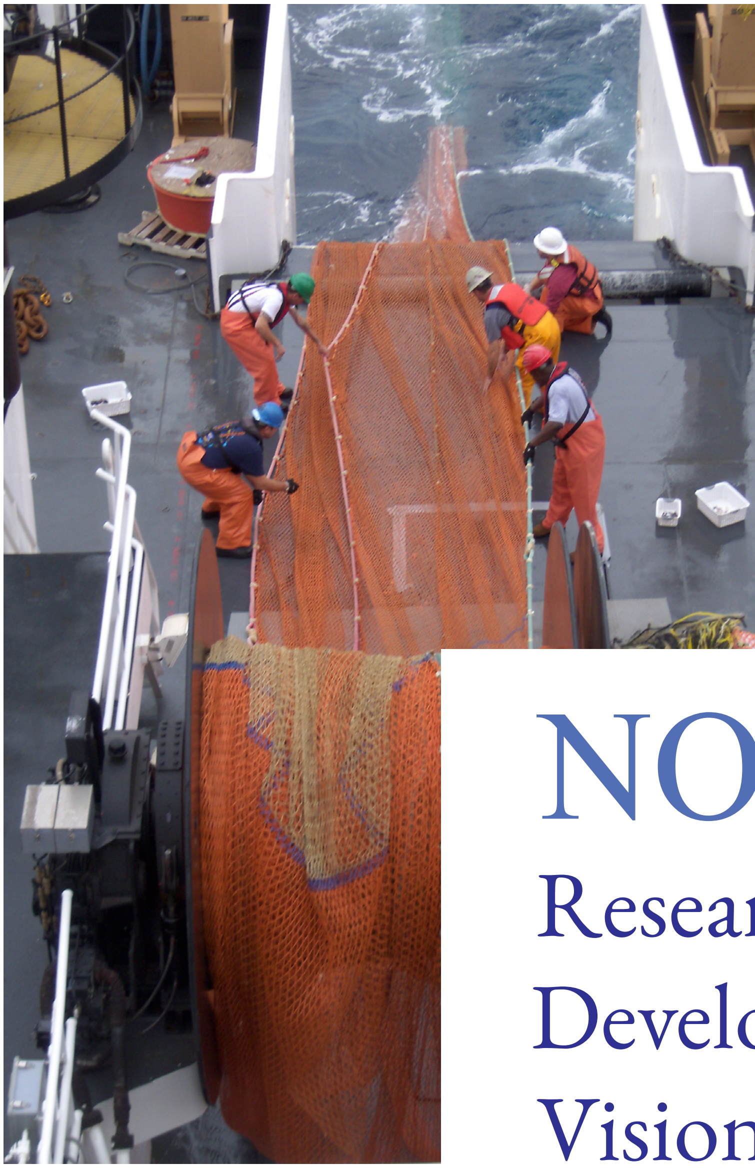

NOAA

Research and Development Vision Areas: 2020–2026

NOAA Research and Development Vision Areas: 2020-2026

NOAA
Silver Spring,
Maryland

June 2020

noaa

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION

NOAA Research Council

Letter from the Administrator

Research and development (R&D) are the foundation of the National Oceanic and Atmospheric Administration's (NOAA) work as the nation's premier ocean and atmospheric science agency. NOAA's R&D reach from the depths of the sea to satellites in space. NOAA transitions its R&D into knowledge for policy development and informed decision making, technology for commercialization, operational forecasts, and other applied scientific products to meet the nation's needs. From severe weather warnings to coastal resilience, fisheries management to environmental observing systems, NOAA science enhances the well-being of all American people.

This NOAA Research and Development Vision Areas: 2020-2026 will set the priority foci for R&D at NOAA over the next seven years. Implementation of the Vision will be captured in NOAA's line office's annual operating plans, and will be adjusted based on budget realities, emerging technologies, and changing societal needs.

The Vision describes R&D priorities within three vision areas:

1. **Reducing societal impacts from hazardous weather and other environmental phenomena** - NOAA saves lives and reduces economic damages by forecasting and communicating weather, drought, flood, climate, space events, and other environmental phenomena.

2. **Sustainable use and stewardship of ocean and coastal resources** - NOAA's R&D efforts enhance the American economy through work supporting the exploration and safe navigation of U.S. waters. NOAA science ensures the productivity and sustainability of aquaculture and fisheries, informs the conservation of critical marine areas, and enables tourism and recreation opportunities.

3. **A robust and effective research, development, and transition enterprise** - NOAA R&D require models, observations, and applications from emerging fields, such as artificial intelligence, for effective and efficient use of economic, social science, physical, and ecological data.

People and partnerships make NOAA R&D possible. More than 6,000 NOAA scientists and engineers produce credible and reliable world-class results. Additionally, NOAA leverages the expertise and capabilities of partners, including the private sector, academia, other agencies, and international groups, to accelerate R&D achievements.

With continued partnerships and dedicated work on the R&D priorities outlined in this document, NOAA is poised to advance its mission of science, service, and stewardship.

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Assistant Secretary of Commerce for Environmental Observation and Prediction
Performing the duties of Under Secretary of Commerce for Oceans and Atmosphere

Contents

Vision and Mission

NOAA's mission is 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.

The vision of the National Oceanic and Atmospheric Administration (NOAA) captures the societal benefits of research and development (R&D) as a future with healthy ecosystems, communities, and economies that are resilient in the face of change[1]. As expressed in NOAA's 20 Year Research Vision (2005-2025), discoveries in science and technology and integration of research across our environment, economy, and human health are key to meet urgent demands from a growing global population[2].

