservation efforts, and coral disease response. These surveys contribute to long-term observations of biological, climatic, and socioeconomic indicators, creating a robust picture of the status and trends of U.S. coral reef ecosystems and the communities connected to them. Photo credit: Rob Waara, NPS

1. A ROBUST AND EFFECTIVE RESEARCH AND DEVELOPMENT ENTERPRISE

NOAA R&D requires observations, models, and applications from emerging fields, such as artificial intelligence, for effective and efficient use of economic, social science, physical, and ecological data. In 2022, building a robust and effective NOAA R&D enterprise included accomplishments in the following categories: Innovation in Technology, Observations and Data, New Tools Supporting Environmental Prediction, and Transitioning R&D.

NOAA models analyze and predict the state of the ocean, atmosphere, cryosphere, land, and biosphere, develop our knowledge of system dynamics, and inform decision making for mitigating hazards and optimizing stewardship. However, complex interactions between physical, biogeochemical, and behavioral phenomena make it difficult to accurately simulate and forecast future events. NOAA's R&D aims to improve predictions and representation of NOAA's models through new techniques, employing new or improved parameters, nesting and coupling Earth system modeling and data assimilation, and transitioning R&D to operations and applications.

1.A INNOVATION IN TECHNOLOGY, OBSERVATIONS AND DATA

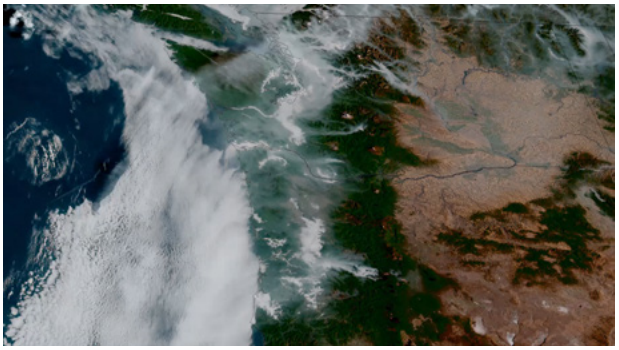
NEW NOAA PARTNERSHIP WITH VIKING EXPEDITIONS EMBRACES TRANSFORMATIVE ADVANCES IN SCIENCE AND TECHNOLOGY

In May, 2022, NOAA Research joined the Viking *Octantis*® for its inaugural cruise season in the Great Lakes. As part of a cooperative agreement with Viking Expeditions, NOAA scientists are collaborating with the Viking Scientific Advisory Group and other institutions to conduct research on changes in the region's weather, climate, ecosystems, and maritime heritage resources. Teams of scientists working on a variety of studies are using the state-of-the-art Viking ships as research vessels of opportunity. Each ship is equipped with a FerryBox, which is a set of instruments continuously collecting and displaying data on water quality, oxygen content, plankton composition, and more. The continuous, simultaneous collection of these vital data in the Great Lakes along repetitive ship routes allows scientists to monitor changes on scales of season, years, and even decades. Viking's expedition ships have also been designated official NOAA NWS weather balloon stations, from which regular launches are undertaken. NOAA's work is being shared and promoted by researchers on board by providing tours and seminars for guests and other staff, as well as working side-by-side with other scientists on research activities. By partnering with Viking Expedition cruises, NOAA Research increases its access to the Great Lakes to stay informed of threats and issues across the lakes - including the impacts of climate change and acidification - while also drawing global attention to NOAA's research, laboratories, and programs serving and protecting the region.

The Viking *Octantis®* sits moored in NOAA's Thunder Bay National Marine Sanctuary, Lake Huron. Many of the nearly 400 passengers are tendered into downtown Alpena where they disembark at the sanctuary's Great Lakes Maritime Heritage Center and enjoy guided tours of interactive exhibits and historic shipwrecks aboard a glass bottom boat. Photo credit: NOAA, Thunder Bay National Marine Sanctuary

NOAA USES GEOSTATIONARY SATELLITE DATA TO ENHANCE OBSERVATION QUALITY AND COVERAGE OF SPARSELY MONITORED AREAS

NOAA and NOAA Cooperative Institute scientists are improving satellite observational capabilities using Geostationary Operational Environmental Satellite (GOES) data, partner satellite data, and machine learning to increase efficiency and coverage of observations that are typically gathered from fixed Earth locations or satellites in low Earth orbit. Estimates of radar, passive microwave imagery, and nighttime visible imagery using the high resolution GOES, help with a variety of challenges associated with low-earth-orbit observations by providing consistently calibrated and constant-resolution estimates every 10-minutes. The "GOES Radar Estimation via Machine Learning to Inform Numerical weather prediction", or GREMLIN, is being used in the High-Resolution Rapid Refresh model (a forecast model that provides detailed hourly updates of rapidly evolving weather), and the GOES-based ProxyVis is now available to forecasters at the National Hurricane Center. Machine-learning derived estimates are also showing promise for tropical cyclone applications. Additionally, GOES-based synthetic passive microwave imagery is now able to convey radar-like images of cloud depth and organization in real time. Each of these capabilities improve observational availability for forecasters, particularly in oceanic and otherwise observationally sparse regions.



This GOES-18 GeoColor satellite image showed valley fog fading as smoke persisted along the Pacific Northwest coast on October 17, 2022. NOAA satellites provide critical data used in models and forecasts and potentially life-saving information in a dynamic fire environment. Image credit: NOAA NESDIS

The Hunga Tonga - Hunga Ha'apai volcano erupted on January 15, 2022. Photo credit: Tonga Geological Services

OBSERVING A UNIQUE TSUNAMI EVENT CAUSED BY THE TONGA VOLCANO ERUPTION MAY LEAD TO NEW UNDERSTANDING OF THESE RARE EVENTS

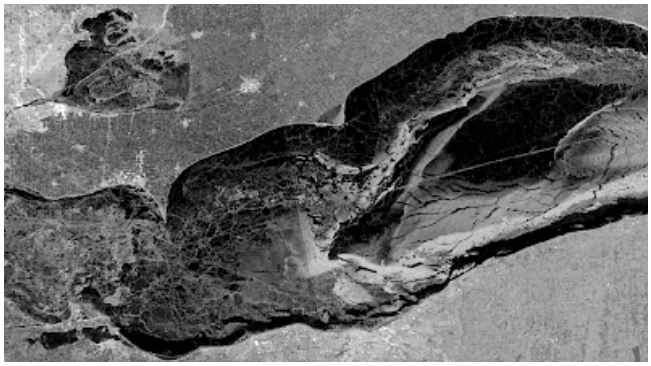
On January 15, 2022, the Hunga Tonga-Hunga Ha'apai volcano erupted, generating a tsunami and triggering tsunami alerts around the world. The pressure wave from the volcanic eruption explosion traveled about 312 meters/second (697 miles per hour), and circled the Earth three times before dissipating. About 5% of tsunamis are generated from volcanic activity, making this a rare event captured by NOAA's observing instruments. The Deep-ocean Assessment and Reporting of Tsunamis (DART) buoy system measured the tsunami wave amplitudes and the atmospheric pressure wave associated with a shock-wave emanating from the volcano explosion. Two NOAA-Saildrone uncrewed surface vehicles captured crucial information such as tsunami wave amplitudes and atmospheric pressure measurements associated with the remote volcanic activity in an observationally-sparse region of the ocean. These data can be used to improve tsunami models and have assisted tsunami researchers to better understand this rare event.

DART buoys detect tsunami waves and transmit real-time sea level information measurements back to the Tsunami Warning Centers. Credit: NOAA

Map of the tropical Pacific showing the positions of DART buoys operated by NOAA and international partners as well as saildrone 1065 and 1066 relative to the Hunga Ha'apai Volcano located in the Pacific island nation of Tonga, which is an archipelago consisting of more than 170 islands. Image credit: NOAA Research's Pacific Marine Environmental Laboratory

OPERATIONAL ACQUISITION OF RADARSAT CONSTELLATION MISSION

The RadarSat Constellation Mission is a constellation of three synthetic aperture radar satellites operated by the Canadian Space Agency. The all-weather, high resolution capacities of synthetic aperture radar provide valuable information for a variety of NOAA's missions including monitoring ice, floods, winds, tropical cyclones, waves, vessel location, and oil spills. NOAA became an international partner with the Canadian Space Agency in March 2021. This partnership allowed NOAA to access approximately 400-600 images per day over North America and the Arctic without incurring additional costs. The addition of the RadarSat Constellation Mission has become a critical data source for ice monitoring products. The U.S. National Ice Center and the NOAA NWS Alaskan Sea Ice Program use these data to generate their analyses and forecasts, which are utilized for wind forecasting by the NOAA NWS Alaska Region, the Great Lakes NOAA NWS forecast offices, the U.S. Coast Guard, the Ocean Prediction Center, the Joint Typhoon Warning Center, and National Hurricane Center. The RadarSat Constellation Mission collections of flooding conditions near the U.S./Canadian borders have been important to monitoring floods by the National Water Center and NOAA NWS Regional Forecast Offices in the Red River of the North, Dakotas, Alaska, and Washington State. NOAA NESDIS has worked to ensure optimal production and delivery for the RadarSat Constellation Mission products and imagery. The RadarSat Constellation Mission is now fully integrated into NOAA NESDIS products and has transitioned into operations.



RadarSat Constellation Mission imagery of Lake Erie ice coverage on January 31, 2022. The RadarSat Constellation Mission has become a valuable data source for ice monitoring products. Image credit: NOAA NESDIS

NEW MULTI-CONSTELLATION GLOBAL NAVIGATION SATELLITE SYSTEM POSITIONING SOFTWARE YIELDS IMPROVED POSITIONING SOLUTIONS

Constellations of Earth-orbiting satellites from different nations around the world make up the Global Navigation Satellite System (GNSS), broadcasting their locations in space and time, providing critical information about positioning, navigation, and timing. The NOAA NOS National Geodetic Survey has developed the new Multi-GNSS Program for the Adjustment of GPS Ephemerides (M-PAGES) that can now process data from any dual frequency satellite in the GNSS, compared to the previous PAGES system, limited to only Global Positioning Systems or "GPS" data. These data are used in a variety of ways ranging from smartphone directions, to safety of aviation operations, navigation of large ships into port, timing of financial transactions, precision agriculture, and emergency responses. Full GNSS data processing capabilities enable access to more satellites that will provide higher quality information to users. M-PAGES will soon be integrated into many public-facing products and services provided by NOAA NOS such as the Online Positioning User Service, orbit production for contribution to the International Global Navigation Satellite System Service, and coordinate determination for the NOAA CORS Network.

1.B NEW TOOLS SUPPORTING ENVIRONMENTAL PREDICTION

ARTIFICIAL INTELLIGENCE SPEEDS DELIVERY OF INFORMATION CRITICAL FOR WHALE CONSERVATION IN ALASKA

Alaska is one of the most important feeding grounds for whales from around the Pacific Ocean. One of the best ways to understand whales is to listen to their calls. NOAA Fisheries in Alaska developed a new artificial intelligence program, Infrastructure for Noise and Soundscape Tolerant Investigation of Nonspecific Call Types, or INSTINCT, which is helping scientists study whales by detecting and identifying their calls from underwater acoustic recordings. Automating this analysis means data critical for whale conservation gets to managers years—sometimes decades—faster. This timely delivery is more important now than ever as climate change is rapidly transforming ecosystems. Although INSTINCT was developed for Alaska, it is adaptable for use across all oceans and is open to the public. This work will be particularly important for collecting much needed information on the endangered North Pacific right whale. With only 30 of these whales remaining in the eastern North Pacific, understanding habitat usage, especially with a changing climate, is critical for protecting them.

North Pacific right whale. Photo credit: NOAA Fisheries

A NEW APPROACH TO APPROXIMATE WAVE HEIGHT FROM ACOUSTIC TIDE GAUGES SUPPORTS IMPROVED FORECASTS AND BETTER UNDERSTANDING OF COASTAL FLOODING HAZARDS

A new method to approximate wave height from acoustic tide gauges was developed and can now be used to improve forecast models and better understand coastal flooding hazards. NOAA NOS utilized existing NOAA tide gauge infrastructure to derive a proxy for wave height at three coastal ocean sites: Duck, NC, Corpus Christi, TX, and Lake Worth, FL. Decades of data representing wave height were used to investigate climatological and seasonal trends providing new insight into the influence of waves and wave driven processes. Researchers and resource managers can use this critical information to better understand inundation and erosion, verify the accuracy of coastal model predictions, and ensure navigational safety for the maritime community. This valuable knowledge supports safer and more resilient coastal communities that play an important role in the New Blue Economy.

NOAA DEBUTS NEXT GENERATION WATER RESOURCES MODELING FRAMEWORK TO ADVANCE WATER PREDICTION CAPABILITIES

NOAA NWS successfully demonstrated the Next Generation Water Resources Modeling Framework (Next Gen), a powerful new capability that will transform hydrologic and water resources prediction at all time scales. For the first time ever, the framework enables different hydrologic models in different portions of a simulated geographic domain to run simultaneously, all on a common channel network. This framework paves the way for enhanced decision support using more detailed geospatial water information nationwide. Next Gen leverages an open-source, interoperable environment that promotes innovation across a wide range of hydrologic, hydraulic, coastal, and water quality sectors to develop tools to address water resources challenges using a common framework. Next Gen will unlock an entirely new approach for agency collaboration across the water enterprise supporting NOAA's development of the unified forecast system, accelerating the research to operations cycle for water resource modeling, and yielding rapid increases in prediction skill.

SIX WAY GLOBAL COUPLED UNIFIED FORECAST SYSTEM -- A FIRST FOR NOAA/NOAA NWS

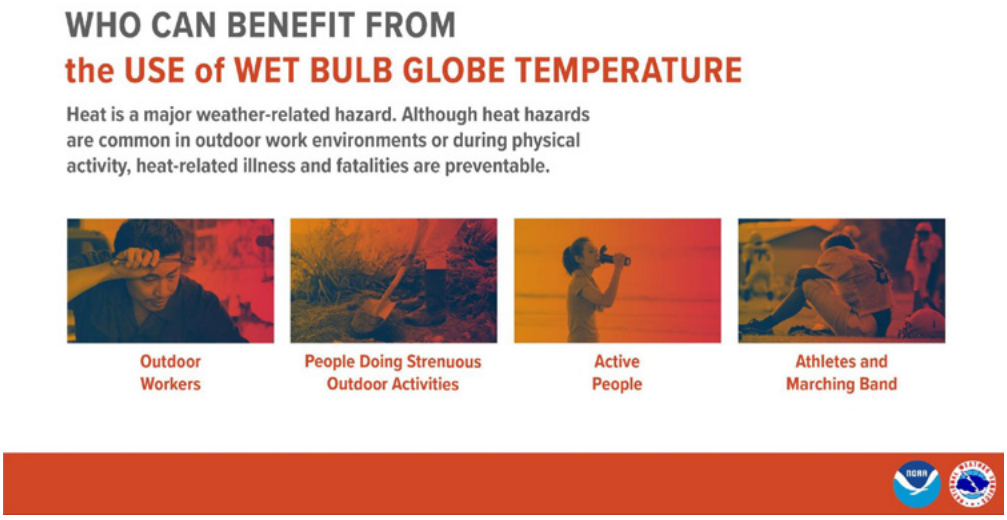
NOAA NWS has developed a global forecast model focused on predicting weather from two weeks to two months (seasonal to sub-seasonal) that includes the atmosphere, ocean, sea ice, waves, land, and aerosols (a six-way coupled model) utilizing the Unified Forecast System (UFS), a community-based, comprehensive Earth modeling framework. In a series of preliminary experiments, all model prototypes demonstrated improved forecast skill overall relative to the current seasonal operational systems at NOAA NWS. The new model extends the horizon for useful forecasts by approximately four to seven days compared to NOAA NWS operational Climate Forecast System. The forecast skill exhibited by these prototypes was found to be superior for multiple measures (air temperatures, sea surface temperatures, precipitation, etc.) when compared to existing operational results at weather-to-sub-seasonal scales. This new global forecast model will potentially enable NOAA NWS to provide improved future sub-seasonal to seasonal predictions for water resources including flood and drought; storm severity and frequency; hurricane intensity and frequency;

marine heatwaves; extreme heat or cold wave; extreme winds; fire severity and danger; and other environmental factors, on a national and global scale. Key decision makers such as water managers, emergency managers, energy producers, farmers, military leaders and other sectors will benefit from being able to make informed decisions which have significant impact on the U.S. gross domestic product, economic vitality, and national security.

1.C TRANSITIONING R&D

NOAA and the Nation extract benefits from NOAA's research when the research results transition into use. Consequently, R&D transitions are essential to addressing NOAA's missions. Examples of NOAA transitions include operational weather forecasting models, integration of tools for improving observation of tropical cyclones, and uncrewed systems and/or sensor payloads for data collection for a wide variety of uses, such as harmful algal blooms and marine mammal monitoring. NOAA characterizes and tracks the maturity of its scientific projects through readiness levels for research, development, demonstration, and deployment. Transition plans help to guide R&D maturation and transition of R&D to its planned end use, ensuring agreement between researchers and the planned adopters. NOAA transitioned products and services, whether internally to NOAA or into the commercial sector, represent tangible scientific outcomes that serve NOAA's mission and benefit the American people.

In fiscal year 2022, NOAA transitioned 70 research projects into operations, applications, commercialization. Some critical transition examples include:



NOAA NWS WET BULB GLOBE TEMPERATURE FORECASTS TRANSITION TO OPERATIONAL

The Wet Bulb Globe Temperature (WBGT) is designed for active, outdoor populations (such as outdoor workers) as a measure of heat stress and is currently used by several NOAA NWS partners such as collegiate and high school athletic departments, marathon and triathlon

organizers, and the military. After two years as an experimental weather parameter, the WBGT forecast is operational as of June 1, 2022. The WBGT forecast utilizes local forecast temperature, humidity, wind, and sky cover along with sun-angle. For the contiguous U.S. the WBGT forecasts are accessible hourly up to 36 hours, every three hours up to three days, and every six hours up to seven days in advance. WBGT forecasts for Hawaii, Guam, and Puerto Rico are available every three hours up to three days and every six hours up to seven days in advance. The WBGT forecast allows NOAA NWS to meet decision support services needs for partners that use this particular heat tool and ultimately will help protect people from heat stress.

THE WORLD'S HIGHEST RESOLUTION GLOBAL STORM SURGE MODEL BECOMES OPERATIONAL

A new three-dimensional component, enhancing the Surge and Tide Operational Forecast System (STOFS) with valuable information about water conditions in the Atlantic Ocean, became ready for use in 2022. The STOFS is the world's highest resolution global ocean modeling system that provides forecast guidance for combined water levels caused by storm surge and tides. STOFS is developed by NOAA NOS in collaboration with academic partners and NOAA NWS. The new three-dimensional STOFS component for the Atlantic Ocean (including Gulf of Mexico and Caribbean) provides water levels, currents, salinity and temperature and is now operational. STOFS-3D-Atlantic uses input from the National Water Model to include the effects of inland hydrology and extreme precipitation on coastal storm surge and provides critical forecast information for coastal resilience and navigation safety.

2. REDUCING SOCIETAL IMPACTS FROM HAZARDOUS WEATHER

This GOES-East GeoColor satellite image taken at 9:56 a.m. EDT on Tuesday, September 27, 2022, and shows Hurricane Ian passing over western Cuba. Image credit: NOAA

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 related to hazardous weather for 2022 have been divided into three groups: observations, models and forecasts, and communications and engagement.