NOAA's mission embodies science, service, and stewardship, and NOAA's research and development enterprise is essential to fulfilling NOAA's mission and legislatively mandated responsibilities.

Research and development at NOAA are investments in the scientific knowledge and technology that enables the United States to protect lives and property, sustain a strong economy, and address environmental challenges. NOAA's R&D priorities are accomplished with a wide breadth of partners and collaborators, including interagency, international, academic, non-governmental, and private organizations. Many of these partners provide feedback (O2R) that improves NOAA's R&D and the resulting products and decision support services.

To meet its partner and stakeholder needs, NOAA transitions its R&D into operations, applications, and commercialization. This transition of NOAA R&D provides reliable information to its stakeholders to reduce societal impacts from hazardous weather and other environmental phenomena, foster the sustainable use and stewardship of ocean and coastal resources (Blue Economy), and overall provide a greater understanding of Earth systems in a robust, effective R&D enterprise.

Divers head out of Whaler's Cove at Point Lobos Ecological Reserve to conduct subtidal surveys for the Reef Environmental Education Foundation. Photo credit: Chad King, NOAA MBNMS.

Purpose and Scope

This seven year NOAA Research and Development Vision Areas (Vision) characterizes the priorities and guidance for NOAA's R&D activities from 2020-2026. 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.

People digging for razor clams on the Washington coast. NOAA produces harmful algal bloom forecasts that allow coastal managers to make decisions about razor clam harvests. Photo credit: Dan Ayres, Washington Fish and Wildlife.

The Vision is organized into three vision areas:

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**

While the document is divided into the three vision areas, there is intrinsic overlap. Each vision area is broken down into key questions. In the body of the Vision, each key question has specific objectives and corresponding NOAA research highlights. The order of the objectives should not be interpreted as an order of importance or priority. While not covering all of NOAA's research activities, these key questions and objectives identify NOAA's broad areas of research and reflect NOAA's current research needs and requirements.

This Vision is built on the strategic foundation and policy guidance provided by the Department of Commerce, key Federal statutes, and various planning documents produced by NOAA. The Vision is presented as a framework with which NOAA, partners, and the public can identify priorities and evaluate progress toward anticipated societal outcomes. In developing this Vision, NOAA obtained input from both internal and external sources. This input captured NOAA's R&D needs, priorities, and gaps in scientific knowledge, technology, and applications. R&D at NOAA are outcome-oriented; consequently, NOAA seeks to transition R&D to knowledge, tools, and useful applications that benefit the communities NOAA serves.

In addition, many NOAA R&D components are interdisciplinary, requiring communication and partnerships across NOAA offices. Often these collaborations extend beyond NOAA to include partnerships with other Federal and State agencies, Tribes, academic institutions, non-governmental organizations, and the private sector. With this Vision, the agency identifies opportunities and potential challenges along the path toward achieving long-term goals and is thus better prepared to respond to changing conditions. This is a dynamic and living document that will be updated in light of the Nation's priorities, budgetary outlook, emerging capabilities, and new scientific challenges.

Purpose and Scope

NOAA will use this document for planning and prioritizing projects and guiding NOAA's investments for NOAA-funded R&D areas. As such, the Vision extends across the seven-year budget horizon, incorporating objectives for the current year, pending year, budgeting year, and the following four-year planning period. NOAA's success in accomplishing R&D is a function of appropriations from Congress (Figure 1). Implementation of the Vision is captured in NOAA components' annual guidance and operating plans, based on budget realities and emerging needs, as well as the NOAA Research and Development Database and annual NOAA Science Report.

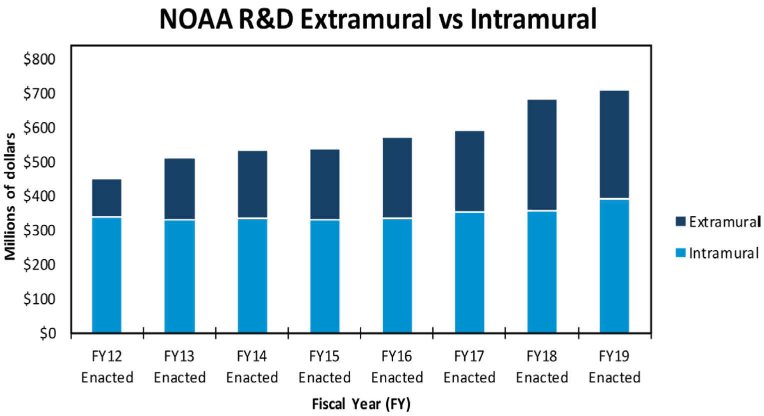
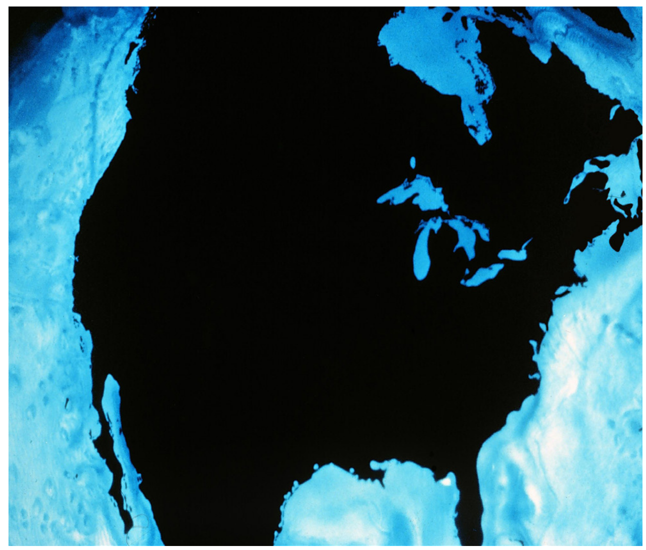


Figure 1. NOAA R&D include intramural and extramural activities. Intramural activities are internal R&D efforts, such as those performed by NOAA laboratories and science centers. Extramural activities include NOAA R&D partnerships and collaborations with non-NOAA entities, such as through grants, contracts, or cooperative agreements.
Note: This graph excludes facilities and equipment from R&D budget calculations.