OBSERVATIONS

NOAA observes environmental conditions through the use of radar, satellites, buoys, uncrewed systems, aircraft, weather balloons, and other instruments. These observations

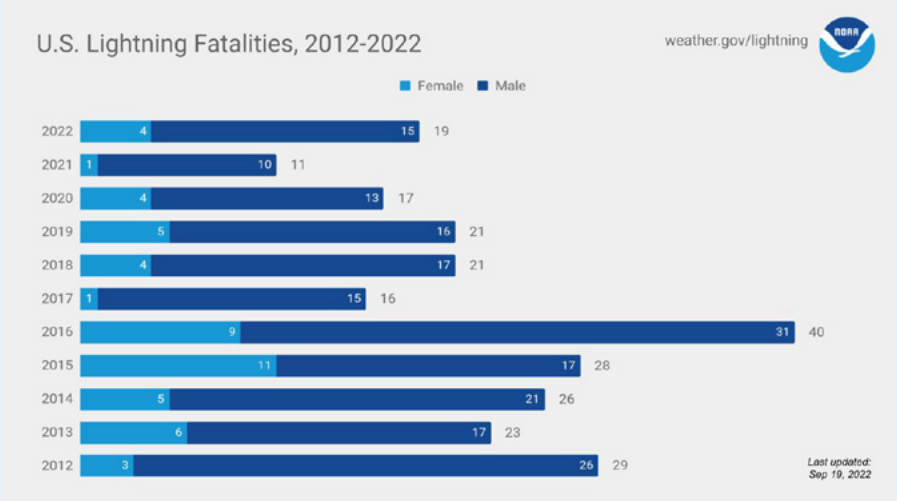
undergo quality control checks and are used as initial conditions for constraining models, among other uses. Past hazardous weather events also serve to inform future forecasts and decision making.

MODELS AND FORECASTS

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. 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.

COMMUNICATIONS AND ENGAGEMENT

NOAA's communication products assist a wide range of users understand the risks when dealing with severe weather phenomena. 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.



This image depicts the number of U.S. Lightning Fatalities from 2012-2022, by gender. There has been an overall decrease in fatalities in general, with a record low number of lightning fatalities in 2021. Credit: NOAA NWS

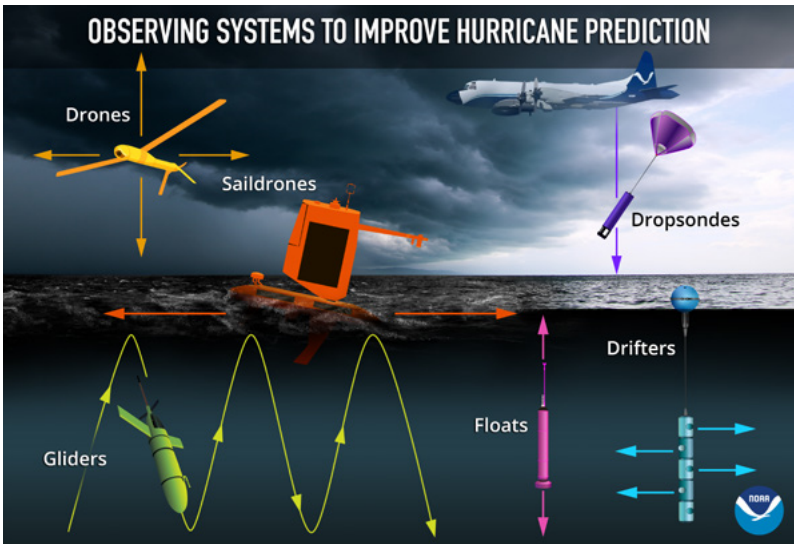
A DECADE OF BUILDING A WEATHER-READY NATION

Weather-Ready Nation (WRN) was established as a NOAA strategic goal in 2011 after a series of extreme weather events. In the decade following, NOAA NWS and many other parts of NOAA have made great progress toward building communities that are ready, responsive, and resilient to extreme weather, water, and climate events. Better forecasts, more effective communication, impact-based decision support services, and a stronger commitment to partners are just a few areas of improvements that have resulted in better societal outcomes. In 2021, there were record low lightning fatalities, several significant tornado events with no deaths, over 93 million Twitter accounts engaged with SafePlaceSelfie Day, and the number of WRN ambassador organizations surpassed 12,000. From 2018-2021, even with 15 landfalling hurricanes, there have been only 8 total storm surge deaths. Storm surge improvements such as operational Storm Surge Warnings, inundation mapping, and more effective evacuation messaging have all contributed to this success. As WRN enters its second decade, efforts will shift toward the community-scale, and to engage underserved and vulnerable communities.

2.A OBSERVATIONS

MANUAL RADIOSONDE OBSERVING SYSTEM DEPLOYMENT ACROSS THE NOAA NWS UPPER AIR NETWORK

Observations of the upper atmosphere allow weather forecasters to evaluate the vertical distribution of temperature, humidity and wind, which is critical to forecasting severe storms and tornadoes. In order to enhance NOAA weather forecasts, NOAA NWS is migrating the entire Upper Air observation system from the legacy 1680 MHz frequency to 403 MHz frequency. Two 403 MHz Manual Radiosonde Observing Systems (MROS) were deployed to accomplish this task. Radiosondes are atmospheric sensors that provide upper-air data that are essential for weather forecasts and research. MROS provides enhancements to the Upper Air observations such as measurements every second. In 2022, NOAA NWS has installed 100% of the new MROS system. This deployment profile and success rate has never been observed before within the Upper Air program, and was achieved despite numerous logistical challenges and COVID-19 related disruptions. Despite these hurdles, NOAA NWS was able to meet mission needs and without this effort, critical Upper Air operations would not have continued. The continuation of Upper Air data collection is critical for our forecasting systems, as they have shown to improve forecasts, which are essential for NOAA's life-saving mission.



Schematic diagram illustrating 2022 hurricane observations by uncrewed underwater, surface, and aerial vehicles in conjunction with aircraft observations. Credit: Sarah Battle

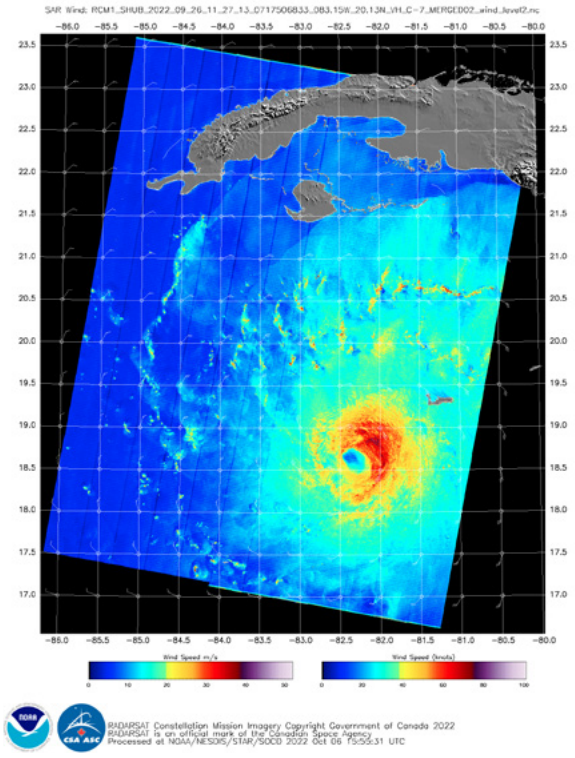
CRITICAL NEW OCEAN AND ATMOSPHERE OBSERVATIONS ADVANCE OUR UNDERSTANDING OF HURRICANE STRUCTURE AND SUPPORT IMPROVED FORECASTING

Improving the accuracy of NOAA's operational hurricane forecasts requires more complete real-time knowledge of atmospheric and oceanic conditions and more realistic representation of key physical processes in hurricane forecast models. During the 2022 hurricane season, NOAA collected critical new observations during major hurricanes using seven uncrewed surface vehicles (Saildrones), underwater gliders with uncrewed aerial drones, and aircraft. Saildrone

observations covered areas where the chances of hurricane occurrence are high between August 1 - October 30, 2022 and captured observations during two major hurricanes: Fiona and Ian. Saildrones acquired critical measurements, such as wind speed and wave height, through the center of Hurricane Fiona's eye while a NOAA underwater glider collected data seven miles northeast of it. In addition to measurements collected by uncrewed systems, NOAA Research hurricane hunters (the NOAA P-3 aircraft) took to the sky, completing a total of 72 research and operational missions on Hurricane Hunter aircraft. In late August, hurricane researchers spent 12 consecutive days conducting 20 research missions into the storm system which was later named Hurricane Earl, marking the longest series of missions into a single tropical system ever conducted by NOAA. The hurricane hunters carry the Imaging Wind and Rain Profiler, an airborne scanning Doppler radar system that measures wind speed and direction in the presence of precipitation just below the aircraft down to just above the ocean surface. These observations, during the 2022 hurricane season, provided NOAA with critical new information about the structure of the inner core of hurricanes and helped increase our understanding of the atmosphere below a hurricane at the air-sea interface.

DETAILED WIND OBSERVATIONS AND CHARACTERIZATION IMPROVES TROPICAL CYCLONE FORECASTING CAPACITIES

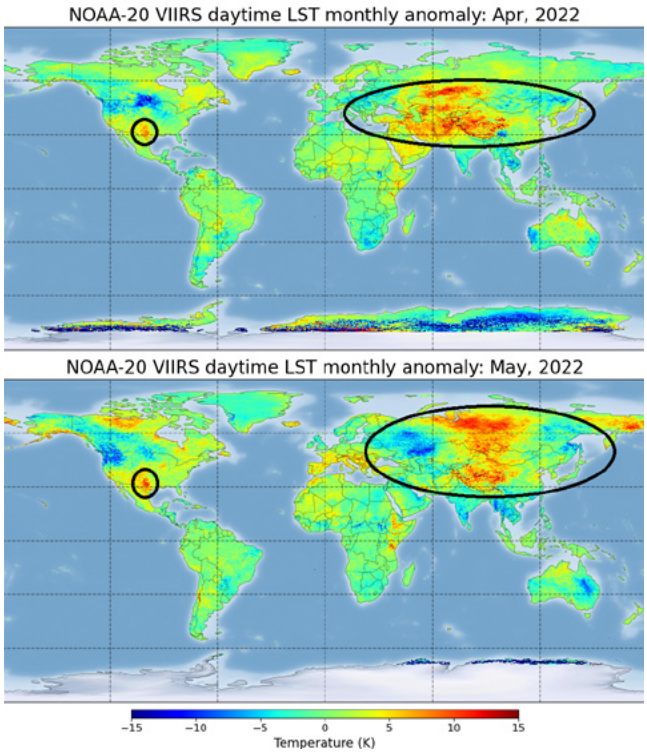
NOAA NESDIS is generating detailed wind speed estimates using synthetic aperture radar imagery. The synthetic aperture radar is an active sensor that collects data by making its own energy, remotely sending a signal to Earth, and then recording the amount of energy reflected back after interacting with Earth. Synthetic aperture radar data are currently used to generate precise wind speed estimates, but have been limited to a range of less than 67 miles per hour. Data from the 2019 hurricane season were used to refine the estimates of wind speeds from tropical cyclones. The synthetic aperture radar wind data are able to provide wind speeds right up to coastlines and provide more detailed storm structure information not previously available. Tropical-storm force wind products include wind speed imagery, radial winds, wind speed threshold imagery, mean winds, and data estimates for integration into the Automated Tropical Forecast System. NOAA NESDIS provides these products to NOAA's National Hurricane Center, the U.S. Military Joint Typhoon Warning Center, and the U.S. Central Pacific Hurricane Center.



This shows a map of ocean surface wind speed over Hurricane Ian on September 26, 2022 at 6:27am ET, from a synthetic aperture radar (SAR) image taken by a satellite from the Canadian Space Agency's RadarSat Constellation Mission. Wind speed maps like this accurately locate the eye of the hurricane and provide important information about the wind field intensity needed by forecasters. Credit: Wind speed map by NOAA's Center for Satellite Application and Research, Water Surface Conditions Science Team. SAR image provided by the Canadian Space Agency's Radarsat Constellation Mission.

MONITORING LAND SURFACE TEMPERATURE ANOMALIES AIDS IN DECISION MAKING DURING EXTREME WEATHER EVENTS

The frequency and intensity of extreme weather events have rapidly increased over the past few decades, posing serious threats to lives and infrastructure. A comprehensive system was developed to monitor land surface temperature anomalies through satellite observations and address concerns from the public. In general, land surface temperature anomalies can be driven by a variety of factors from large-scale climate events (e.g., El Niño/La Niña) to local hazard impact (e.g., wildfire). These anomalies are often a response to frequency and intensity of extreme weather events. A series of monthly summaries provide focus and help detection of corresponding strong weather anomalies and high-impact environmental events. Recent studies included multiple hazardous weather events, encompassing heatwaves, wildfires, winter storms, strong cold events, drought, and their potential impacts to the environment. The new land surface temperature anomaly monitoring system has improved understanding of weather anomaly status, raised people's awareness of increasing risks due to changes in climate, and helps decision making.



Monthly land surface temperature (LST) anomalies for April (upper) and May (lower), 2022. The "low-high-low" pattern across Eurasia moved eastward and expanded to the north; a significant heat event in Texas lasted two months and as a result of a significant heatwave around May 20th, warm anomalies were observed throughout the east coast of the US. Image credit: NOAA

A NEW OBSERVATIONAL STRATEGY TO IMPROVE LAKE-EFFECT SNOW SITUATIONAL AWARENESS

Winter weather around the Great Lakes is strongly influenced by the Lakes themselves, most notably through the production of lake-effect snow caused by cold air moving across the relatively warmer lakes. NOAA-supported surface snow microphysics and profiling radar observations from the Marquette, MI, NOAA NWS Weather Forecast Office have contributed valuable data which have helped build knowledge about the variability in the micro scale physics of snow associated with different snowfall regimes in the Great Lakes region. The ground-based observations allow for the development of better forecasting guidance on snow-to-liquid ratios and total snowfall accumulations associated with different snowfall regimes and environmental conditions. These observations are directly translated into a new snowfall rate estimation product derived by combining Geostationary Operational Environmental Satellite and Next Generation Weather Radar observations, helping to fill radar observational gaps and improve lake effect snow fall awareness and decision making in the Great Lakes region.

Installing the Micro Rain Radar (profiling radar) at the Marquette, MI National Weather Service Weather Forecast Office. Photo credit: NOAA NWS

NOAA SATELLITE ESTIMATES OF PARTICULATE MATTER EXPAND AIR QUALITY OBSERVATIONS TO MILLIONS OF PEOPLE IN RURAL AREAS

NOAA and the Environmental Protection Agency (EPA) have partnered to update the EPA's air quality information portal (AirNow) by importing NOAA's hourly surface particulate matter ($PM_{2.5}$) estimates from Geostationary Operational Environmental Satellite Advanced Baseline Imager (ABI) aerosol optical depth product. AirNow is accessed by more than a million users daily and the inclusion of NOAA satellite based estimates of hourly $PM_{2.5}$ levels will fill in gaps between air quality monitors that are clustered in urban areas and increase access to air quality observations in rural areas exposed to harmful pollutants. The five-minute

ABI data are composited into hourly maps, which minimizes gaps from clouds and provides optimal coverage. After AirNow upgrades in 2023, these hourly maps of $PM_{2.5}$, used by air quality forecasters, firefighters, and others, will be displayed as a rolling 3-hour average product on the AirNow portal, a user-friendly site where the public can view air quality information at the local and national scale.

2.B MODELS AND FORECASTS

NOAA NWS IMPROVES NEARSHORE WAVE PREDICTION FORECASTING

Multiple coexisting wave systems are common at any point in the ocean, each containing their own unique height, period, and direction. Details on each of these wave systems provide valuable information for marine customers. Currently, NOAA NWS Weather Forecast Offices provide the Coastal Waters Forecast as the wave height (highest third of the waves) or as wind wave and swell. With the use of the updated Nearshore Wave Prediction System, NOAA NWS can now provide height, period, and direction of the significant wave systems that make up the significant wave height. Providing greater wave detail with more clarity for marine users such as ship pilots, tug operators, and recreational boaters will help support planning and safety on the water.

ONLINE AIR-QUALITY FORECAST CAPABILITY

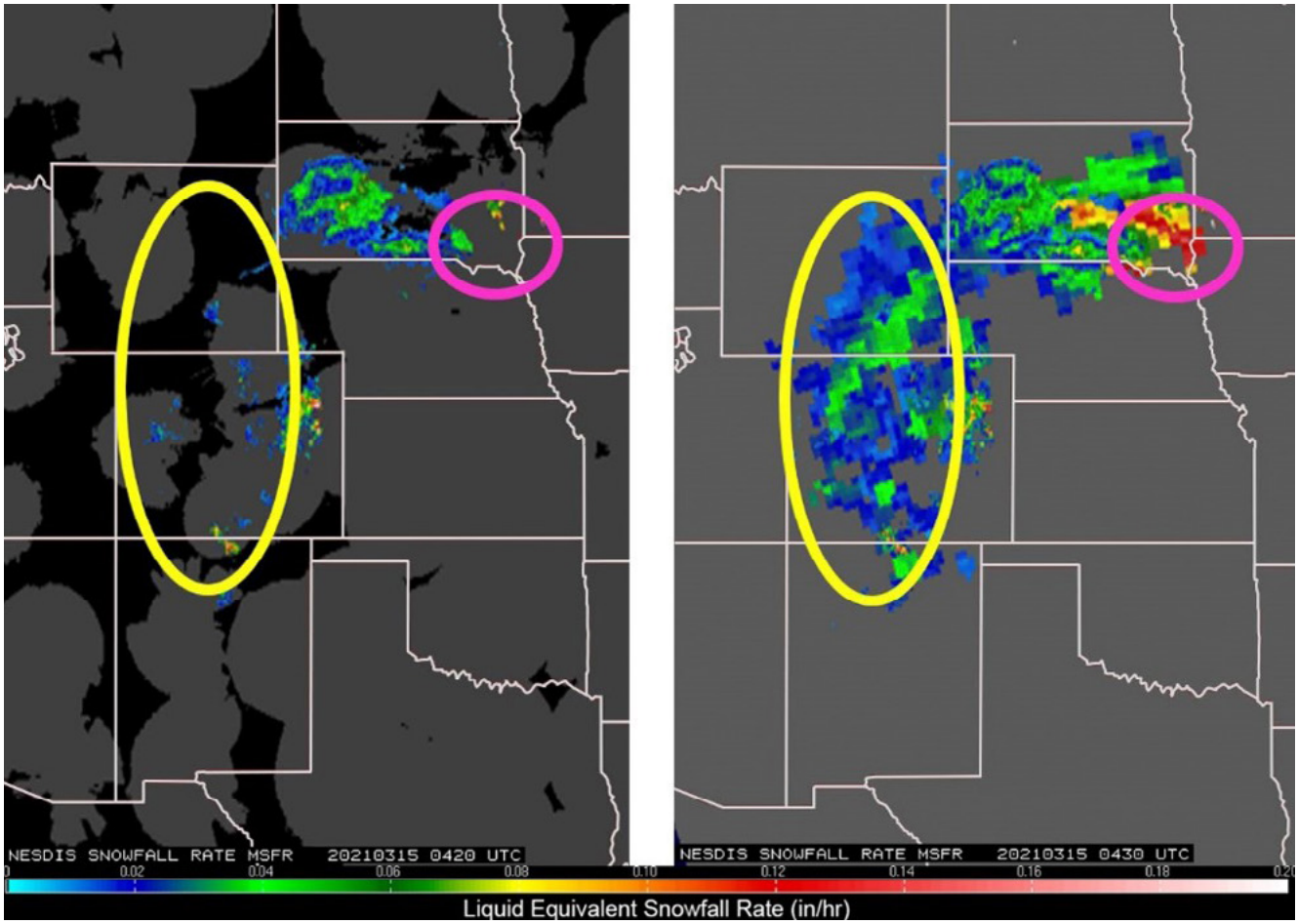
Poor air quality causes over 100,000 deaths annually in the U.S., it exacerbates existing illness in vulnerable populations, and it disproportionately affects underserved communities. Wildfires worsen air quality for local communities and their smoke sometimes covers multiple states from coast to coast. Working with NOAA Research, NOAA NESDIS and universities, NOAA NWS is leading an effort to build a new regional online air quality prediction system that brings together atmosphere and land models. The goal of the project is to improve prediction of the impact of wildfire smoke on air quality. The online system integrates the UFS based atmospheric model with the Community Multiscale Air Quality model. The new system is expected to provide more accurate forecast guidance to local and state air quality forecasters, the general public and other stakeholders. The initial real-time demonstration of this system began in the summer of 2022 and is ongoing.

VOLCANIC ASH ENSEMBLE FORECAST

The accidental release of a hazardous material into the atmosphere can adversely affect the health and lives of the exposed population and emergency responders. The Hybrid Single-Particle Lagrangian Integrated Trajectory, or HYSPLIT, is one of the most widely used models for atmospheric trajectory and dispersion calculations, helping to determine the distance and direction air particles and pollutants will travel. It is also NOAA's operational model for emergency applications such as the simulation of atmospheric plumes from radioactive emissions, chemical releases, smoke originating from wildfires, volcanic ash, and wind-blown dust. One of the key objectives of this project is to assess and communicate the uncertainty in the forecasting of the transport, dispersion, and deposition of materials such as volcanic ashes,

by using simulations generated by HYSPLIT. This new forecast system began operating in December 2022. This would be the first HYSPLIT ensemble dispersion capability to predict and quantify Volcanic Ash plume uncertainty for serving both public and private sectors, especially the aviation industry.

PROVIDING FORECASTERS BETTER SITUATIONAL AWARENESS OF APPROACHING SNOWSTORMS IN RADAR DATA SPARSE REGIONS

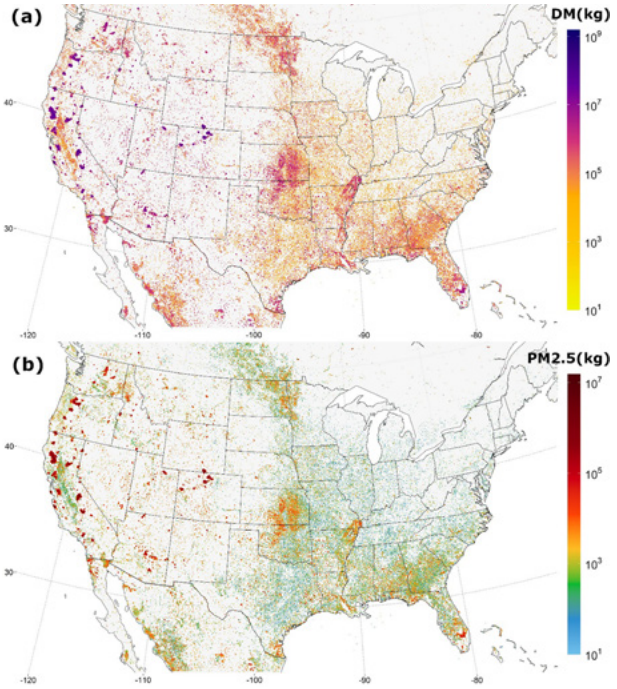


The NOAA NESDIS satellite-radar merged snowfall rate product fills gaps in radar only coverage during a strong winter storm on March 15, 2021. (Yellow - Radar Gap, Pink - Intense Snowfall Gap) Image credit: NOAA NESDIS

Radar is a critical tool for weather forecasting, including forecasting snowfall during winter storms. However, radar coverage gaps are common throughout the country, especially in the western United States and mountainous regions where land can block the radar beam. NOAA currently has a snowfall rate product that is derived from a constellation of polar-orbiting satellites. With an unobstructed view of the Earth, the polar-orbiting satellites provide broad spatial coverage that can help fill in radar gaps. A newly developed satellite and radar merged snowfall rate data product uses the spatial coverage of satellite observations and the rapid update of radar data. Short-term forecasting benefits from how quickly the direct broadcast satellite data are available to forecasters. The satellite-radar merged product is now incorporated into the Advanced Weather Interactive Processing System. Forecasters can use the information to provide weather and social media updates on heavy snowfall.

A NEW SATELLITE EMISSIONS PRODUCT WILL IMPROVE THE ACCURACY OF NATIONAL AMBIENT AIR QUALITY FORECASTS

The current NOAA NWS operational air quality forecast model guidance for ozone, particulate matter ($PM_{2.5}$), and smoke relies on fire detection and the rate at which radiative energy is released from a burning fire, or fire radiative power, from polar-orbiting satellites. These once-a-day updates of fire emissions in air quality forecast models do not capture the important daily variation of fire activity that influences air quality. NOAA NESDIS developed a new algorithm (known as 'RAVE') that blends fire radiative power from both polar-orbiting satellites and geostationary satellites. The algorithm generates emissions of various air quality related trace gasses, smoke aerosols, and greenhouse gasses in real-time that are then used in air quality forecasts. The new emissions product is expected to improve the accuracy of the NOAA NWS National Ambient Air Quality Forecast Capability for ozone and $PM_{2.5}$.



RAVE algorithm estimates of the amount of annual dry mass (DM) burned due to fires between April 2020 and March 2021 is shown in (a). The amount of fine particulate matter ($PM_{2.5}$) released from the fires consuming the dry mass is shown in (b). Image credit: Li, F., X. Zhang, S. Kondragunta, X. Lu, I. Csiszar, and C. C. Schmidt, Hourly biomass burning emissions product from blended geostationary and polar-orbiting satellites for air quality forecasting applications, Remote Sensing of Environment, in press, 2022.

2.C COMMUNICATIONS AND ENGAGEMENT

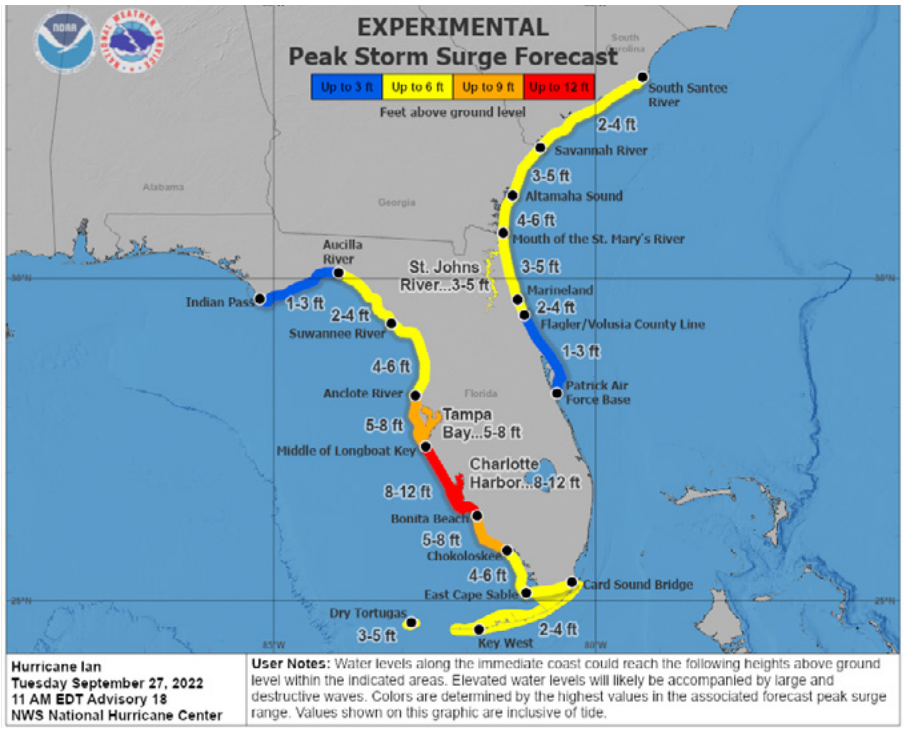
THERE'S A CHANCE OF WHAT? ASSESSING NUMERACY SKILLS OF FORECASTERS, PARTNERS, AND THE PUBLIC

Advancements in weather forecasting have increased the availability of probabilistic weather information, such as weather forecasts, reports, and storm prediction models that are subject to chance, and more importantly, have highlighted a critical need to understand the most effective way to communicate probabilistic information to people. Past research suggests that people want probabilistic information and find it useful for making decisions in the face of uncertainty; however, people are diverse in their abilities to comprehend and use probabilities when making decisions. To increase the equity of forecast information, NOAA Research, in collaboration with NOAA NWS, funded a project to examine how forecasters, emergency managers, and the American public interpret and comprehend probabilistic tropical cyclone information, such as a storm surge flooding map. Using a concept known as numeracy, or one's ability to use and understand numerical information, this study suggests that probability information helps people make decisions in the face of uncertainty. The study also found

that having lower levels of numeracy can impact their risk literacy and decision-making process. By designing forecast products that take into account the diverse numeracy needs of end users, comprehension and response to probabilistic forecasts will be improved.

IMPROVED PEAK STORM SURGE FORECAST GRAPHIC

Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tide. Since May 2020, NOAA NWS has been providing an experimental graphic that depicts the Peak Storm Surge Forecast from the Tropical Cyclone Public Advisory Product when watches or warnings are in effect. The graphic has been modified for the 2022 season to include an updated disclaimer and color coding for the peak storm surge inundation forecast. This improved graphic allows to better communicate storm surge threat to the public, decision makers and officials.



Experimental peak storm surge forecast graphic for Hurricane Ian on September 27, 2022 at 11AM EDT. Image credit: NOAA NWS

3. BUILDING A CLIMATE READY NATION

As outlined in NOAAs 2022-2026 Strategic Plan, NOAA is uniquely positioned to support the whole-of-government effort to address the climate crisis, strengthen resilience, and promote economic growth. Together with its partners, NOAA will build a Climate Ready Nation whose prosperity, health, security and continued growth benefit from and depend upon a shared understanding of — and collective action to reduce — the impacts of climate change. 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. Comprehensive service delivery and

decision support tools are necessary to build a Climate Ready Nation to meet the needs of businesses, federal partners, and communities most vulnerable to climate and weather hazards. 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. This chapter is organized into three sections to highlight key focus areas for a Climate Ready Nation: Monitoring Climate Change, Predicting Future Change, and Environmental Impact and Human Response.

MONITORING CLIMATE CHANGE

NOAA monitors the climate to assess changes in temperature, precipitation, sea ice concentration, and the frequency and intensity of storms and climatic phenomena like El Niño over a range of timescales. Some examples of how NOAA monitors climate are measuring greenhouse gas concentrations, quantifying sea ice changes through satellites, assessing changes in the pH of seawater, and evaluating changes in the water cycle.

PREDICTING FUTURE CHANGE

Using data collected from years of monitoring climate change, scientists are able to predict future changes to our climate on scales ranging from weeks and months (subseasonal) to seasons and decades. Whether it is diagnosing when a long drought will come to an end, or modeling atmospheric rivers, these forecasts help the nation prepare for and adapt to future conditions.

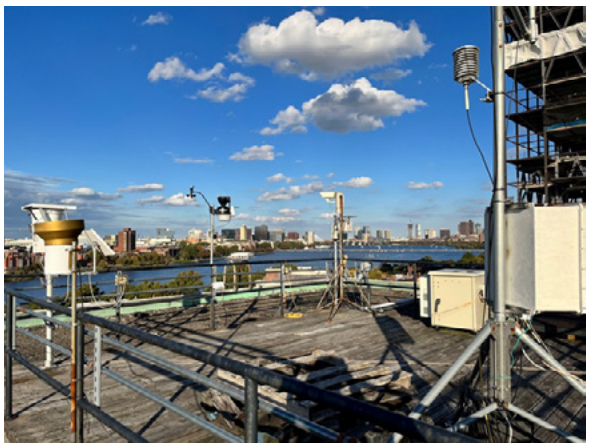
ENVIRONMENTAL IMPACT AND HUMAN RESPONSE

Interpreting the dynamic state of global climate change and how it impacts society remains a priority of NOAA research and development. NOAA's social scientists are a key part in understanding how hazardous climate and weather phenomena impact human perception and behavior which results in improved communication of these forecasted threats and ultimately reduces societal impacts.

3.A MONITORING CLIMATE CHANGE

METHANE EMISSION INVENTORIES MISS FOSSIL FUEL SOURCES LEADING TO EMISSION UNDERESTIMATES IN NORTH AMERICA

Natural gas has become an increasingly important energy source in the U.S. because of its low cost and lower carbon dioxide emissions relative to other fossil fuels. However, natural gas emissions are a primary source of methane — the shorter lasting but more powerful greenhouse gas. A new collaborative study, used atmospheric measurements of methane concentrations to track emissions over eight years (2012-2020) in Boston, MA.



Urban observatory on the roof of Boston University where researchers have monitored atmospheric methane and carbon dioxide for eight years. Photo credit: Lucy Hutyra

Specifically, researchers used the HYSPLIT transport model to find discrepancies in existing methane inventories, demonstrating that emissions from the use and distribution of natural gas are about six times higher than current estimates. The results suggest that consumption-driven processes, like using natural gas for heating, may produce more than half of these emissions, rather than pipeline leaks. Accounting for this underestimation may require future policy action to mitigate the climate impact of these newly characterized emissions.

RESEARCHERS CLIMB MOUNTAINS TO IMPROVE WEATHER AND WATER FORECASTING TOOLS

The Colorado River Basin is a primary water source for six states and 40 million people from Denver to Los Angeles. In mountainous headwater regions, snowmelt generates the majority of streamflow and water reservoir storage in the basin. A 20-year drought and warming, caused by climate change, have significantly impacted water availability, resulting in the first-ever declaration of shortage conditions in 2021 by the United States Bureau of Reclamation.

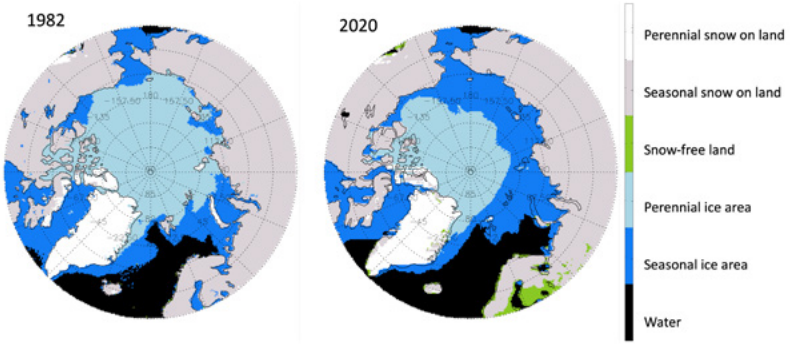
With growing population, new predictions about the ongoing drought, and an estimated 10-50% further reductions in Colorado River flow by mid-century, there's a growing need for careful water resource management. To help address this need, NOAA and partners from universities, federal and state organizations, and industry are participating in a two-year Study of Precipitation, the Lower Atmosphere and Surface for Hydrometeorology, or SPLASH. A driving motivation for SPLASH is to gain a better understanding of the physical processes impacting the watershed, and how much water ends up in the Colorado River. A network of radars, instrumented towers, and individual sensors is measuring temperature, precipitation amount, soil moisture, snowpack properties, land-atmosphere interactions, and other variables. Additionally, instrumented aircraft will collect snowpack survey observations at key times, and small uncrewed aircraft will investigate the basin at altitudes where it's unsafe to fly crewed planes. Several interesting findings to date include: 1) an intense winter storm event at the end of December 2021 was responsible for a significant fraction of the year's total snowfall; 2) a rapid snow melt in spring 2022 resulting from dust and black carbon (source is likely from wildfires and drought affected regions) accumulating on the snow surface; 3) an active summer monsoon season with numerous precipitation events. The team has also been working with NOAA NWS partners to identify errors in operational precipitation products in the SPLASH region.

Janet Intrieri and Chris Cox, from NOAA Research's Physical Science Laboratory, install an Atmospheric Surface Flux Station for SPLASH. Photo credit: Gijs de Boer, NOAA/ Cooperative Institute for Research in Environmental Sciences

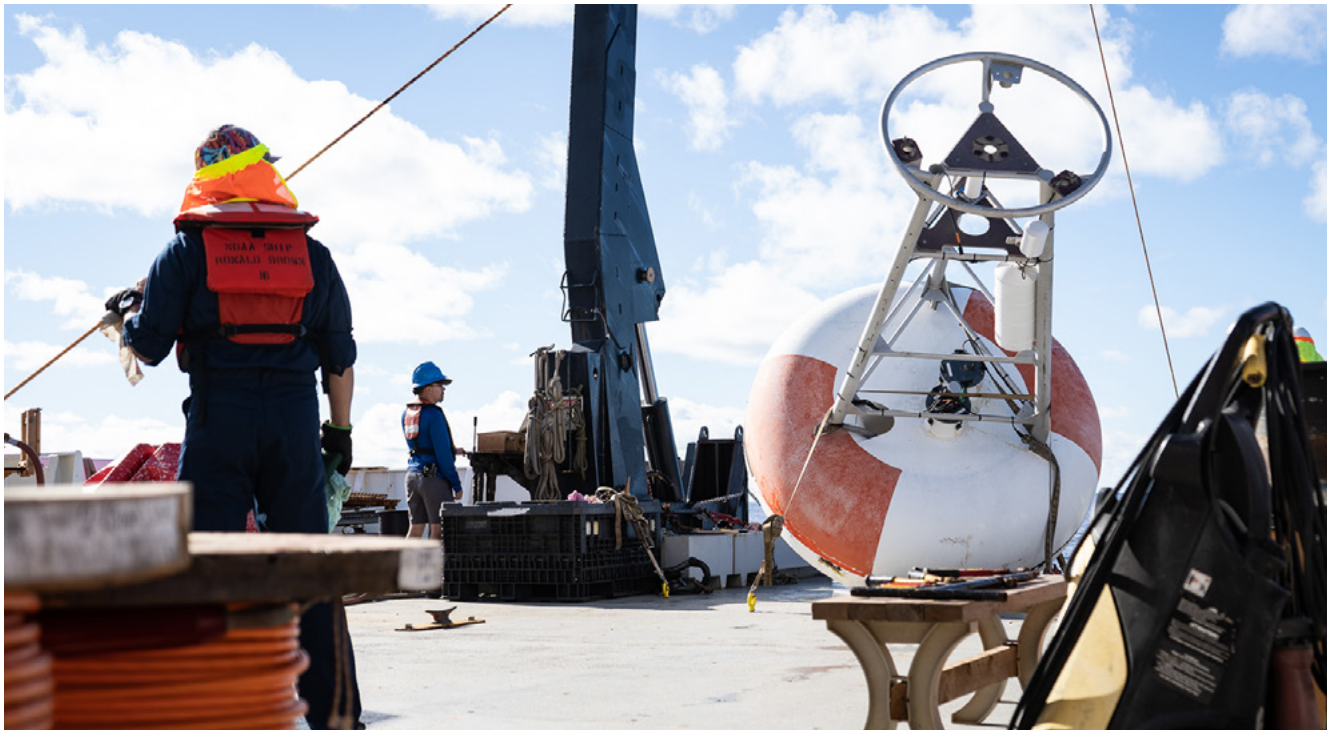
One of the four field sites set up for the SPLASH field campaign. Shown are instruments at the Kettle Ponds site. Photo credit: Ryan Currier, NOAA

SATELLITES PROVIDE NEW INFORMATION ON ARCTIC SEA ICE DECLINE

Research using NOAA's satellite climate data records has produced new insights on dramatic, multi-decadal changes in Arctic sea ice area, thickness, and volume for perennially and seasonally ice-covered areas, and gives a new estimate of when the Arctic may be ice-free in the summer. Sea ice is a critical part of the climate system through its interaction with the atmosphere and the ocean, while also playing an important role in marine ecosystems, navigation, and national security. This work employs a new perspective based on ice longevity to determine where ice is persistent and where it is disappearing. These analyses highlight the presence and persistence of ice in an area that directly influences arctic weather and climate, marine transportation, and ecosystems. Findings show that the Arctic has become less ice-covered in all seasons, however summer and autumn stand out with the most changes. The loss of the perennial sea ice-covered area is the major factor in the total sea ice loss in all seasons. If the current rates of sea ice changes in extent, concentration, and thickness continue, the Arctic is expected to have ice-free summers by the early 2060s.