Satellite photo of North America. Image credit: D. Norton, NOAA GLERL.

NOAA abides by the Federal definitions of R&D set by the National Science Foundation:

Research – Systematic study directed toward a fuller scientific knowledge or understanding of the subject studied.

Development – Systematic use of the knowledge or understanding gained from research, directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes.

NOAA R&D strike a balance among mission relevance, time to maturity, cost of research projects, and risk. Additionally, NOAA funds both extramural and intramural research.

NOAA's operational science activities, routine product testing, quality control, routine mapping and surveys, collection of general-purpose statistics, and the training of scientific personnel are not considered R&D; however they serve as significant drivers for R&D activity.

Guiding Principles for R&D

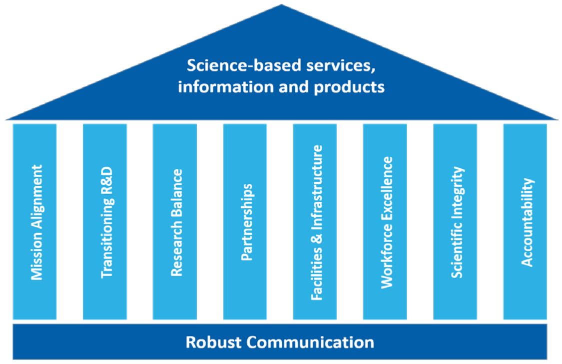


Figure 2. NOAA R&D guiding principles.

In directing, formulating, and evaluating R&D, NOAA follows eight principles outlined in NOAA Administrative Order (NAO) 216-115A[3]:

1. Mission Alignment: NOAA R&D serves NOAA's mission "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".

2. Transitioning Research into Operations, Application, Commercialization, and other Uses (R2X): NOAA maintains a mission-oriented enterprise that aims to identify and apply R&D outputs to new and improved products, services, or more effective and efficient operations, and includes "operations to research" to provide feedback on what research is needed to improve operations and applications. NOAA Administrative Order 216-105B[4] outlines requirements for coordinating NOAA-wide transition activities, establishing specific transition plans for projects evolving beyond Readiness Level 4, funding of testbeds, and committing resources to carry out transitions responsibilities. The NOAA Research Council and NOAA Line Offices implement the guidance to improve the effectiveness of NOAA R&D transition activities.

3. Research Balance: NOAA must balance its portfolio of R&D activities to optimally achieve NOAA's strategic objectives while continually strengthening the quality, relevance, and performance of its R&D products. R&D activities are investments in the future; therefore, tradeoffs must be assessed among competing investment options in terms of focus, benefits, costs, risks, and time horizons.

4. Partnerships: NOAA engages in interagency, academic, public-private, and other partnerships for enhanced innovation, stakeholder input, and return on investment for the American public. NOAA funds external research and leverages the expertise and capabilities of domestic and international partners to develop new techniques and accelerate the pace at which R&D are conducted. Examples of NOAA partnerships include university Cooperative Institutes, regional activities (e.g., NOAA Regional Integrated Sciences and Assessments), interagency activities, international engagements, Memoranda of Agreement (MoA), the National Oceanographic Partnership Program (NOPP), the Educational Partnership Program (EPP), public-private activities such as CRADAs, and citizen science projects.

5. Facilities and Infrastructure: Successful implementation of the Vision requires NOAA to maintain and improve the "hard" assets that enable R&D. These "hard" assets include laboratories and science centers, ships, aircraft, high performance computing capacity, satellites, and buoys. These platforms must be maintained, updated, and operated to continue to support NOAA's world-class R&D.

Guiding Principles for R&D

6. Workforce Excellence: NOAA hires and trains a diverse and inclusive scientific workforce through outreach events, internships, fellowships, and professional development opportunities. NOAA's highly skilled employees drive excellence in R&D that is reflected in achievement awards and recognition in science, engineering, leadership, professional excellence, and more. NOAA's outreach and education programs help to create a scientifically literate public and diverse recruitment pool to maintain the flow of scientists into the NOAA workforce.

7. Scientific Integrity: NOAA scientists act with integrity to produce credible and reliable R&D results. To guide the culture of scientific excellence at NOAA, NOAA's Scientific Integrity Policy, NAO 202-735D[5], outlines the responsibilities for scientists, those who use scientific results to set policy, and managers.

8. Accountability: NOAA will regularly evaluate its R&D and adjust activities and priorities as needed. Accountability for NOAA's R&D portfolio rests with the NOAA Chief Scientist in collaboration with Line Office Assistant Administrators (AAs). Those responsible and accountable for R&D activities will be assigned authority to manage and direct the efforts. NOAA uses five types of evaluations, listed in the NAO 216-115A, which are periodic, laboratory/science center/program, ad hoc, progress-to-plan, and portfolio R&D evaluations. Science managers may seek assistance from NOAA's Science Advisory Board (SAB) to participate in laboratory, cooperative institute, or program reviews, in accordance with the SAB charter and concept of operations. The outcome of the reviews are communicated to the NOAA Chief Scientist, via the NOAA Research Council.