Spatial distribution of Arctic sea ice in 1982 (left) and 2020 (right) for perennial and seasonal sea ice and snow on land. Image credit: NOAA NESDIS



A large red and white PIRATA buoy is shown on deck of the NOAA Ship *Ronald H. Brown* during the 2021 PIRATA Northeast Extension Research cruise. Photo credit: NOAA Research's Atlantic Oceanographic & Meteorological Laboratory

VITAL OCEAN OBSERVATIONS COLLECTED DURING THE COVID-19 PANDEMIC

NOAA scientists and partners from an assortment of universities and Cooperative Institutes successfully collected crucial ocean and climate observations while navigating COVID-19 challenges. The most comprehensive ocean acidification sampling of the Gulf of Mexico to date was completed by the fourth Gulf of Mexico Ecosystems and Carbon Cruise. The multi-institution effort monitored ocean acidification conditions across the Gulf of Mexico to assess trends and potential impacts to coastal ecosystems. Increases in levels of carbon dioxide in the atmosphere that are absorbed into the ocean contribute to more acidic seawater that can be harmful to marine species, impacting fisheries and marine ecosystems. In addition to monitoring ocean acidification in the Gulf of Mexico, scientists sampled and studied the abundance, diversity, and health of a variety of marine organisms to understand how ocean conditions are impacting their survival.

NOAA scientists and partners also completed the Prediction and Research Moored Array in the Tropical Atlantic (PIRATA) Northeast Extension cruise, which serviced and redeployed buoys and other instrumentation to measure the physical characteristics of the ocean, such as air and sea temperatures, wind speed, and other parameters along 23°W. Air-sea interactions in this region have a strong impact on weather and climate variability in surrounding countries and can be a determining factor for the prediction of extreme weather and ocean changes. Buoys in the PIRATA array provide critical real-time data for models of the Atlantic climate system, supporting the societal need for improved global weather and climate variability predictions. These research efforts represent two examples of sustaining long- term data collection, deploying instrumentation, and furthering the understanding of the ocean's physical, chemical, and biological properties.

3.B PREDICTING FUTURE CLIMATE

DEVELOPMENT OF A REAL-TIME CLIMATE ATTRIBUTION ANALYSIS PRODUCT

NOAA NWS has developed a real-time climate attribution analysis product to understand how predictable and skillful sub-seasonal to seasonal forecasts are to predict weather patterns and conditions two weeks to two months in the future. This analysis evaluates the skill of the most recent seasonal temperature and precipitation climate variations and utilizes a hierarchy of modeling approaches to evaluate the predictability of these anomalies. This product was recently used to show that the large-scale below-normal temperatures that occurred over most of the central United States in January, February, and March 2022 were not forced by sea surface temperature anomalies and were unpredictable. The product demonstrated that the skill was low in forecasting the individual monthly anomalies for the January to March, 2022 period beyond a few days lead. Analysis of this type allows NOAA to improve forecast skill for future events. The product also helps to answer questions from stakeholders about the performance of official extended-range predictions, knowledge base about the causality of observed climate variations, and communicate the physical basis for predictions in the future.

DIAGNOSIS OF THE EXTENDED DROUGHT THAT BEGAN AT THE TURN OF THE CENTURY

NOAA NWS and colleagues completed a study to analyze the enhanced drought conditions that have occurred in the western, central, and southeastern United States starting in 2000. The study found that the dominant forcing of these drought conditions was the precipitation deficit, with above normal evaporation due to elevated surface temperatures playing a contributing role. The temperature and precipitation changes were attributed to concurrent global sea surface temperature anomalies, which are known to drive drought in these regions. A shift toward a wetter and cooler pattern, helping to improve drought conditions, requires a phase change in one or more of these sea surface temperature patterns. Understanding the cause of drought in the U.S. helps better inform prediction of onset, intensification, and termination of future extended duration droughts.

NEW GLOBAL FORECASTING CAPABILITIES FOR MARINE HEATWAVES CAN STRENGTHEN CLIMATE RESILIENCE

Marine heatwaves disrupt ocean ecosystems, cause economic losses in global fisheries, contribute to human-wildlife conflicts, and cause widespread coral bleaching events. NOAA scientists found that existing global climate forecasts, based on seasonal (1-12 months in advance) sea surface temperatures, can be used to effectively predict the onset, intensity, and duration of many marine heatwaves. These predictions can be scaled globally or regionally, and will inform key actions to be taken to reduce the impact of marine heatwaves on marine life. Strategizing the monitoring and allocation of resources for vulnerable ecosystems including coral reefs and other sensitive marine life may be optimized with advanced knowledge of marine heatwaves, helping to mitigate the harmful effects of extreme weather events. The need for marine resource managers to balance the consequences of taking precautionary

actions, such as limiting fisheries ahead of a marine heatwave (which may provide ecological benefits and economic impacts to the fishing industry) remains, but now with enhanced forecast knowledge, the decision-making process is better informed, facilitating proactive management efforts. The use of existing global climate forecasts opens the door for operational marine heatwave predictions that can improve climate resilience for ocean ecosystems.

Aircraft Commander Captain Jason Mansour and Flight Director James Carpenter of NOAA Corps fly a research mission into an atmospheric river off of the U.S. West Coast in December 2022. Photo credit: Lieutenant Junior Grade Nicolas Osborne, NOAA Corps

NOAA IS ON A MISSION TO BETTER UNDERSTAND THE IMPACTS OF ATMOSPHERIC RIVERS

Starting in December 2022, the West Coast of the U.S. experienced intense rainfall and flooding. Atmospheric rivers include naturally occurring air currents that can bring heavy rain and mountain snow. Precipitation from these events can be excessive, leading to flooding, or beneficial contributing to regional water supply.

On average, about 30 to 50 percent of annual precipitation in the west coast states occurs in just a few atmospheric river events. NOAA studies atmospheric rivers to improve forecasting capabilities and better understand atmospheric river impacts on communities and the physical environment.

CLIMATE AND ECOSYSTEM MODELING EFFORTS IN ALASKA TO PROVIDE INFORMATION FOR HELPING FISHING INDUSTRY AND COASTAL COMMUNITIES ADAPT TO CLIMATE CHANGE

NOAA Fisheries kicked off the second phase of its Alaska Climate Modeling Project in the Bering Sea and a new climate modeling project for the Gulf of Alaska. This work is possible because of long-term investment in Alaska ecosystem surveys, cooperative data collection efforts with community members and research partners, and laboratory and field studies on fish and marine mammal age, growth, habitat use, and diets. The data from these foundational studies are used both to develop and to validate the ecosystem and climate models. In turn, the new models will be able to provide near-term and long-term climate projections to support adaptive science (e.g., suggest areas for more focused research) and management actions to

ensure sustainable fisheries, healthy marine mammal populations and marine ecosystems and resilient coastal communities. This year, NOAA Fisheries also produced climate science action plans for each of the three different regions as part of NOAA Fisheries Climate Science Strategy reflecting ongoing and needed research to support ecosystem-based fisheries management and climate-ready management in Alaska. NOAA continues to play an important role in advancing international climate discussions, such as the International Panel on Climate Change Sixth Assessment Report (2022), by sharing lessons learned in Alaska and other parts of the U.S. to understand and address climate change impacts on commercial, recreational and subsistence fisheries and coastal communities.

3.C ENVIRONMENTAL IMPACT AND HUMAN RESPONSE

LEVERAGING THE NATIONAL ACADEMIES SOCIETAL EXPERTS ACTION NETWORK TO ADDRESS THE CLIMATE CRISIS

Understanding the dynamic state of global climate change and how it affects weather and environmental resources impacting society remains a priority of NOAA R&D. In coordination with the National Science Foundation (NSF), NOAA is engaging with the Societal Experts Action Network run by the National Academies of Science to address Climate Change policy challenges, as highlighted in the White House Fact Sheet. This program was created in 2020 by the National Academies of Science in response to the COVID-19 pandemic and received support from the NSF and the Alfred P. Sloan Foundation. NOAA is leading this collaboration to ensure alignment with NOAA climate related social, behavioral, and economic questions along with the NOAA Social Science Committee, Service Delivery, and the new NOAA NWS Social, Behavioral, and Economics office needs. By expanding the scope of the Societal Experts Action Network to the climate topic area, NOAA and other federal, state, and local governments may more readily have access to information needed to better and more equitably serve American and international communities.

MARINE HEATWAVES AMPLIFY TENSIONS BETWEEN WHALES AND FISHERIES ON THE WEST COAST

NOAA Fisheries researchers and partners quantified tradeoffs between risk of entanglement of whales in crab fishing gear and lost fishing opportunities for crab fishers on the West Coast due to efforts to mitigate whale risk. The tension between the recovery of wildlife populations and this lucrative human activity was found to be exacerbated by a large marine heatwave, which is a sustained period of time with unusually warm ocean temperatures. Future fisheries management may thus require multi-pronged approaches, including improved forecast systems, technological innovations, and enhanced understanding of fishing behavior. This work builds upon years of partnership between NOAA Fisheries, states, and commercial crab fishers to understand the ecosystem drivers that bring whales into habitats where crab fishing occurs, and to adopt monitoring plans and fisheries management policies that will reduce entanglements.

NOAA SUPPORTS OFFSHORE WIND PLANNING PROCESS

In support of the Biden Administration's goal of producing 30 gigawatts of energy from offshore wind farms by 2030, NOAA is providing regulatory and technical support to the Bureau of Ocean Energy Management, the permitting agency for offshore wind farm leasing. In the Southeast and Gulf of Mexico region, NOAA Fisheries is working closely with NOAA NOS across our fisheries, protected resources and habitat programs, and in collaboration with our marine spatial planning experts to provide new and comprehensive insight to support the lease site selection process. The center helped to create Geographic Information Systems layers that depicted the regions where existing commercial fisheries, critically endangered species such as Rice's whale, and other trust resources might overlap with broad call areas considered for lease. A model calculated the risk of impact to each factor considered and produced a series of locations that minimally conflicted with identified competing uses, while providing increased opportunity for offshore wind energy development. The results were used by the Bureau of Ocean Energy Management to inform multi-million dollar lease auctions scheduled to take place in early 2023 in the Gulf of Mexico region.

4. SUSTAINABILITY 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 2022, NOAA's scientific accomplishments for enhancing the sustainable use and stewardship of ocean and coastal resources included the following categories: Observations, Models and Tools Supporting Fisheries Management, Forecasts and Projections, and Ecosystem Assessments and Characterization.

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.

MODELS AND TOOLS SUPPORTING FISHERIES MANAGEMENT

NOAA uses various models and tools to address a range of research and management needs for fisheries and species conservation. Some models generate short-term projections to support management advice. Other models stimulate long-term evaluation of fisheries management strategies. Some models investigate the impacts of climate change as they relate to fisheries and threatened/endangered species.

FORECASTS AND PROJECTIONS

NOAA predicts changes in ecosystems to understand potential future risks thus protecting species, resources, and mitigation human health risks. For example, forecasting

harmful algal blooms, which can be toxic, can help inform local communities to avoid certain shellfish species or entire coastal areas altogether.

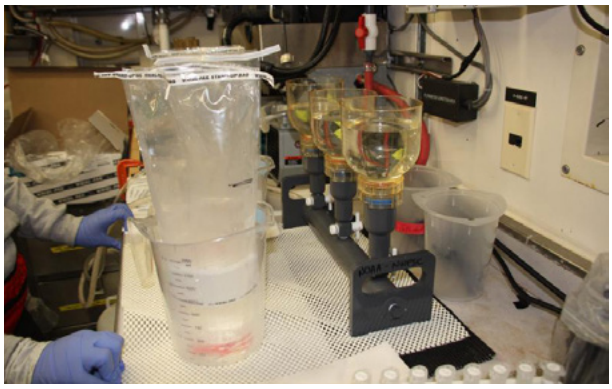
ECOSYSTEM ASSESSMENT AND CHARACTERIZATION

NOAA scientists must describe the biotic (living) and abiotic (non-living) features of a landscape to properly characterize a habitat. Characterizing the environments in which a species inhabits or travels through is crucial to understand the threats a species faces. Species conservation relies upon careful assessment of key indicators of ecosystem status including (but not limited to) water temperature and salinity, fishing activity, ocean current velocity, phytoplankton assemblages, coral distribution, and sediment composition.

4.A OBSERVATIONS

ENVIRONMENTAL DNA PROVIDES AN AFFORDABLE ALTERNATIVE TO MEASURE FISH POPULATIONS

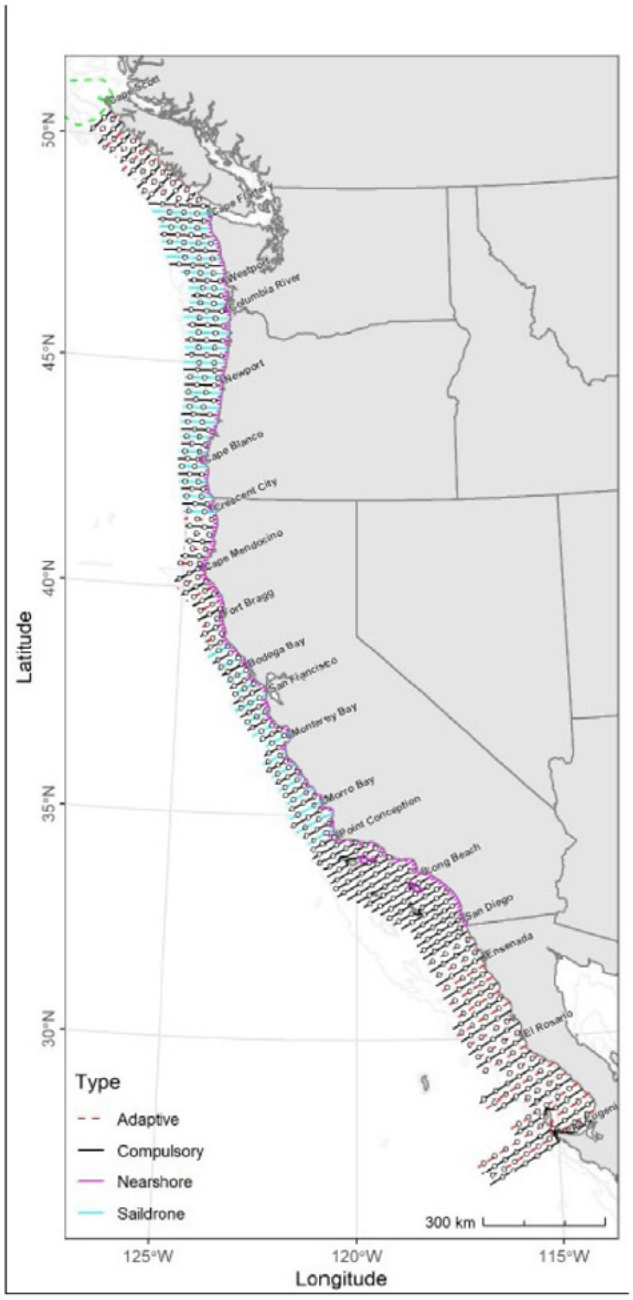
For the first time, NOAA researchers demonstrated that environmental DNA, known as eDNA, offers a less-expensive means of measuring populations of fish such as Pacific hake, or whiting, which supports the largest commercial fishery off the West Coast. Traces of DNA that fish species leave behind in the water, referred to as eDNA, can reveal the abundance and distribution of fish over large areas of the ocean as accurately as conventional fisheries survey methods. Sampling for eDNA, or collecting water from the environment being studied, is also less disruptive to fish, especially vulnerable species, than catch surveys and netting methods, as well as being useful to detect species that are less frequently seen during visual surveys. Fishery managers and fishing fleets depend on such assessments to understand the distribution of species and how many fish may be available for fishing fleets to catch.



A scientist is shown measuring Environmental DNA from water samples on board the NOAA Ship *Bell M. Shimada*, collected during the 2019 hake survey. Photo credit: NOAA Fisheries

A conductivity, temperature, and depth instrument is shown on deck. Scientists gathered water samples at multiple depths across 186 locations off the West Coast during hake surveys on the NOAA Ship *Bell M. Shimada* in 2019. Photo credit: NOAA Fisheries

NOAA FISHERIES COMPLETES 86-DAY SURVEY FROM CANADA TO MEXICO FOR THE FIRST TIME SINCE THE 1960'S



A map outlines the survey transects for the vessels surveying small coastal pelagic species. The solid lines show the course of the survey, with the magenta lines showing nearshore transects and blue lines showing the course of Saildrones. Image credit: NOAA Fisheries

NOAA Fisheries completed the first survey of Pacific sardine, Northern anchovy, Pacific mackerel, jack mackerel, and Pacific herring stocks spanning the west coast Exclusive Economic Zones of the U.S., Canada, and Mexico. This achievement supports the first comprehensive assessments of transboundary stocks of sardine, anchovy, and Pacific mackerel, which will significantly improve science, management and potentially commercial fishing opportunities. For example, while the fishery for the managed and overfished northern stock of Pacific Sardine has been closed since 2015, this survey facilitated the first direct assessment of the biomass, demography and distribution of the entire southern stock of Pacific Sardine that has been increasingly and persistently present in U.S. waters since 2018. NOAA Fisheries researchers combined international science, diplomacy, industry collaboration, and collective sampling from NOAA Ship *Reuben Lasker*, Mexican R/V *Jorge Carranza*, two industry vessels, and three Saildrones. This was the first fisheries survey that NOAA Fisheries has conducted off the Pacific coast of Mexico in five decades and was accomplished during the pandemic. This ambitious assessment of commercial valuable species will help determine how many fish can be caught off the West Coast.