Drivers

In 2004, the NOAA Science Advisory Board (SAB) conducted a review of NOAA science and recommended strategic planning for the agency's research activities. Strategic planning facilitates internal and external communication about research priorities and objectives and serves as a tool for meeting NOAA's long-term goals[6]. In response to the SAB's recommendation, NOAA created R&D Plans for 2005-2009, 2008-2012, and 2013-2017, and this current document.

The NOAA R&D Vision Areas for 2020-2026 builds on the 2013-2017 R&D Plan, internal and public input, legislative mandates and authorities, administrative guidance (e.g., Department of Commerce 2018-2022 Strategic Plan), NOAA planning documents (e.g., program office strategic plans, NOAA Aquaculture Strategic Plan FY2016-2020), and NOAA SAB recommendations to address emerging priorities and refine previously identified R&D objectives. The Vision also reflects public and internal comments solicited during a public town hall, NOAA Strategic Council meetings, and Federal Register public comment periods. The R&D objectives in this Vision will be adjusted in accordance with resource availability and Congressional appropriations. New priorities may emerge as technologies, resources, and societal needs change. The Vision is not intended to encompass the wide breadth of R&D that NOAA performs; rather, it focuses on highlighting NOAA's current priorities for the next seven years.

Evaluation

Figure 3. Key steps in managing NOAA's research and development portfolio: planning, execution/ monitoring, evaluation, and reporting (Procedural Handbook, NAO 216-115A, 2017).

Evaluation is a key and iterative step in managing NOAA's R&D portfolio, and is particularly critical for assessing tradeoffs among competing investments in terms of their benefits, costs, and risks (Figure 3). Evaluation answers fundamental questions about the R&D portfolio's successes and effectiveness, and its data are useful for improving the portfolio's products, services, and outcomes and as critical input for guiding future R&D direction and strategies. The Vision will be periodically evaluated following the guidance in the procedural handbook for NOAA Administrative Order (NAO) 216-115a[7] on R&D in NOAA. NOAA uses five types of evaluations, listed in the NAO, which are periodic performance reviews, program/laboratory reviews, progress-to-plan reviews, portfolio reviews, and *ad hoc* reviews.

A Shoreline Assessment Team studies damage to the coast in Buzzards Bay after an oil spill. Part of NOAA's role after a spill is to use science to figure out exactly what damage has been done so the ecosystem can be restored. Photo credit: NOAA.

Evaluation

NOAA will use metrics that cover a broad research portfolio to indicate outputs and outcomes of R&D activities. These metrics can be linked into an R&D value chain that describes the connections between inputs, outputs, and outcomes as R&D is transitioned from basic research to full operation/application/commercial release. Building upon lessons learned from evaluations of previous NOAA R&D Plans, NOAA will leverage the following existing mechanisms to track the progress toward R&D Vision Area objectives.

- The NOAA Science Report, a yearly compilation of NOAA's R&D accomplishments, will provide an annual summary of R&D projects working toward this Vision's objectives.
- NOAA laboratories, centers, and programs create Annual Operating Plans (AOPs) that capture upcoming NOAA projects. The Vision can inform AOP development, and the AOPs in turn inform R&D Vision Area progress evaluation.
- NOAA conducts reviews of NOAA programs, laboratories, and science centers. These reviews will assess progress toward this Vision's objectives.
- The NOAA Research and Development Database (NRDD) contains information about the R&D projects conducted and funded by NOAA in a secure, web-based performance management and business intelligence tool. The NRDD was initially populated in 2017, with subsequent annual updates and submissions. NRDD submissions will be used to monitor NOAA's R&D portfolio and progress made on this Vision's objectives.
- NOAA uses bibliometrics, such as those reported in the annual NOAA Science Report from the Research Publication Tracking System, to assess the output of peer-reviewed scientific articles.
- The Government Performance and Results Act (GPRA) of 1993 and Government Performance and Results Modernization Act (GPRMA) of 2010 require federal agencies to measure their performance. Performance is tracked and reported annually (e.g., DOC Annual Performance Plan and Report, DOC Annual Strategic Review) and provide high-level R&D output and outcome metrics to inform the Vision's evaluation from a value-chain perspective.

Remotely operated vehicle Deep Discoverer is recovered from a dive. Image courtesy of NOAA Okeanos Explorer Program, Gulf of Mexico 2014 Expedition.

Summary of Vision Areas

Since its creation, the NOAA vision, mission areas, and science activities have been guided by the applicable authorities that drive NOAA as a science-based agency with explicit foci (e.g., fisheries, oceans, research, satellites, weather). NOAA has matured as an agency, from a focus on R&D within a single discipline toward increasing integration between multiple disciplines and partnerships. The context for NOAA R&D evolves over time as scientific advances demonstrate the changes taking place in the coupled Earth system, relative to baseline states of the oceans and atmosphere (and made possible through long-term data collection and R&D). This Vision reflects that evolution with a focus on three main areas that are more fully described below and throughout this document: improving warnings and forecasts for hazardous weather events to reduce societal and economic impacts; informing decisions on the balance of growing the Blue Economy (e.g., aquaculture, domestic fisheries, maritime commerce) with conservation of vital ocean and coastal resources; and maintaining and building an effective R&D enterprise that supports R&D (e.g., infrastructure) and transitions R&D to operations, which are vital to meeting priority goals and objectives.

The Magnuson-Stevens Fishery Conservation and Management Act (MSA, 1976) governs marine fisheries in the United States. In a broad sense, MSA was initially adopted to extend U.S. territorial waters, control foreign fishing activities in U.S. waters, prevent overfishing, allow overfished stocks to recover, and conserve and manage fishery resources. The MSA required the establishment of comprehensive fishery research programs aimed at understanding the abundance and availability of fish (e.g., fish biology, pollution impacts, habitat degradation, etc.). The MSA has been reauthorized (1996, 2006, 2007), with amendments that clearly demonstrate the growth of fishery research, to include biological, physical, and environmental aspects that impact fish, as well as the economic and social impacts that changes in allocating fishery yield have on fishing communities. By expanding the research scope, the MSA has evolved over time to balance the benefits of U.S. fishery resources to the Nation with the need to protect the ecosystems upon which fishery species depend.

A launch from NOAA Ship RAINIER in the Alaska Peninsula. Photo credit: Personnel of NOAA Ship RAINIER.

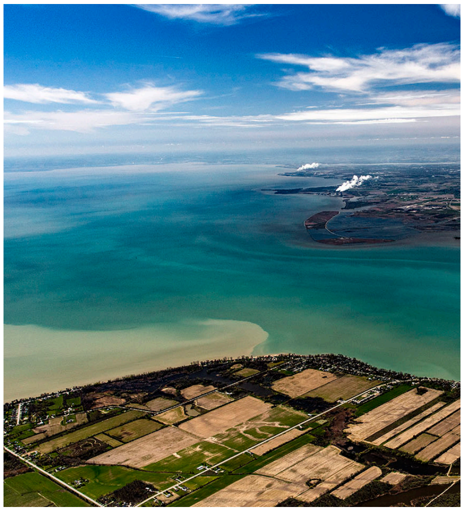
Summary of Vision Areas

Vision Area 1

Research and development addressing the first vision area, **reducing societal impacts from hazardous weather and other environmental phenomena**, is focused on environmental phenomena that impact society. It also encompasses social science to better understand how people interpret and evaluate NOAA forecasts and warnings, and thus prepare for and respond to weather, water and climate-dependent events. The physical phenomena addressed range from local incidences of extreme weather (e.g., heat waves, arctic blasts, tornadoes, hurricanes, flooding, and droughts) to global-scale climate variability (e.g., global mean temperature, sea level rise, sea ice, ocean warming, and acidification) to space weather caused by variability of the sun (e.g., geomagnetic storms, ionospheric disturbances, and energetic particle radiation). NOAA's ability to save lives and protect property benefits from understanding how risk communication leads to improved societal response to forecasts of severe weather and changes in environmental phenomenon. NOAA relies on emergency managers, water resource managers, and other government agencies at the state, local, and tribal levels to make informed decisions for their communities. Optimizing NOAA's communication of risk encourages informed decisions and active response to the risk, thereby improving societal and economic outcomes, and building a weather-ready nation.

A radar monitoring severe storms. Photo credit: Robin Tanamachi, NOAA/OAR/NSSL.

Vision Area 2



South entrance of Detroit River to the right and northeast corner of Lake Erie to the left. Photo credit: NOAA/OAR/GLERL.

Research and development addressing the second vision area, **sustainable use and stewardship of ocean and coastal resources**, examines the biological/geological/chemical (biogeochemical) elements of ecosystems, including the physical phenomena impacts on biogeochemical processes and, conversly, the biogeochemical influences on the physical realm. Humans, as a part of ecosystems, can and do alter biogeochemical and physical aspects of the Earth; consequently, there are critical interconnections between domains that must be understood. To better understand ecosystems, NOAA needs to develop the knowledge, tools, and technologies to understand, protect, and restore coastal and marine ecosystems and undertake basic research. Stewardship of these resources balances conservation with sustainable uses, such as support of subsistence, recreational, and commercial fishing communities, recreational opportunities, renewable energy production, and maritime commerce. Integral is the ability to understand the socioeconomic effects of associated decisions on communities.

Summary of Vision Areas

NOAA's third vision area, **a robust and effective research, development, and transition enterprise**, focuses on the basic building blocks of the R&D enterprise itself. NOAA relies on observing platforms to collect long-term and complex data sets (often referred to as Big Data) that are analyzed to understand both physical and biogeochemical phenomena. These data are used in both simple and complex models (e.g., atmospheric, biogeochemical, physical, economic, ecosystem, integrated, coupled, and nested models) developed to simulate systems and predict system changes. These models also produce Big Data. NOAA is moving forward in integrating economic and social science data with physical and ecological information. These data sets, where not restricted by legislation or legal requirements, are made available to the public under the Foundations for Evidence-Based Policymaking Act[8] that codified the Public Access to Research Results executive order, providing the private sector development opportunities for novel applications.

The GOES-17 satellite above the thermal vacuum chamber. Photo credit: Lockheed Martin.

Aurora australis and Milky Way seen over NOAA Atmospheric Research Observatory at South Pole Station. Photo credit: Ross Burgener, NOAA/OAR/ESRL/GMD.

Over the period 2011-2018, NOAA staff published more than 15,500 peer-reviewed scientific articles in the fields of marine and freshwater biology, remote sensing, oceanography, environmental sciences, fisheries, ecology, geosciences, and meteorology and atmospheric science, among others[9]. These articles significantly furthered lines of scientific inquiry in their fields - more than 90 percent were cited by other papers within the scientific literature.

Summary of Vision Areas

Vision Area 1. Reducing societal impacts from hazardous weather and other environmental phenomena

1.1. How can forecasts and warnings for hazardous weather and other environmental phenomena be improved?

1.2. What is the state of the global climate and how are changes affecting local weather, including extremes, environmental hazards, and water quality and availability?