NOAA Ship *Reuben Lasker*, a fisheries survey vessel, departed San Diego, CA in July 2021 to assess coastal pelagic species such as sardine and anchovy. Photo credit: Paul Hillman/NOAA Fisheries

An uncrewed aerial system (UAS) attaches a suction-cup equipped synchronous motion, acoustic recording tag (DTAG) to a sei whale. This is the first time a UAS was used to tag sei whales and the first use of a UAS to tag free-swimming large whales in U.S. waters. Photo taken under NOAA Fisheries Permit No. 18786-06. Photo credit: Laura Howes

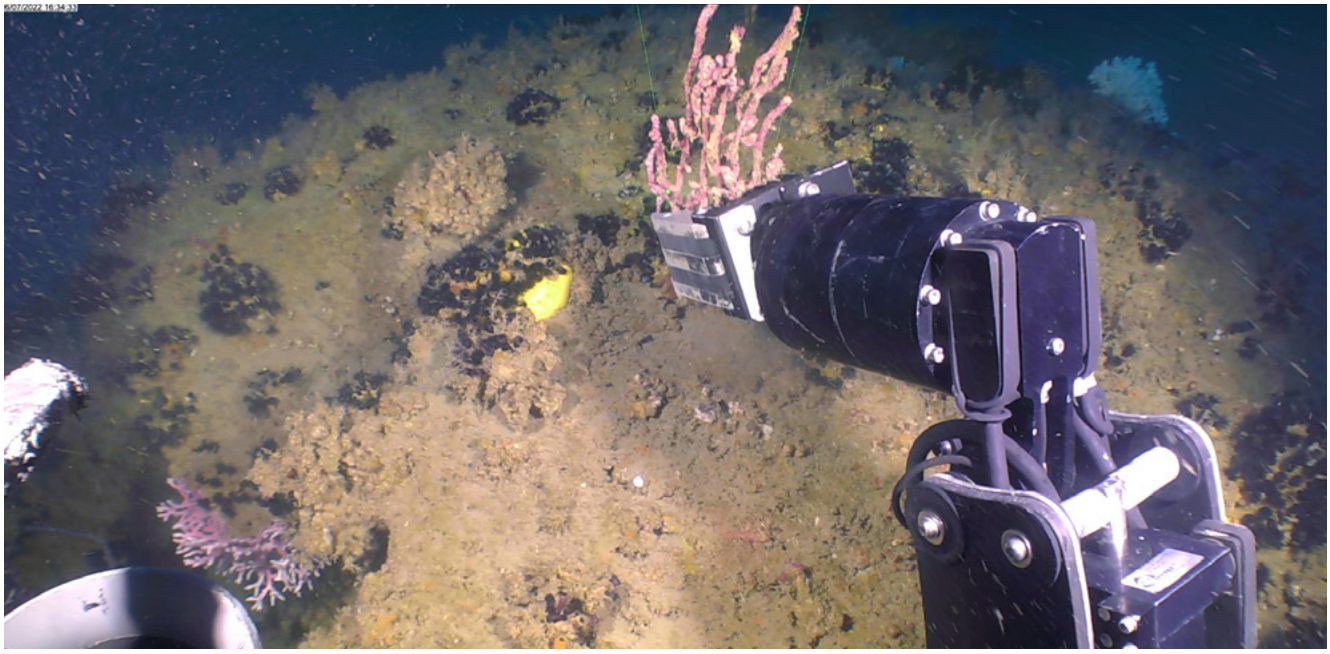
FIRST-EVER SUCCESSFUL DRONE-BASED TAGGING OF ENDANGERED SEI WHALES IN THE U.S.

NOAA's Stellwagen Bank National Marine Sanctuary and the Bureau of Ocean Energy Management partnered with Syracuse University, Ocean Alliance, and University of Michigan to attach digital acoustic recording tags to sei whales using uncrewed aerial vehicles (UAV) or drones. Tag attachment has typically been accomplished using a small boat to approach within a few meters of the whale. A long pole is then used to place the tag on the animal's back. Use of the UAV means tags can be attached from greater distance, making it safer for animals and people. Additionally, the speed and maneuverability of the UAV as compared to the boats means tags can be placed on animals more efficiently. Data collected using the tags will shed important light on how whales respond to noise, which researchers will use to inform strategies – including passive acoustic monitoring – to protect this endangered species from the potential impacts of offshore wind energy and other human-caused activities. This initiative was the first use of drones to successfully tag multiple large whales, and the first in U.S. waters to tag endangered sei whales with state-of-the-art multi-sensor tags.

"The use of UAVs to tag whales is the first major innovation related to attaching tags to whales," said Dr. David Wiley, research ecologist at Stellwagen Bank National Marine Sanctuary.

ECOSYSTEM RESTORATION OF MESOPHOTIC AND DEEP BENTHIC COMMUNITIES IMPACTED BY THE 2010 DEEPWATER HORIZON OIL SPILL

NOAA NOS and its partners completed eight scientific cruises in the Gulf of Mexico to advance our ability to understand, manage, and restore deep seafloor communities impacted or damaged by the 2010 Deepwater Horizon oil spill. At Deepwater Horizon oil spill impact and reference sites, scientists conducted high-resolution seafloor mapping surveys from ships and autonomous underwater vehicles, deployed remotely operated vehicles to do visual surveys for habitat assessment and live coral sampling in deep benthic habitats across the north-central Gulf of Mexico. Prior to the spill, our understanding of mesophotic (receiving low light or less light than near surface waters) and deep fish and invertebrate communities was extremely limited. The research cruises are supporting efforts to pinpoint restoration sites, monitor how the areas change over time and bounce back from damage and pollution, and inform methods of deep-sea coral restoration. The activities conducted this year are part of a five-year strategy to help scientists better understand the ecology and function of these communities and support future restoration and management.



A remotely operated vehicle is used by the Undersea Vehicles Program to survey coral for sampling in the Gulf of Mexico. Photo credit: UNCW-Undersea Vehicles Program

4.B MODELS AND TOOLS SUPPORTING FISHERIES MANAGEMENT

NOAA FISHERIES LAUNCHES THE FISHERIES INTEGRATED MODELING SYSTEM: THE NEXT GENERATION STOCK ASSESSMENT PLATFORM

NOAA Fisheries developed the Fisheries Integrated Modeling System (FIMS), a user-centered stock assessment software to better support sustainable fisheries management. The software uses Fish stock assessments to analyze catch and survey data evaluating the impact of fishing on fish populations and provides scientific guidance regarding sustainable catch levels. NOAA Fisheries assembled the FIMS Implementation Team, composed of a core coding team and representatives from each NOAA Fisheries Science Center, and the FIMS Council, made up of external experts and stakeholders. Collaborative development of fish population assessment software will be easier to update and adapt due to a shared development paradigm and direct user involvement during all phases of FIMS' development. This will provide better information for fishery managers to support sustainable fishery management.

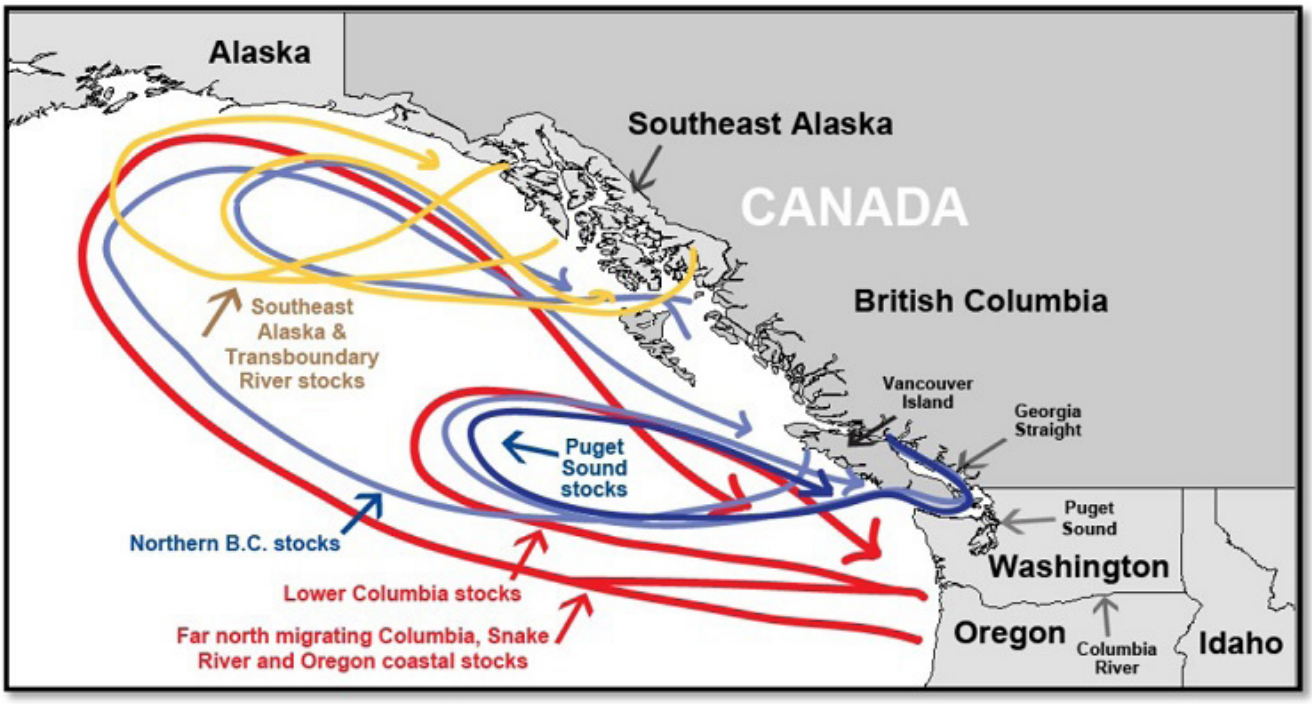
GENETICS RESEARCH MAY HELP FISHERS AVOID SPECIFIC SALMON AND REDUCE BYCATCH IN ALASKA

NOAA Fisheries in Alaska is studying salmon to better understand and address bycatch, or unintentional catch, of salmon in commercial groundfish fisheries. The goal is to help local fishing fleets avoid salmon and is especially relevant given historic declines in Chinook and chum salmon runs on the Yukon River due to climate change. Independent fisheries observers on fishing vessels collect a variety of important information including collect length, sex, genetic information, and fish scales. Geneticists use these data to both determine the rivers where all salmon caught in commercial trawl fisheries originate and to learn more about where these salmon travel in the ocean. These data are then used by state management agencies and Federal resource managers to help address bycatch of salmon in federally-managed commercial fisheries.

Alaska Fisheries Science Center genetics researchers collected water samples for a nearshore environmental DNA study at the "Eagle Beach" site near Juneau, AK. Photo credit: Wes Larson, NOAA Fisheries.

A NORTH PACIFIC INTERNATIONAL RESEARCH COLLABORATION STUDIES THE WINTER ECOLOGY OF SALMON

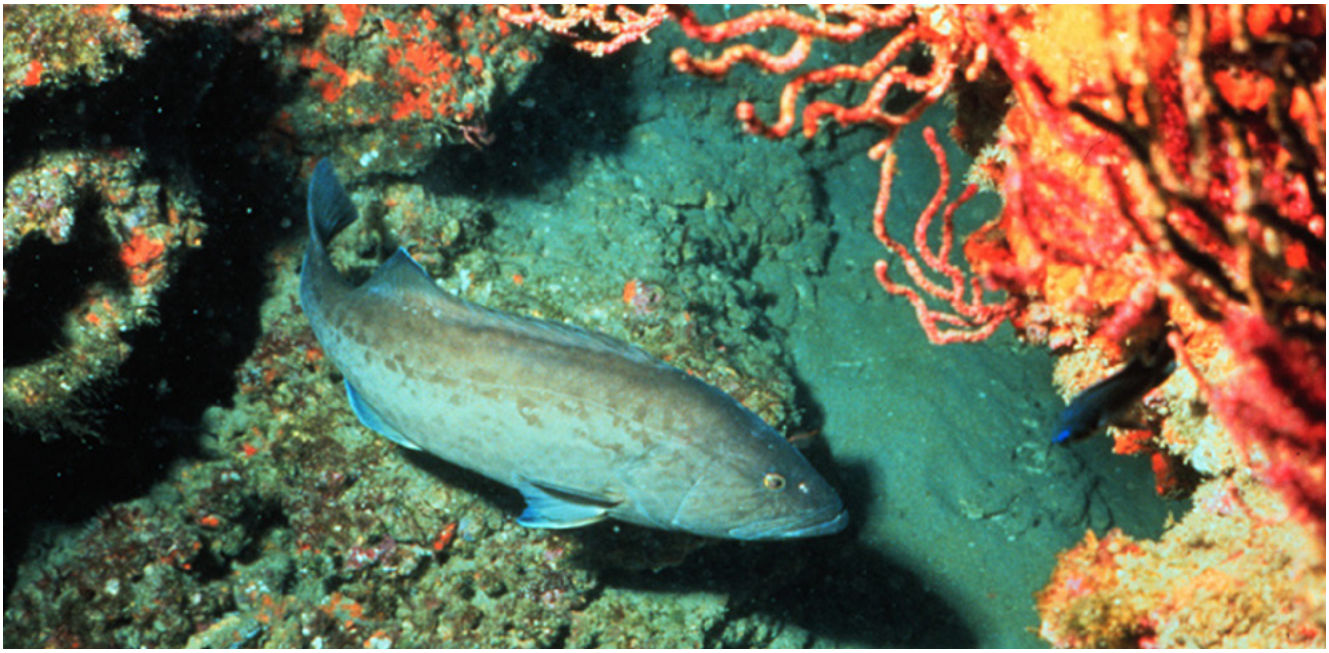
In February and March 2022, research ships from the United States, Canada, and Russia set out into one of the roughest oceans in the world to unravel a mystery: What determines whether salmon that migrate across the North Pacific come back alive? Researchers currently have only a cursory understanding of which type of salmon uses which sections of the ocean, and what limits their survival during their years at sea. The two-month 2022 Pan-Pacific Winter High Seas Expedition reflects the most ambitious attempt to: 1) Map how salmon and steelhead migrate through the ocean, 2) Determine what affects their returns to rivers around the Pacific Rim, including West Coast and Alaska rivers such as the Columbia, Fraser, Sacramento, Yukon, and Kuskokwim. Information collected from this expedition will provide a foundation for assessing, forecasting and managing salmon into the future and may help to build resilience for the species and the people who depend on them. The information also provides critical insights that may help us protect Alaska salmon stocks and recover West Coast and steelhead stocks that may face increasing pressure from climate change.



Different Chinook salmon stocks follow varied migration patterns through the Pacific Ocean. Image credit: NOAA Fisheries

A NEW ECOSYSTEM MODEL IS USED TO INFORM GAG GROUPER STOCK ASSESSMENT AND MANAGEMENT

NOAA NOS funded the creation of a fisheries ecosystem model focused on supporting fisheries assessments and management in the Gulf of Mexico by including ecosystem processes and predator-prey interactions. The model includes spatial mapping allowing for the assessment of red-tide event distributions and the abundance of gag grouper populations by age. This information can help tie specific red-tide events with mortality rates of gag grouper, providing critical information for the 2022 gag grouper stock assessment and to the Gulf of Mexico Fishery Management Council and the Gulf Council's Scientific and Statistical Committee who provide catch limit recommendations. Catch limits are critical for sustaining iconic fish species like the gag grouper, which are prized by recreational and commercial fishers along Florida's Gulf Coast.



Gag grouper are an iconic species on Florida's Gulf Coast. Photo credit: NOAA Fisheries

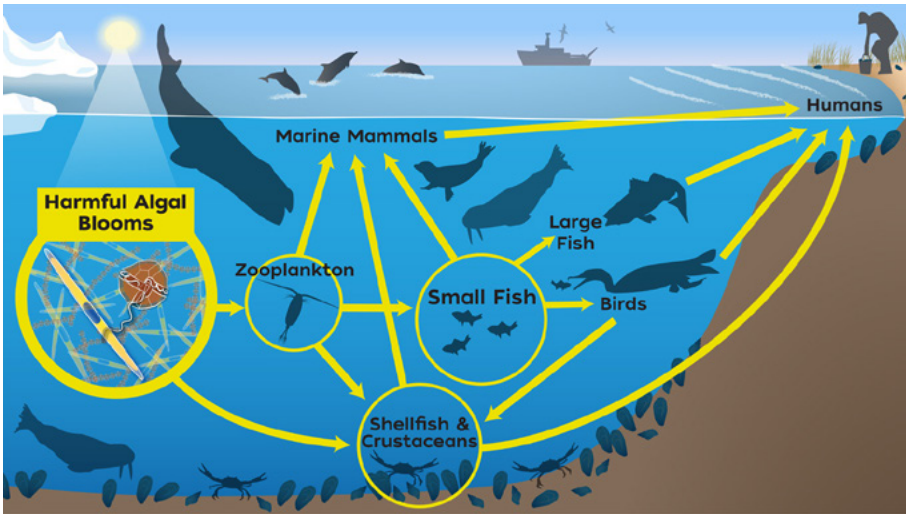
4.C FORECASTS AND PROJECTIONS

EXPANSION OF A CITIZEN SCIENCE HARMFUL ALGAL BLOOM OBSERVATION PROJECT TO PROTECT HUMAN HEALTH AND LOCAL ECONOMIES

Harmful algal blooms (HABs) occur when colonies of algae — simple plants that live in marine and freshwater environments — grow excessively and produce toxic or harmful effects on people, marine species, and other animals. HABscope is a low cost microscope system that can be used by citizen scientists with cell phones to identify the HAB species Karenia brevis (the species observed during red tide events in the Gulf of Mexico) cell concentrations in the water along a beach. HABscope leverages AI to detect HAB species, providing quick results.

This project expands the capacity of HABscope methods to other HAB species beyond K. brevis to continue addressing important HAB-related resource and public health issues, expanding the use of citizen science to cost effectively monitor the environment for HABs of concern. With this expansion, HABscope technology can improve HAB detection for Pyrodinium bahamense in Florida to better protect the health of 1.6 million citizens and Alexandrium monilatum in Chesapeake Bay to mitigate impacts to the developing aquaculture industry. This work allows for improved and more efficient detection and enumeration of the HABs of interest resulting in better HAB forecasts. As a result, HABscope will help mitigate harmful impacts on the shellfish industry.

Chris Holland, an oceanographer at NOAA's National Centers for Coastal Ocean Science (NCCOS), analyzes water samples using the HABscope on Venice Beach, Florida. Photo credit: NOAA/NCCOS



Toxins produced by HABs can be accumulated and transferred throughout the food web when algal cells are eaten by zooplankton, fish, and shellfish that are, in turn, consumed by other animals and humans. At sufficiently high levels, these toxins can sicken or kill both humans and wildlife. Image credit: Natalie Renier, WHOI Graphic Services, open access under Creative Commons Attribution 4.0 International License

EXPANDING HARMFUL ALGAL BLOOM MONITORING TO UNCOVER THE MECHANISMS BEHIND GEODUCK CLAM TOXICITY IN SOUTHEAST ALASKA

The Southeast Alaska geoduck clam fishery, worth $4.9 million annually in past years, is an economically important wintertime fishery. However, the fishery has been plagued by unexplained toxicity from paralytic shellfish toxins from the marine dinoflagellate Alexandrium sp., resulting in substantial economic losses and unpredictable closures. Researchers are investigating the relationship between Alexandrium and geoduck clam

toxicity, engaging geoduck harvesters in research activities, and analyzing two decades of state agency toxicity data. Alexandrium concentrations in commercial harvest areas were mapped and ecological pathways for algal toxins transfer to accumulate in geoducks were explored. The role of harvesting approaches to amplify or mitigate shellfish toxicity was also studied. Findings including maps of Alexandrium benthic cyst abundance and results that appear to rule out cyst ingestion as a potential pathway for wintertime geoduck clam toxicity. These results have been shared with harvesters and fisheries managers in Southeast Alaska. The gained understanding of the relationship between cyst distributions in commercial harvest areas and mechanisms of toxicity will inform the development of management strategies to mitigate paralytic shellfish toxin impacts on this commercially important fishery.