1.3. How can the utility of space weather products and services be enhanced?

1.4. How can NOAA enhance communications, products, and services to enable informed decision-making?

Vision Area 2. Sustainable use and stewardship of ocean and coastal resources

2.1. How can knowledge, tools, and technologies be leveraged to better understand, protect, and restore ecosystems?

2.2. How can healthy and diverse ecosystems be sustained while meeting the needs of indigenous, recreational, and commercial fishing communities?

2.3. How can the growth of sustainable aquaculture in the United States be accelerated?

2.4. How can the conservation of coastal and marine resources, habitats, and amenities be balanced with growth in tourism and recreation?

2.5. How can efficiencies be maximized and safety improved under increasing maritime traffic and larger vessel sizes?

2.6. What exists in the unexplored areas of the ocean?

2.7. How can NOAA utilize and improve socioeconomic information to enhance the sustainability of ecosystem services, public engagement practices, and economic benefits?

Vision Area 3. A robust and effective research, development, and transition enterprise

3.1. How can unified modeling be integrated and improved with respect to skill, efficiency, and adaptability for service to stakeholders?

3.2. How can earth observations be advanced and their associated platforms be optimized to meet NOAA's needs?

3.3. How can information technology, Big Data, and artificial intelligence be utilized and improved to accelerate and transition R&D efforts and form new lines of business and economic growth?

3.4. How can NOAA ensure its investments are informed by focused social science research and application?

Vision Area 1: Reducing Societal Impacts from Hazardous Weather and Other Environmental Phenomena

Weather impacts the lives of Americans every day, from daily temperature and precipitation to extreme weather events. By receiving expert, accurate and timely information and supported by emergency managers, water resource managers, and other government agencies, the public can make informed decisions about how to respond, saving lives and property. NOAA R&D improves the forecasts and warnings provided to the public. This work includes improving the fundamental understanding of weather and climate phenomena through observations and other studies in order to develop the best models to provide accurate forecasts and predictions. It also includes a better understanding of how to effectively communicate this information to enhance public understanding and proactive decision-making. NOAA R&D focuses across all time scales, including sub-hourly nowcasts and warnings, daily forecasts and watches, sub-seasonal to seasonal predictions, and climate projections for the next decades to century. Further, NOAA R&D seeks to improve space weather products and services to help protect infrastructure and activities vital to national security and the Nation's economy. This R&D will ensure society is prepared for and has the information needed to appropriately respond to weather and other environmental phenomena, and build a weather-ready nation.

Photo captions (left to right, top to bottom). NOAA Hurricane Hunters fly into Hurricane Florence. Photo credit: NOAA Aircraft Opeartions Center. A raging fire. Photo credit: SciJinks, NOAA. Lightning. Photo credit: NOAA. NOAA investigates a partially submerged vessel following Hurricane Michael. Photo credit: Lt. j.g. Michelle Levano, NOAA. A sign for tsunami evacuation in Newport, Oregon. Photo credit: Crew and Officers of NOAA Ship MILLER FREEMAN. The Automated Surface Observation Systems (ASOS) provide weather observations from airports across the U.S. Photo credit: NOAA.

Key Question 1.1: How can forecasts and warnings for hazardous weather and other environmental phenomena be improved?

Weather, water, and climate events cause an average of approximately 650 deaths and $15 billion in damage per year[10]. Timely and accurate forecasts and predictions for weather, water, and climate events save lives and money, with weather forecasts generating more than $30 billion in economic benefits to U.S. households[11]. NOAA R&D provides foundational data, models, forecasts, and information products and services to better prepare communities, ecosystems, and economies for high-impact environmental events.

Research Highlight

NOAA is integrating the Finite Volume Cubed-Sphere Dynamical Core (FV3), a scalable and flexible dynamical core for weather and climate modeling into its operational forecasting systems. The FV3 is central to the Unified Forecast System (UFS) which is a community modeling framework that NOAA is adopting for research and operations. In 2019, NOAA implemented the first instantiation of the UFS into its operational modeling suite called the Global Forecast System (GFS). In addition to the GFS, NOAA is upgrading its Global Ensemble Forecast System (GEFS) that will be coupled to global waves and aerosols during summer of 2020, using the same FV3 dynamical core at higher resolution (25 km) and increasing the number of ensemble forecasts from 21 to 31 and extending the forecast length from 16 to 35 days. The major benefit of the FV3 dynamic core is its ability to forecast weather at cloud resolving resolutions of 1 km and higher. NOAA is taking advantage of this scalability by adopting a stand-alone regional (SAR) configuration along with multiple movable nests to meet the requirement of improved fine-scale and short-range forecasts within the UFS framework. Research and development is being done with the FV3 to dramatically improve NOAA's ability to accurately predict severe storms, hurricanes, and winter storm events.

Objectives:

- Develop and operate next-generation weather and earth system unified models using a community-based approach in concert with advances in high-performance computing and understanding of processes.
- Develop integrated physical and ecological water modeling and prediction across a range of timescales and watershed sizes, with the appropriate timeliness, resolution, reliability, and accuracy required to help inform decision-making.
- Incorporate water quality (including temperature, salinity, and dissolved and suspended constituents) into an integrated water prediction capability with associated decision support services.
- Produce reliable and timely foundational forecasts of sub-seasonal and seasonal (S2S) conditions that influence the incidence and severity of hazardous weather, and advance attribution of causes of high-impact events on S2S time scales.
- Provide means of quickly and precisely detecting and measuring tsunami generation events, and provide tsunami forecasting capability based on models and measurements for increasing the preparedness of communities and safeguarding port and harbor operations.
- Advance understanding of data assimilation methods aimed at improving the representation of convective scales and optimize capabilities for predicting specific convective hazards.

Key Question 1.2: What is the state of the global climate and how are changes affecting local weather, including extremes, environmental hazards, and water quality and water availability?

Global land and ocean temperatures have been above the 20th-century average for 43 consecutive years (1977-2019)[12]. With global climate change comes changes in the frequency and intensity of extreme weather, inundation, fresh water availability, the carbon cycle, sea ice extent, and temperature[13]. The physical impacts of climate change affect important resources and capabilities, such as water, energy, transportation, and human health. NOAA R&D promotes better understanding of the state and drivers of global climate, increasing the Nation's ability to prepare for, adapt to, and mitigate negative impacts of a changing climate.

Objectives:

- Advance research on climate variability and change occurring across all timescales, focusing on the impacts of weather extremes and coastal inundation, and changes in freshwater resources, sea ice extent, and ocean conditions.
- Advance research on ocean-cryosphere-climate processes and integrate it into climate and weather models, along with assimilating ocean/cryosphere observations.
- Advance research on atmospheric chemistry, composition, and processes in the earth system, quantifying their effects on air quality, climate, and weather systems.
- Assess the roles of internal variability in the earth system, natural radiative forcing (e.g., solar changes, volcanic eruptions, coupled ocean-atmosphere-ice-land variability) and changing radiative forcing (from greenhouse gases and aerosols) in causing seasonal-to-decadal changes in the climate system, including extremes.
- Identify causes for observed regional and seasonal differences in U.S. trends (e.g., temperature, precipitation, visibility, wind, aerosols, clouds) across latitude, longitude, altitude, and topography to improve predictions and projections, especially for extreme events.
- Strengthen the foundational understanding and detection capabilities for Arctic climate and ecosystem changes.
- Advance the understanding of the human health impacts of climate phenomena on all timescales (e.g., heat, vector linked disease, air and water quality).

Research Highlight

NOAA R&D led the way for the Fourth National Climate Assessment, a product of the interagency U.S. Global Change Research Program. The assessment synthesizes the observations and projections of future temperature, precipitation, sea level rise, large-scale climate variability, extreme storms, Arctic change, and ocean acidification. The predictions and projections in the assessment inform planning and mitigation efforts. NOAA's ongoing R&D contributions to the National Climate Assessment are represented at every step of the process: long-term observations of carbon dioxide that feed climate models, the climate models that predict future conditions, and work with regions, States, and local communities to plan for and mitigate the projected effects.

Key Question 1.3: How can the utility of space weather products and services be enhanced?

Space weather impacts a number of important technologies upon which our society is highly and increasingly more reliant. Impacted technologies include: electric power transmission; air, sea, and land-based satellite navigation and communication; aviation; and satellites, as well as human space travel. NOAA's space weather products and services utilize data and numerical models that cover the entire region from the Sun to Earth. NOAA R&D seeks to understand the changing product and service needs as technologies and their vulnerabilities evolve. For example, the growing use of precision navigation, the increased reliance on satellite-based technologies, and the anticipated increase in human space exploration and commercial space transportation will all require expanded and improved products and services. NOAA R&D also coordinates with interagency partners to direct external funding to address the highest priority needs and to assess research advances and implement them in operations.

Research Highlight

The Space Weather Prediction Center is introducing a coupled atmosphere-ionosphere model (WAM-IPE) to predict dynamics in the upper atmosphere and ionosphere. This model will incorporate disturbances that can originate in the lower atmosphere and propagate upwards, as well as those driven by solar activity from above. This model will enable more accurate predictions of ionospheric and upper-atmospheric disturbances that impact communication, navigation, and satellite orbit determination and collision avoidance.

Objectives:

- Develop new communication, navigation, and radiation products to address the requirements of the International Civil Aviation Organization (ICAO) and the establishment of the Space Weather Prediction Center (SWPC) as an ICAO global Space Weather Center.
- Transition the Whole Atmosphere Model - Ionosphere Plasmasphere Electrodynamics (WAM-IPE) model to operations, enhancing the product specifications and forecasts for communication and navigation customers.
- Improve radiation-environment products for the upcoming human exploration initiative, for satellite operations, and for commercial space transportation.
- In coordination with interagency and international partners, implement the National Space Weather Strategy and Action Plan to advance NOAA's products and services and national preparedness.

Key Question 1.4: How can NOAA enhance communications, products, and services to enable informed decision-making?

Social science research plays a critical role in connecting the improvements of NOAA's weather, water, climate, and space forecast information to the goal of meeting the public's growing forecast needs. Understanding societal needs and decision contexts provides NOAA with information to prioritize what type of forecast improvement will yield the greatest economic and societal benefit. NOAA R&D seeks to understand current use of NOAA's forecast information and how to improve products, services, and communication to save lives and reduce property damage and other negative economic impacts.

Objectives:

- Assess how people receive, interpret, perceive, and respond to weather, water, climate, and space information, especially warnings, with respect to protective action decision-making.
- Define and implement optimal predictive information content, including risk thresholds, uncertainty, probabilistic information, and lead-times, to design products and services that enable decision-making and maximize effectiveness of forecast improvements.
- Advance understanding of decision-making needs, capacity, and use of weather, water, climate, and space weather information.
- Understand the forecaster operational decision environment to optimize usability of new modeling tools and technologies by evaluating and understanding the cognitive demands on the human forecaster using social and behavioral science.
- Enhance the integration of social, behavioral, and economic science into weather, water, and climate research and development to understand how to blend forecast advancements with societal needs and response.