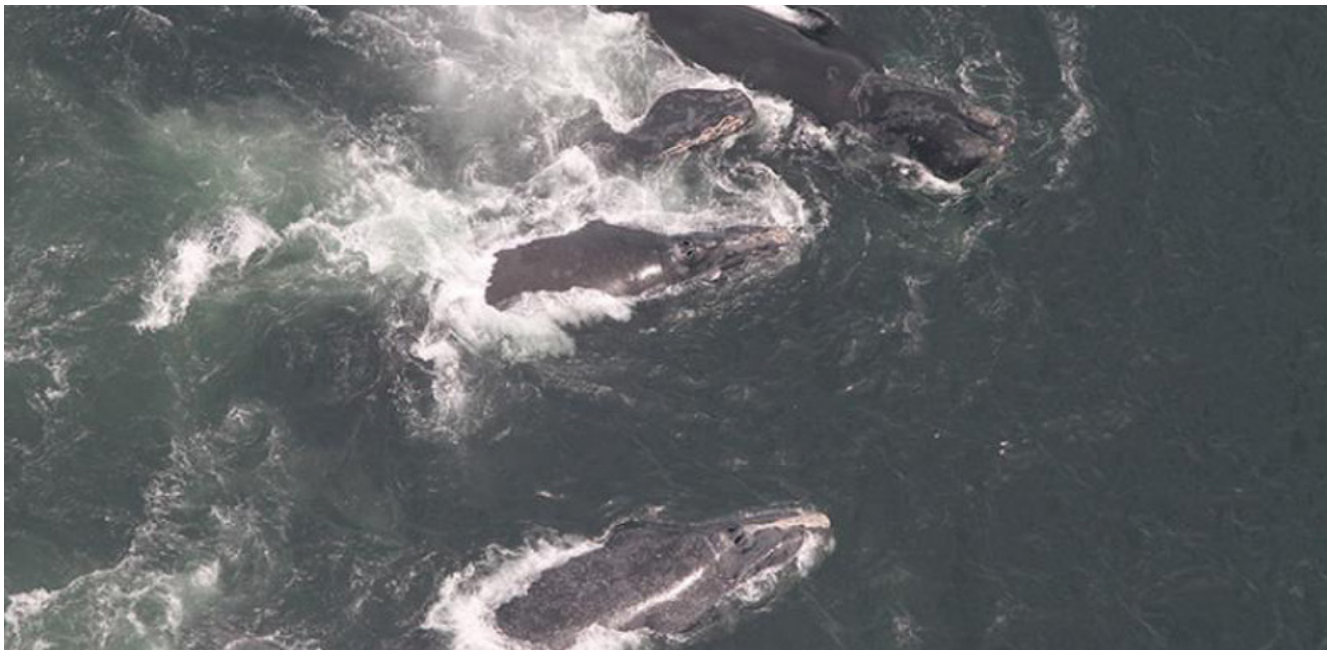
Courtney Hart at the University of Alaska Fairbanks (UAF), is shown conducting various stages of NCCOS ECOHAB funded field and lab research on geoducks. Photo credits: Jared Weems (UAF) and Jamie Musbach (NOAA/Sea Grant, previously at UAF)

TROPHIC TRANSFER AND EFFECTS OF HAB TOXINS IN ALASKAN FOOD WEBS

A NOAA Fisheries-led research team, funded through NOAA NOS is investigating HAB species composition and cell densities in Alaskan Arctic and Subarctic waters, including the ability to model toxin transfer pathways to zooplankton, shellfish, finfish, marine mammals, and potential risks to human health. Large accumulations of the resting cyst stages of HAB species on or near the seafloor lay dormant in unfavorably cool Arctic waters, but as waters warm due to climate change, conditions can support algal blooms and their associated toxins. Algal blooms, and the toxins they produce, immediately threaten an array of marine life and the coastal communities who rely on fish and shellfish resources, including through susceptibility to paralytic shellfish poisoning, which has been identified as the most critical HAB concern for the region. The research team found that during unusually warm conditions, paralytic shellfish toxins were present in all sampled layers of Arctic Alaskan food webs tested, including phytoplankton, zooplankton, benthic clams, benthic worms,

and pelagic fish, as well as walruses and bowhead whales that are harvested for subsistence purposes in the Bering, Chukchi, and Beaufort seas. This is the 1,000th publication supported by NOAA ECOHAB, presenting continued evidence for a climate-driven, expanding threat of massive, recurrent toxic blooms in Alaskan Arctic waters. These toxic algal blooms may have detrimental effects on the health of important marine resources within Arctic ecosystems and the Alaskan Native and subsistence communities who depend on these resources.

4.D ECOSYSTEM ASSESSMENT AND CHARACTERIZATION



Four North Atlantic right whales socialize in what is known as a surface active group in the Gulf of St. Lawrence. Photo credit: NOAA Fisheries/Alison Ogilvie

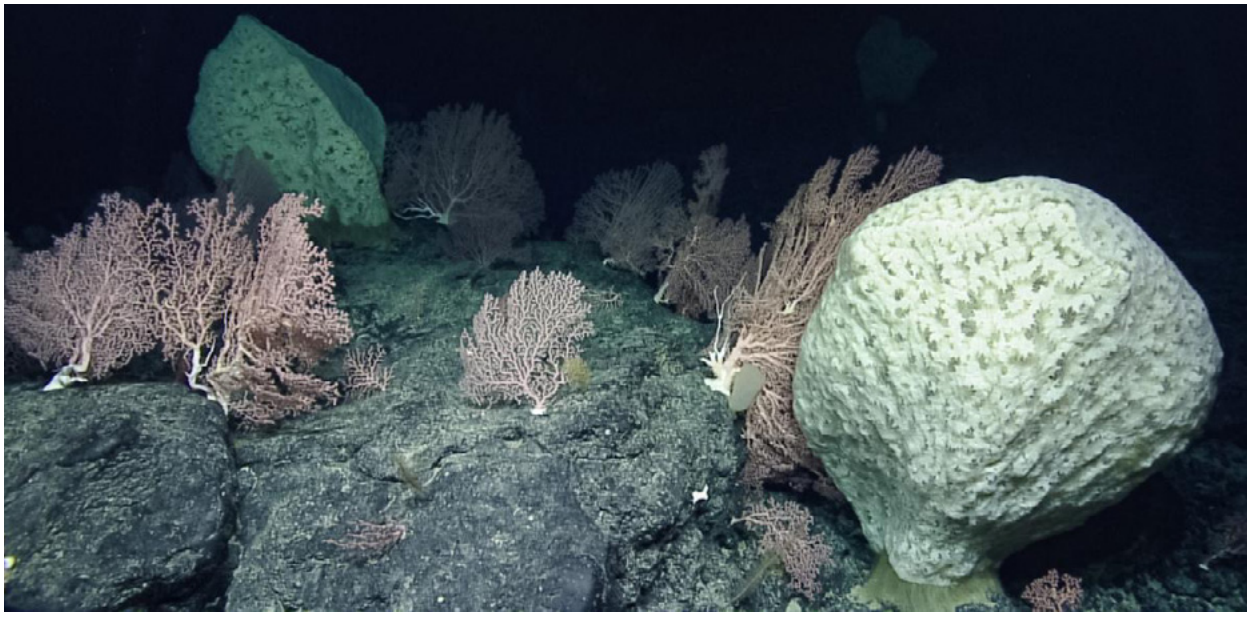
FORTY PERCENT OF NORTH ATLANTIC RIGHT WHALES USE THE GULF OF ST. LAWRENCE AS SEASONAL HABITAT

Understanding when and where endangered species are present is a key factor in designing effective protection measures. Canadian and U.S. scientists identified 187 individual North Atlantic right whales (about 40% of the species) in Canada's Gulf of St. Lawrence from 2015 to 2019. For this study, researchers examined photographs of North Atlantic right whales to explore their demographics, seasonal distribution, and movement patterns in the Gulf. The whales were identified by unique patterns of rough patches of tissue called callosities, on the top and sides of their heads. These whales were sighted feeding and socializing, primarily in the summer and autumn seasons both in the northern and southern portions of the Gulf. Almost all of the individual whales returned each year, a pattern not previously described in other habitats, and some stayed as long as 5 months. This study shows that the Gulf of

St. Lawrence is currently an important habitat for a large and loyal segment of this species. Northern and southern regions of the Gulf of St. Lawrence are separated by the Laurentian Channel and Honguedo Strait and act as major shipping corridors connecting commercial vessel traffic from the Atlantic Ocean to the St. Lawrence Seaway and the Great Lakes. This region of the Gulf of St. Lawrence, where right whales, fishing, and shipping traffic overlap, presents an opportunity for U.S. and Canadian managers to safeguard a particular portion of the North Atlantic right whale population, including reproductive females and calves, through the development of protective measures.

CHARACTERIZING THE EXTENT OF DEEP-SEA CORAL HABITAT WITHIN THE PAPAHĀNAUMOKUĀKEA MARINE NATIONAL MONUMENT FOR PLANNING AND RESOURCE PROTECTION

NOAA NOS and its partners developed new predictive habitat models that mapped the potential spatial distributions of 22 genera of deep-sea corals and sponges in Papahānaumokuākea Marine National Monument (PMNM). PMNM was established in 2006 and expanded in 2016 to protect a range of Native Hawaiian cultural, maritime heritage, and unique natural resources in the Hawaiian Archipelago. Since PMNM is such a large and remote area, PMNM resource managers identified a critical need for additional information about vulnerable and ecologically significant communities, including those in the deep-sea below 200 meters. Species distribution models are an essential tool to fill these types of information gaps, where deep-sea coral and sponge data are sparse, but timely information is needed to support conservation and management decisions. The deep-sea coral and sponge predictions developed here leverage existing data from the region, and were designed to inform the Office of National Marine Sanctuaries' ongoing management plan revision and sanctuary designation processes as well as guide its research and exploration efforts in the future.



Pink corals and huge white sponges observed at Tamana Seamount in Papahānaumokuākea Marine National Monument during Ocean Exploration Trust's 2021 Lu'uaeaahikiikapapakū expedition. Photo credit: Ocean Exploration Trust

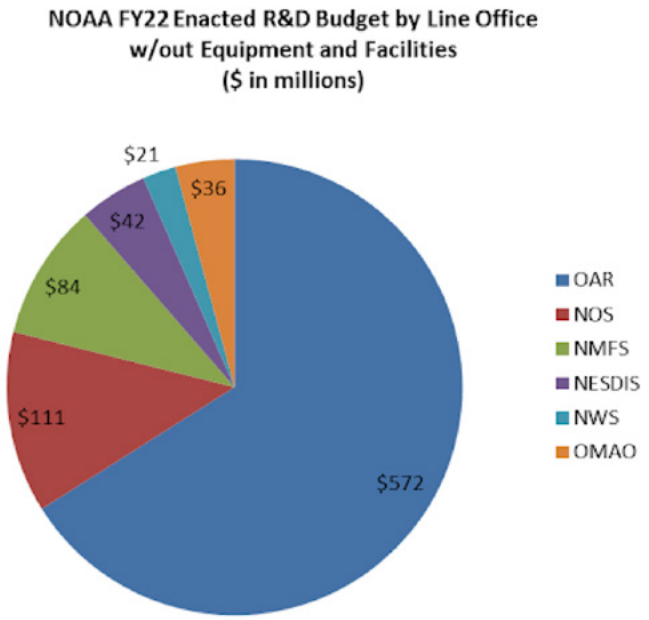
RESOURCES AND ACTIVITIES THAT SUPPORT R&D

INVESTING IN NOAA R&D

WHAT IS THE BUDGET FOR NOAA RESEARCH?

NOAA dedicated $1,198.3 million, approximately 20% of the agency's total budget, to R&D in fiscal year 2022 (FY22), with R&D defined as all research and development activities, including expenditures on R&D-related facilities and equipment purchases. This continues an eight-year trend of increased R&D expenditures, highlighting NOAA's efforts to address increased stakeholder needs for environmental intelligence and services in the face of a changing planet.

Note: Mission Support includes construction of R&D facilities. NOAA's satellite acquisition programs, which design, build, and launch NOAA's operational satellites, are not included.

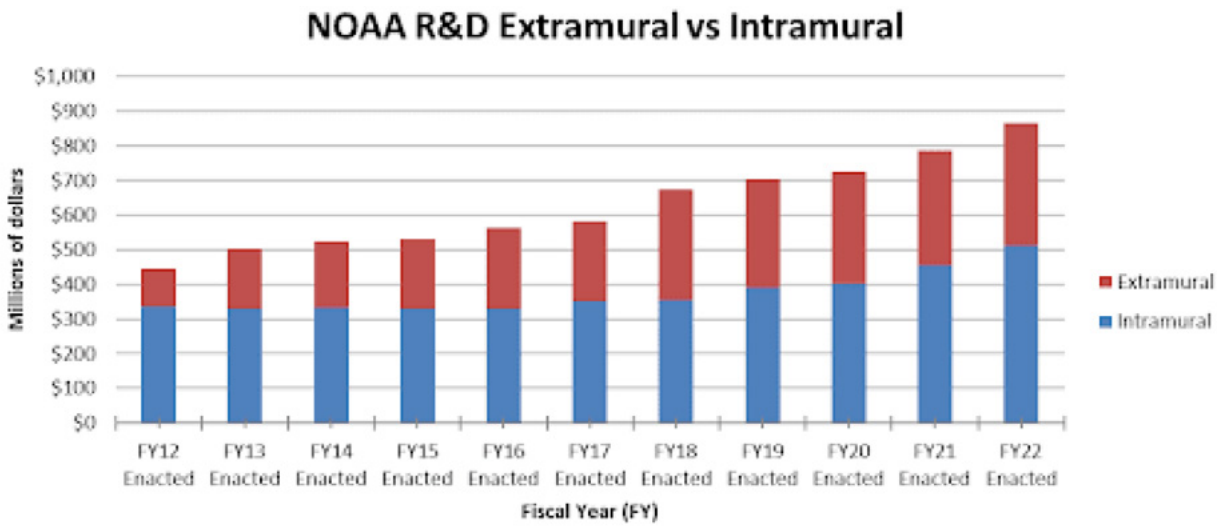


WHERE DO NOAA'S R&D INVESTMENTS GO?

Approximately 59% of NOAA's FY22 R&D budget went to internal R&D efforts, with the remaining 41% set aside for extramural research, enabling partnerships and collaborations with non-NOAA entities.

Note: The graph below excludes facilities and equipment from R&D budget calculations.

In FY22, NOAA also received support for R&D efforts under the Disaster Relief Supplemental Appropriations Act, 2022 (P.L. 117-43), $85.9 million, and the Infrastructure Investment and Jobs Act (P.L. 117-58), $189.1 million. These funds will support improvements to hurricane intensity and track forecasting, precipitation and flood prediction, wildfire prediction, detection, and forecasting, as well as coastal and ocean observing systems and research supercomputing.



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, 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.

REFERENCES:

NOAA (2016a), NOAA Administrative Order 216-115A - Research and Development in NOAA, National Oceanic and Atmospheric Administration, Washington, D.C.

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. Internal award winners can be found within the NOAA Office of Human Capital Services website and the 74th Annual Department of Commerce Honor Awards.

In 2022, scientists at NOAA were presented with external science awards for their excellence. The following list highlights a subset of these external awards.

PROFESSIONAL SOCIETIES AND ASSOCIATIONS:

AMERICAN METEOROLOGICAL SOCIETY (AMS)

- **Banner I. Miller Award** - Awarded to Kate Musgrave and John Knaff for developing a new application to significantly improve the prediction of rapid intensification of tropical cyclones in the Western North Pacific.
- **Walter Orr Roberts Lecturer** - Awarded to Julie DeMuth for groundbreaking interdisciplinary research to improve hazardous weather risk communication and dedicated work promoting the exchange of knowledge across the meteorology and social sciences communities.
- **Kenneth C. Spengler Award** - Awarded to Dr. Neil Jacobs for leadership in fostering community collaboration across the weather, water, and climate enterprise through the perspectives of science, policy, and business.
- **Award for Early-Career Professional Achievement** - Joseph Trujillo Falcón was awarded this for innovative and extensive collaboration in risk communication for Spanish-speaking communities and leadership as an exceptional student member across multiple AMS boards and committees.
- **AMS Honorary Member** - Harry (Bob) Glahn was selected as an AMS Honorary Member. AMS Honorary Members are persons of acknowledged preeminence in the atmospheric or related oceanic or hydrologic sciences, either through their own contributions to the sciences or their application or through furtherance of the advance of those sciences in some other way.
- **AMS Fellow** - Qin Xu and Meghan Cronin were elected as AMS Fellows. 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.

AMERICAN GEOPHYSICAL UNION (AGU)

- **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.
- **Bert Bolin Global Environmental Change Award & Lecture** – Awarded to Thomas Delworth for major contributions in atmosphere-ocean interactions through pioneering climate modeling.
- **AGU Fellow** - Steve Brown was elected as an AGU Fellow in recognition of remarkable innovation and sustained scientific impact. AGU Fellows embody AGU's values by fostering equity, integrity, diversity, and open science; by mentoring; through public engagement; and in their communications.

AMERICAN ACADEMY OF ENVIRONMENTAL ENGINEERS AND SCIENTIST

- **2022 Paul F. Boulos Excellence in Computational Hydraulics/ Hydrology** - Awarded to Noemi Vergopolan for original, innovative research on hyper-resolution land surface modeling.

AMERICAN SOCIETY OF CIVIL ENGINEERS

- **2022 American Society of Civil Engineers President's Medal** - Awarded to Deborah H. Lee for leadership of the Environmental and Water Resources Institute to provide for the technical, educational, and professional needs of its members, and to serve the public in the use, conservation, and protection of natural resources, and enhancement of human well-being.

AMERICAN ASTRONAUTICAL SOCIETY

- **Earth Science and Applications Award** - Awarded to the Geostationary Lightning Mapper Instrument Team for providing a novel and unique observational capability that has directly contributed to the nation's weather forecasting by improving severe weather observations, predictions, and warning lead-times, and having created new interdisciplinary research opportunities for the Earth and planetary sciences.

CANADIAN HYDROGRAPHIC ASSOCIATION

- **Sam Masry Prize** - Awarded to Larry Mayer for outstanding contributions to the hydrographic profession and /or its related disciplines.

NATIONAL WEATHER ASSOCIATION

- **Larry R. Johnson Special Award** – Awarded to the GSL Hazard Services Team. Because of their work, 20 NOAA National Weather Service (NOAA NWS) Offices were able to evaluate and issue long-duration winter and non-precipitation weather watches, warnings, and advisories for millions of people from 2020-2022, years ahead of the operational transition in 2023-2024.

STRUCTURAL ENGINEERS ASSOCIATION OF OREGON

- **$40 Million** - Awarded to Diego Arcas and Yong Wei. This state of-the-art facility is the first of its kind in the United States to be designed as a vertical evacuation refuge for tsunamis and using performance-based design resilience criteria exceeding standard building code requirements. Diego Arcas and Yong Wei have also won the 2021 Learning by Design Grand Prize Award for this project.

NORWEGIAN SCIENTIFIC ACADEMY FOR POLAR RESEARCH

- Larry Mayer was elected to the **Norwegian Scientific Academy for Polar Research**

SCIENTIFIC PEER-REVIEWS OR CITATIONS:

AMERICAN METEOROLOGICAL SOCIETY

- **AMS Editors Award for the Journal of Atmospheric Sciences** - Awarded to Maria Gehne for multiple concise, thoughtful, and thorough reviews.
- **AMS Editors Award for the Journal of Climate** - Awarded to Antonietta Capotondi for numerous high-quality and thorough reviews.
- **AMS Editors Award for Weather and Forecasting/Monthly Weather Review/ Journal of Applied Meteorology and Climatology** - Awarded to Ryan Lagerquist for contributing numerous rigorous and constructive reviews in the areas of machine learning and artificial intelligence across three journals.
- **AMS Editors Award for Weather and Forecasting** - Michael Brennan was awarded this for providing numerous superb reviews over many years in areas relating to tropical meteorology and operational prediction

WASHINGTON STATE ACADEMY OF SCIENCE

- Vera Trainer was named as a **new member of the Washington State Academy of Science** for foundational research on the regional to international impacts of harmful algal blooms, especially their ecological, physiological and economic impacts, to provide foundation for understanding the effects of climate change on coastal ecosystems, and highlighting the need for inclusion of affected communities in decision making.

OTHER AGENCIES OR INSTITUTIONS:

NATIONAL HURRICANE CONFERENCE

- **Outstanding Achievement Award** - Awarded to Jessica Schauer for outstanding leadership of NOAA NWS' effort to introduce new storm surge watches and warnings, the potential storm surge inundation graphic, time of arrival of tropical-storm-force winds graphics, updates to NOAA NWS Weather Forecast Office Hurricane Threats and Impacts graphics, and enhancements to NOAA NWS Wireless Emergency Alerts (WEA) for storm surge and hurricane warnings.

DEPARTMENT OF INTERIOR

- **Environmental Achievement Award** - Awarded to WCR - California Central Valley Office for environmental remediation and restoration associated with the San Joaquin River Restoration Program, a multi-agency effort to restore the upper 152-miles of the San Joaquin River from Friant Dam to the confluence with the Merced River.

U.S. FISH AND WILDLIFE SERVICE

- **U.S. Fish and Wildlife Service Rachel Carson Award for Scientific Excellence** - Awarded to Rachel Johnson for diagnosing and treating endangered winter run Chinook salmon that suffered thiamine deficiency.

NCSU OFFICE OF INCLUSIVE EXCELLENCE AND THE SOCIETY FOR MULTICULTURAL SCIENTISTS

- **Distinguished Alumni Award** - Awarded to LaTreese Denson in recognition of

accomplishments since graduating.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

- **Robert H. Goddard Honor Award in Quality and Process Improvement** - Matt Seybold was awarded for his outstanding creation of the GOES-18 Split Post-Launch Test approach including adaptation of post-launch test events, scheduling, and data product maturity.

THE NORTH PACIFIC MARINE SCIENCE ORGANIZATION (PICES)

- **PICES Ocean Monitoring Service Award** - Awarded to EcoFOCI for their efforts to secure the long-term the physical and biological observations that are critical to detecting and understanding ecosystem changes, and it draws attention to the need for time series observational data despite challenges associated with financial constraints. The PICES Ocean Monitoring Award recognizes individuals and programs working in North Pacific marine science who have contributed outstanding service in the fields of ocean observations, ocean monitoring, and the management and dissemination of observational data.

INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS

- **2022 Institute of Electrical and Electronics Engineers Corporate Innovation Award** - Awarded to NOAA Research's ARGO Program for innovation in large-scale autonomous observations in oceanography with global impacts in marine and climate science and technology.

U.S. DEPARTMENT OF AGRICULTURE

- **2021 Farm Service Agency Administrator's Awards for Service to Agriculture** - Awarded to Chuck Weirich for ensuring U.S. Department of Agriculture programs are delivered efficiently, effectively, with integrity, and with a focus on customer service. This award is the highest award available in the Farm Service Agency and it is highly competitive.

THE OHIO STATE UNIVERSITY

- **Heiskanen Award** - Awarded to Dan Roman. This award is to be made to the person who has most successfully forwarded the cause of geodesy and strengthened the reputation of the Department of Geodetic Science and Surveying in the field of geodesy.

EPA GULF OF MEXICO PROGRAM

- **Gulf Guardians - Partnerships** - Awarded to Mark Finkbeiner for his leadership of the Gulf of Mexico Seagrass Monitoring Community of Practice that has been active in gathering expertise, identifying information priorities, synthesizing existing needs and coordinating with scientists and resource managers in the Gulf.

PACIFIC SEABIRD GROUP

- **Special Achievement Award** - Awarded to Shannon Fitzgerald for his dedication to develop innovative methods and collaborations to monitor and mitigate seabird bycatch for over 34 years.

NORTH PACIFIC FISHERY MANAGEMENT

- **Terry Quinn II Distinguished Science Award** - Anne Hollowed and Jim Ianelli were recognized for outstanding contributions in fishery science.

CAREER COMMUNICATIONS GROUP, INC.

- **Women of Color STEM Outstanding Achievement Award, Technology Rising Star** – Awarded to Jean Lim for demonstrated excellence in applying machine learning, software development, and bioinformatics to improve eDNA analyses and ecosystem-based fisheries management in the Gulf of Mexico.

BIBLIOMETRICS

This chapter represents a rigorous assessment of NOAA's scholarly research output between 2017 and 2021. Through analysis of publications authored during that time period, NOAA's core research areas were identified and used to establish a robust scholarly performance metric to demonstrate NOAA's productivity and impact within these research areas. As a benchmarking exercise, these metrics were then compared with those of other federal agencies conducting research in these disciplines.

The research areas listed below represent the bulk of NOAA's scholarly output between 2017 and 2021, with approximately 81 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

NASA: National Aeronautics and Space Administration

USDA: U.S. Department of Agriculture

SI: Smithsonian Institution

METHODOLOGY

Scholarly data and metrics for this report were obtained using InCites (Clarivate Analytics), a web-based platform that allows for the assessment of the research productivity and relative impact of research organizations based on peer-reviewed articles indexed in Web of Science. For the purposes of this report, a "NOAA article" is defined as a peer-reviewed journal article 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 2017 and 2021 and indexed in the InCites dataset as of October 6, 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 2017 and 2021.

This report focuses on NOAA's eight core research areas, determined by using the WoS research schema which is 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 in the top 10 percent by citation, and international collaborations and were obtained using InCites and WoS. 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 2021 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:

AS (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 2017-2021

10,551 Total Publications

122 *h*-index

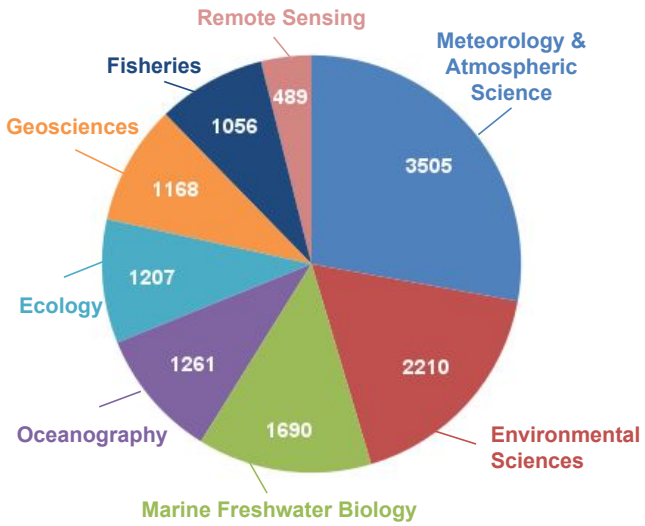
168,492 Sum of Times Cited

91.8% % of Articles Cited

17.7% of Articles in Top 10% by citation

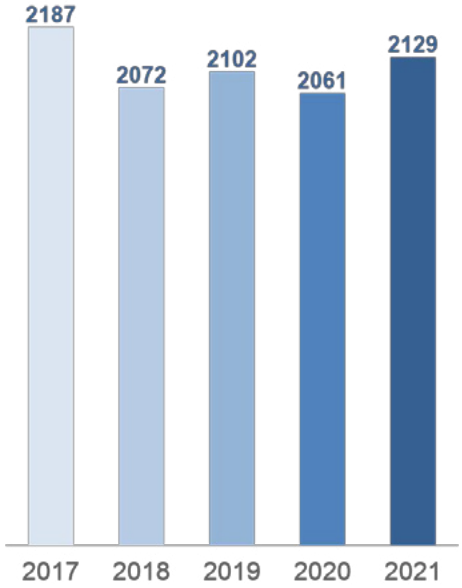
A "NOAA article" is defined as a peer-reviewed publication indexed in the Web of Science (WoS) Core Collection and identified by WoS indexers as having one or more authors who list their affiliation as National Oceanic and Atmospheric Administration. This report analyzes articles that fit this criteria and were published between 2017 and 2021 and indexed in the InCites dataset as of October 6, 2022. As an organization, NOAA has an *h*-index of 122 meaning that of the 10,551 articles published by NOAA authors in the period this report reflect, 122 have been cited at least 122 times.

Top Research Areas



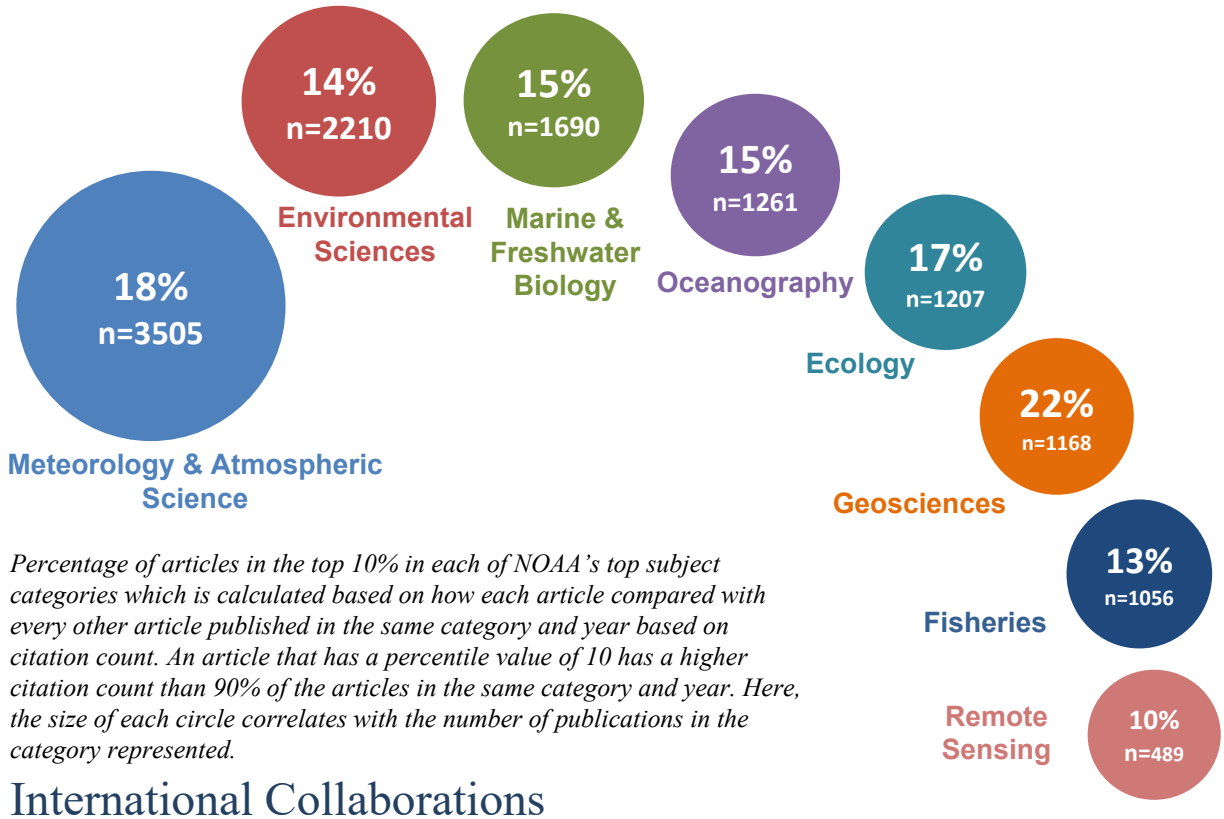
81% of NOAA articles fall within these eighth subject categories. Subject categories are defined, and assigned to articles, by Web of Science based on the journal in which each article was published. A single article may be assigned to multiple subject categories.

Articles per year



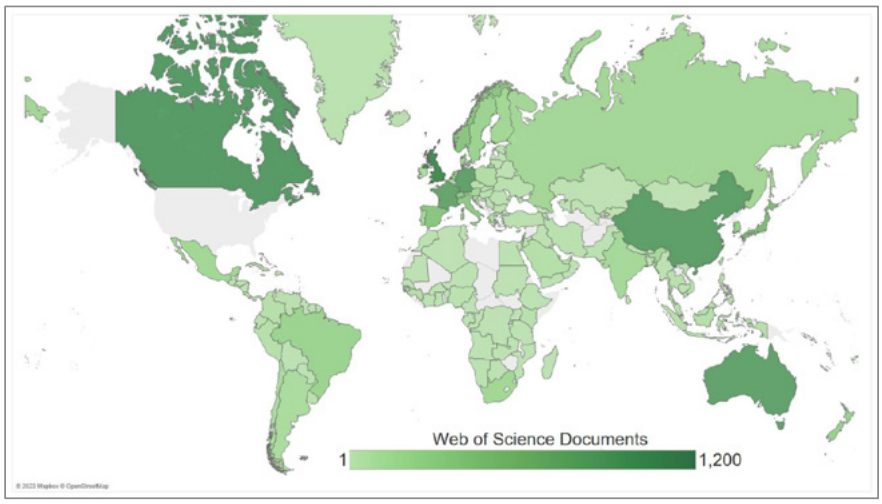
Non-cumulative number of NOAA articles published per year. On average NOAA authors have published 2,110 articles annually between 2017 and 2021.

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

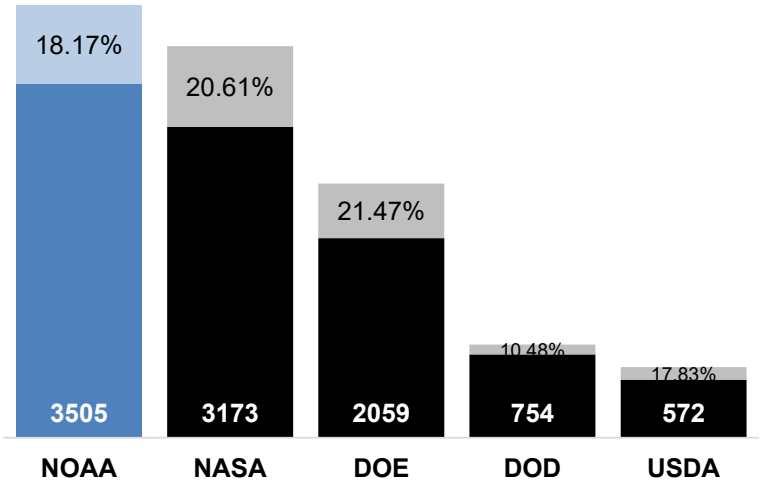


NOAA authors have collaborated with authors at more than **6,000** institutions in **169** countries and territories.

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 co-authored with NOAA authors. Minimum and maximum data values are given in the legend. The U.S. is not included (10,551 documents).

Meteorology and Atmospheric Sciences

Total Number of Articles by Agency



Between 2017 and 2021, NOAA published an average of 701 articles per year in the field of meteorology and atmospheric sciences, resulting in a total of 3505 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.

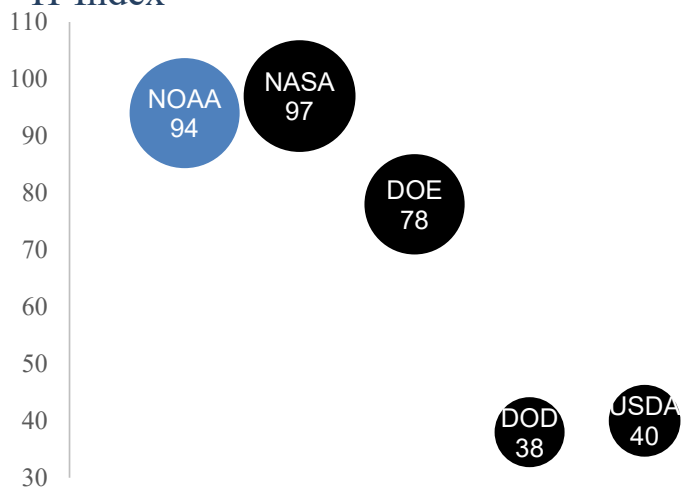
Top Journals where NOAA Publishes

- 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.
- Lessen, et al. 2019. Improvements in the GISTEMP Uncertainty Model. J Geophys Res Atmos.

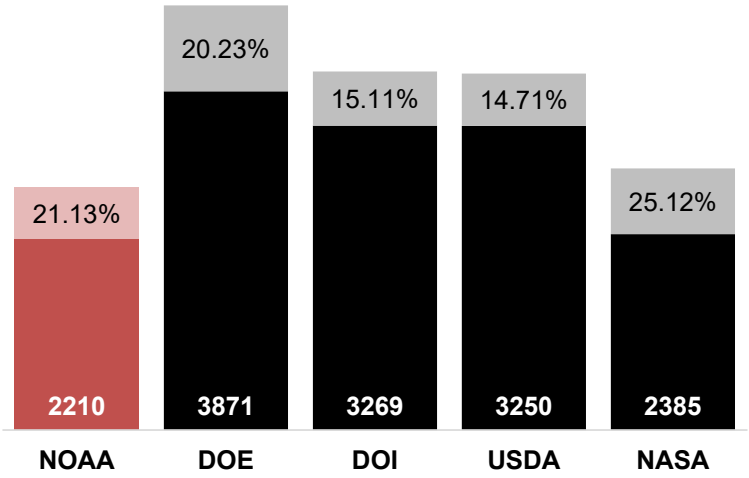
H-Index



Within the field of meteorology and atmospheric sciences, NOAA has an *h-index* of 94—meaning that 94 of these articles have been cited in the peer-reviewed literature at least 94 times.

Environmental Sciences

Total Number of Articles by Agency



Between 2017 and 2021, NOAA published an average of 442 articles per year in the field of environmental sciences, resulting in a total of 2,210 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in environmental sciences.

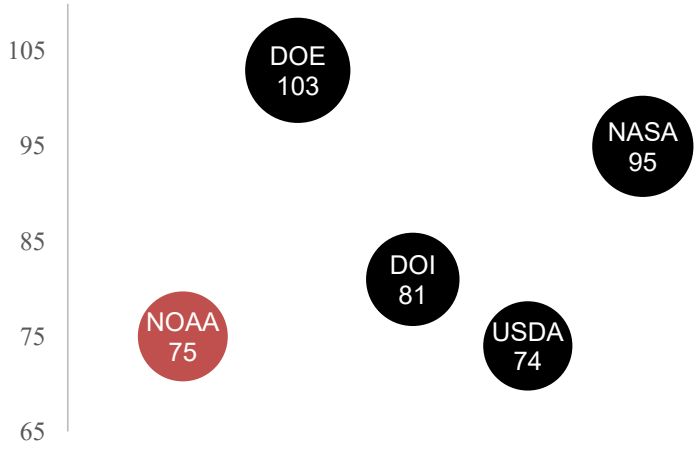
Top Journals where NOAA Publishes

- Atmospheric Chemistry and Physics
- Frontiers in Marine Science
- Remote Sensing
- Environment Science & Technology
- Atmosphere

Highly Cited NOAA Articles

- Jung, et al. 2018. Validation of ATR FT-IR to identify polymers of plastic marine debris, including those ingested by marine organisms. Marine Poll Bull.
- Box, et al. 2019. Key indicators of Arctic climate change: 1971-2017. Environ Res Lett.
- Rolph,et al. 2017. Real-time Environmental Applications and Display sYstem: READY. Environ Model & Soft.

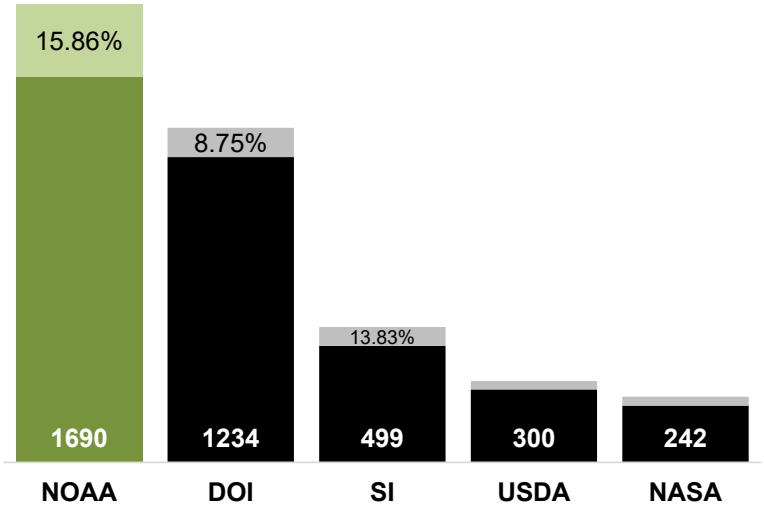
H-Index



Within the field of environmental sciences, NOAA has an *h-index* of 75—meaning that 75 of these articles have been cited in the peer-reviewed literature at least 75 times.

Marine & Freshwater Biology

Total Number of Articles Per Agency



Between 2017 and 2021, NOAA published an average of 338 articles per year in the field of marine & freshwater biology, resulting in a total of 1,690 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.

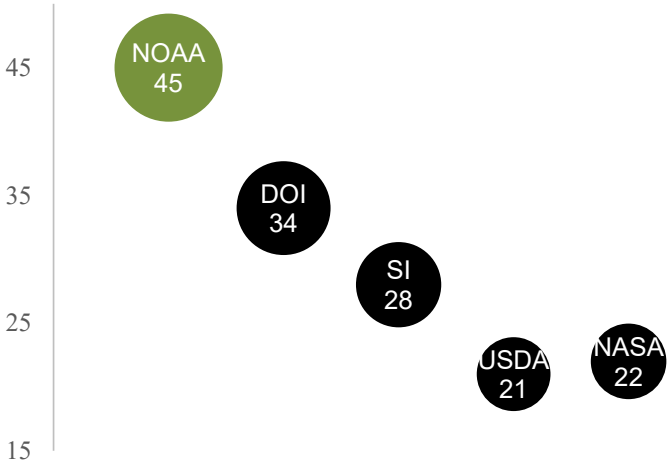
Top Journals where NOAA Publishes

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

Highly Cited NOAA Articles

- Eakin, et al. 2019. The 2014-2017 global-scale coral bleaching event: insights and impacts. Coral Reefs.
- Wells, et al. 2016. Future HAB science: Directions and challenges in a changing climate. Harmful Algae.
- Ryabinin, et al. 2019. The UN Decade of Ocean Science for Sustainable Development. Frontiers in Marine Science.

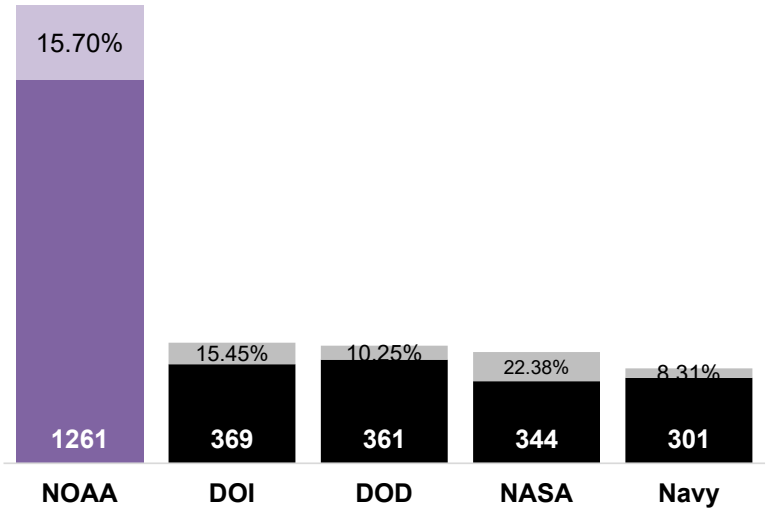
H-Index



Within the field of marine & freshwater biology, 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.

Oceanography

Total Number of Articles by Agency



Between 2017 and 2021, NOAA published an average of 252 articles per year in the field of oceanography, resulting in a total of 1,261 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in oceanography.

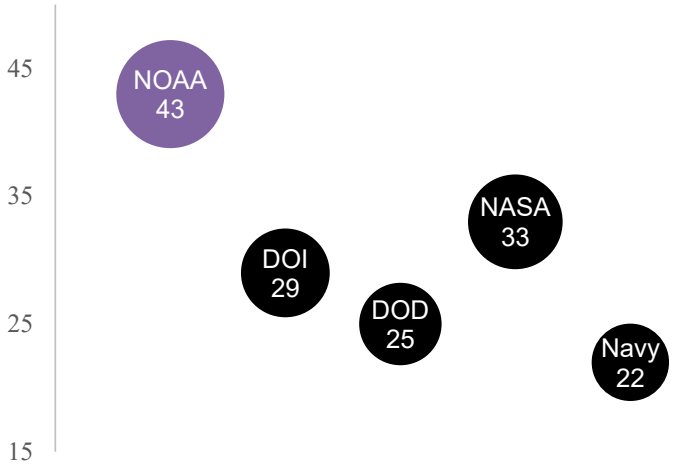
Top Journals where NOAA Publishes

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

Highly Cited NOAA Articles

- 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.
- Kleisner, et al. 2017. Marine species distribution shifts on the US Northeast Continental Shelf under continued ocean warming. Progress in Oceanography.

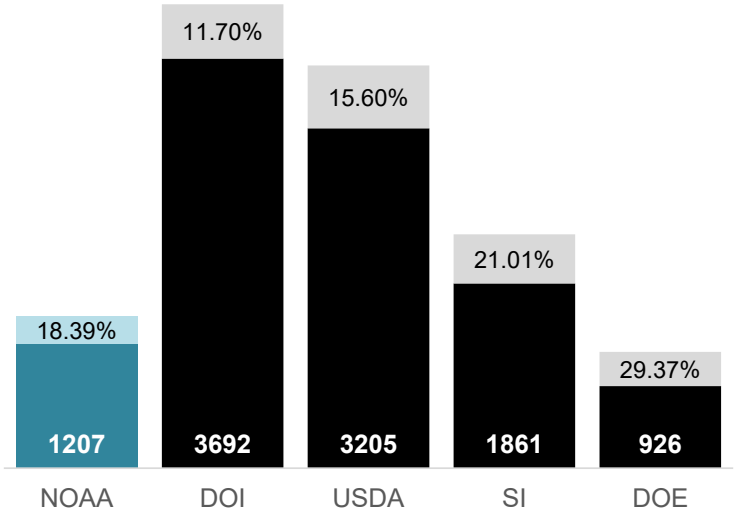
H-Index



Within the field of oceanography, NOAA has an *h-index* of 43—meaning that 43 of these articles have been cited in the peer-reviewed literature at least 43 times.

Ecology

Total Number of Articles by Agency



Between 2017 and 2021, NOAA published an average of 241 articles per year in the field of ecology, resulting in a total of 1,207 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in ecology.

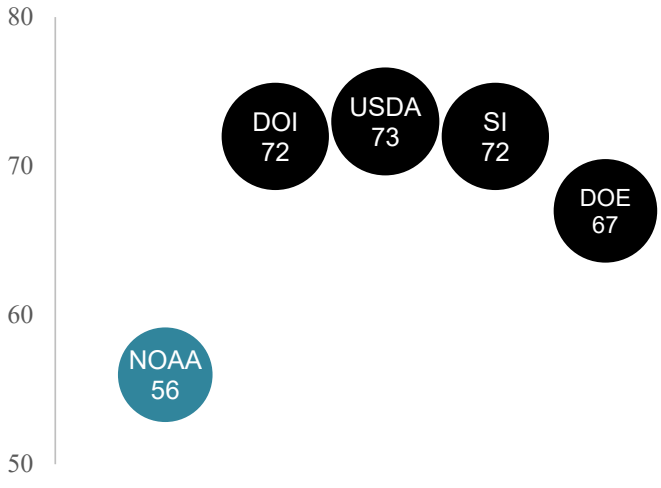
Top Journals where NOAA Publishes

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

Highly Cited NOAA Articles

- 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.
- Miloslavich, et al. 2018. Essential ocean variables for global sustained observations of biodiversity and ecosystem changes. Global Change Biology.

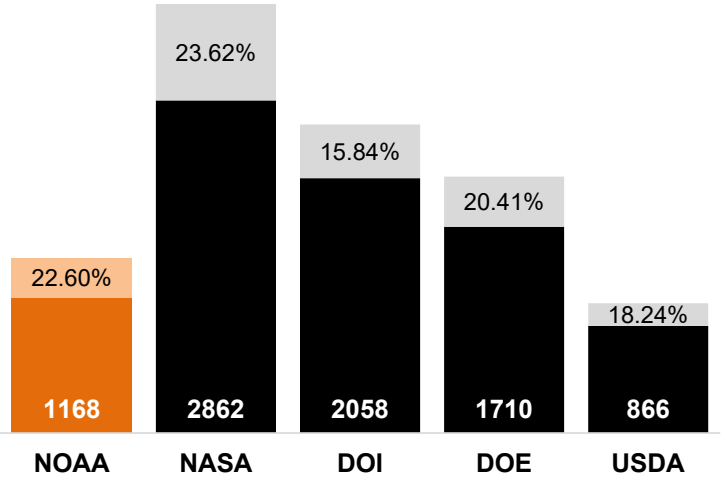
H-Index



Within the field of ecology, NOAA has an *h-index* of 56—meaning that 56 of these articles have been cited in the peer-reviewed literature at least 56 times.

Geosciences

Total Number of Articles by Agency



Between 2017 and 2021, NOAA published an average of 234 articles per year in the field of geosciences, resulting in a total of 1,168 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in geosciences.

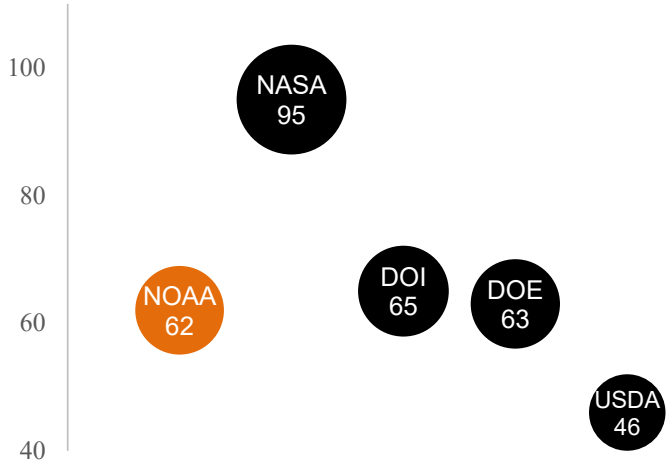
Top Journals where NOAA Publishes

- Geophysical Research Letters
- Remote Sensing
- Geoscientific Model Development
- Global Biochemical Cycles
- Earth and Space Science

Highly Cited NOAA Articles

- Meinshausen, et al. 2017. Historical greenhouse gas concentrations for climate modelling (CMIP6). Geoscientific Model Develop.
- Le Quere, et al. 2018. Global Carbon Budget 2018. Earth System Science Data
- Nisbet, et al. 2019. Very Strong Atmospheric Methane Growth in the 4 Years 2014-2017: Implications for the Paris Agreement. Global Biochem Cycles.

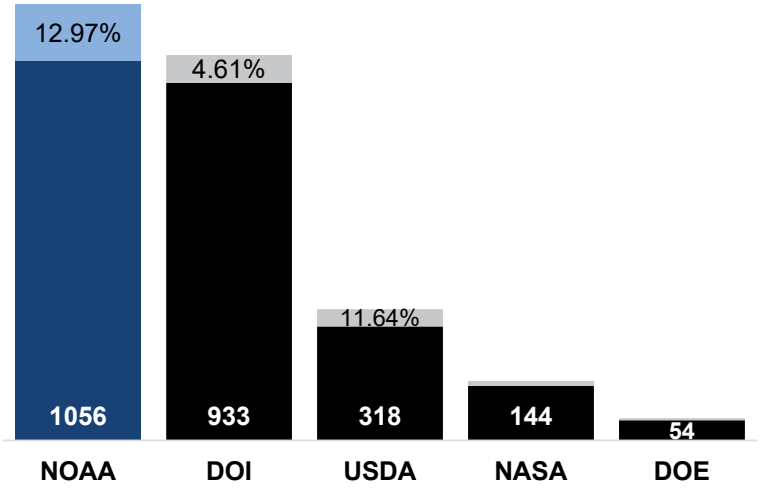
H-Index



Within the field of geosciences, NOAA has an *h-index* of of 62—meaning that 62 of these articles have been cited in the peer-reviewed literature at least 62 times.

Fisheries

Total Number of Articles by Agency



Between 2017 and 2021, NOAA published an average of 211 articles per year in the field fisheries, resulting in a total of 1,056 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in fisheries.

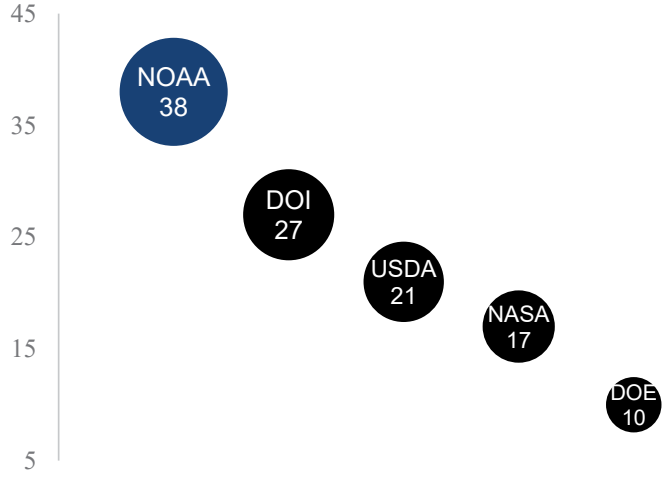
Top Journals where NOAA Publishes

- ICES Journal of Marine Science
- Fisheries Research
- Canadian Journal of Fisheries & Aquatic Science
- Fishery Bulletin
- Fish and Fisheries

Highly Cited NOAA Articles

- Hyder, et al. 2018. Recreational sea fishing in Europe in a global. Fish & Fisheries.
- Frose, et al. 2017. Estimating fisheries reference points from catch and resilience. Fish & Fisheries.
- Erisman, et al. 2017. Fish spawning aggregations: where well-placed management actions can yield big benefits for fisheries and conservation. Fish and Fisheries

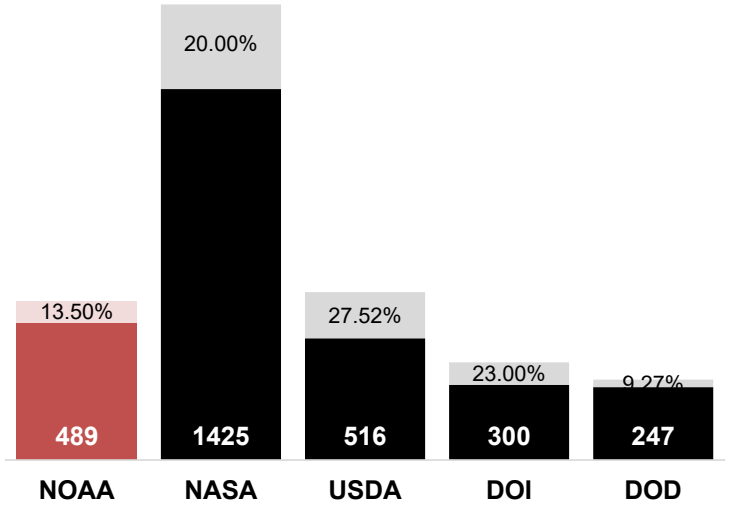
H-Index



Within the field of fisheries, NOAA has an *h-index* of 38—meaning that 38 of these articles have been cited in the peer-reviewed literature at least 38 times.

Remote Sensing

Total Number of Articles by Agency



Between 2017 and 2021, NOAA published an average of 98 articles per year in the field of remote sensing, resulting in a total of 489 articles. Also shown is the percentage of these articles which fall within the top 10 percent of the most cited articles in remote sensing.

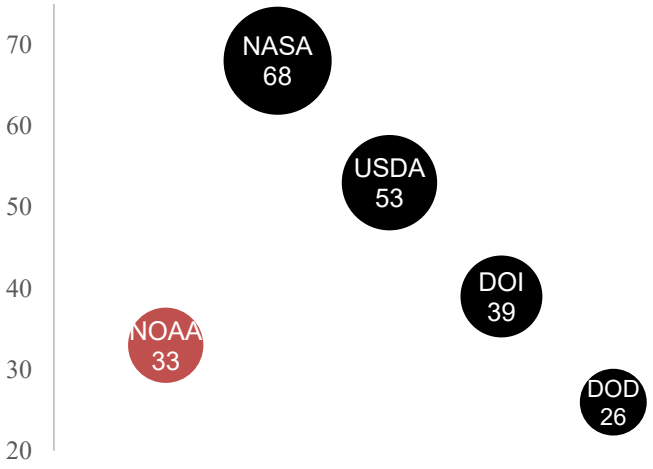
Top Journals where NOAA Publishes

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

Highly Cited NOAA Articles

- 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.
- O'Reilly and Werdell. 2019. Chlorophyll algorithms for ocean color sensors-OC4, OC5 & OC6. Remote Sensing of Environment.

H-Index



Within the field of geosciences, NOAA has an *h-index* of 33—meaning that 33 of these articles have been cited in the peer-reviewed literature at least 33 times.