Research Highlight

Forecasting a Continuum of Environmental Threats (FACETs) is a new paradigm for the weather watch and warning process. Under this new paradigm, weather forecasters communicate the public's vulnerability to hazardous weather by using "threat grids" that rapidly update as new information becomes available, enabling more precise watches and warnings. Social and behavioral science is integrated into FACETs R&D, as hazardous weather forecasting is a physical science done by humans for humans. For example, NOAA has conducted baseline studies to be better able to understand how these more precise watches and warnings affect people's behavior through studying the importance of probability and intensity in how extreme weather risks are characterized. These results will be used to design more user-friendly storm information to protect lives and property.

Vision Area 2: Sustainable Use and Stewardship of Ocean and Coastal Resources

NOAA R&D aim to improve our ability to understand, protect, manage, and restore ecosystems that support healthy fisheries, increase opportunities for aquaculture, balance conservation with tourism and recreation, provide safe and efficient maritime traffic, and explore what we do not know about the ocean. Coastal, ocean, and Great Lakes resources are vital to the communities that depend on them for ecosystem services (e.g., food, energy production, storm mitigation, recreation, economic prosperity). Declines in the health of ecosystems that provide these services directly impact human health and well-being. Demands on ecosystems for seafood, energy production, and other pressures that contribute to economic growth are increasing as many long-term species population trends show declines. Depleted fish stocks and declines in protected species may reduce employment and economic activity related to coastal and marine waters. Sea level rise, sea ice loss, and ocean warming and acidification challenge the resilience of coastal communities and change habitats and the relative abundance and distribution of species. Increasing coastal populations, economic expansion, global trade, and new trade routes in the Arctic increase the need for safe and efficient maritime transportation. NOAA needs to support informed decisions that balance conflicting demands as well as economic and environmental considerations.



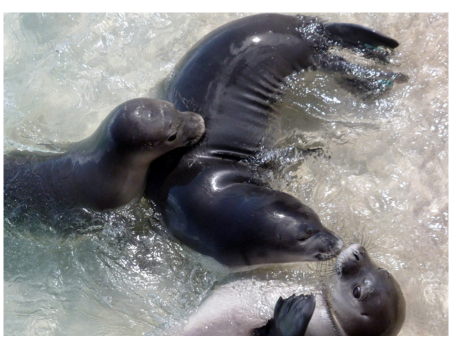
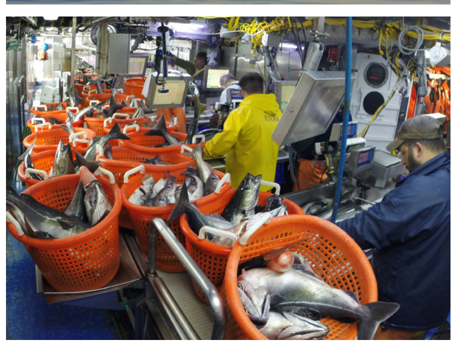
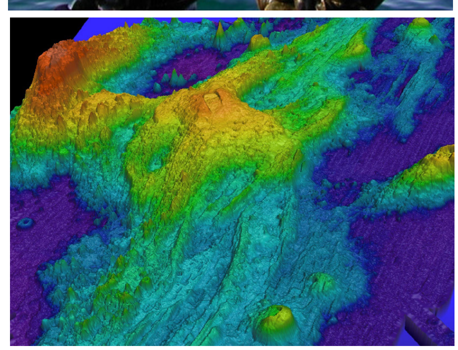





Photo captions (left to right, top to bottom). A diver ascending from abalone surveys. Photo credit: Adam Obaza, NOAA/NMFS/WCR/PRD. The Monterey Bay SportsFest at Del Monte Beach. Photo credit: Steve Lonhard, NOAA/MBNMS. Mussels on longlines used for aquaculture. Photo credit: NOAA. Monk seal pups playing in the shallows at French Frigate Shoals. Photo credit: NOAA/PIFSC/HMSRP. Cod, pollock, and haddock in baskets to be counted and measured. Photo credit: NOAA Teacher at Sea Program, NOAA Ship HENRY B. BIGELOW. Axial Volcano off the coast of Oregon on the Juan de Fuca Ridge. Photo credit: NOAA PMEL.

Key Question 2.1: How can knowledge, tools, and technologies be leveraged to better understand, protect, and restore ecosystems?

Environmental changes and human actions can impact the range, processes, and functioning of the interrelated elements of ecosystems, which in turn may modify the ecosystem services from which society benefits. Shallow water coral reef ecosystems alone cover less than 1 percent of the Earth's seafloor while supporting an estimated 25 percent of all known marine species[14] and providing $3.4 billion in value to the U.S. economy each year[15]. NOAA R&D will leverage knowledge, decision support tools, and emerging technologies to identify the role of physical, chemical, and biological interactions within coastal and ocean ecosystems to inform resource-use decisions for better conservation and restoration of these systems.

Objectives:

- Develop and leverage emerging technologies, such as unmanned aerial, underwater, and surface vehicles, eDNA, and passive and active acoustic sound mapping, to augment survey capacity and provide more accurate, precise, and synoptic information of key marine fishery and protected species populations and their habitats.
- Improve biomass and mortality estimates and address measurement and process uncertainty with emerging technologies, and increase environmental sampling aboard existing surveys.
- Increase knowledge and understanding (e.g., incorporating Traditional Ecological Knowledge) of the mechanisms and combined effects of environmental changes resulting from atmospheric, ocean, cryosphere, and land-based forces on marine species and ecosystems.
- Develop analytical models and tools to understand and quantify impacts of environmental change in large marine ecosystems and species of interest, including protected species.
- Improve and scale-up existing and innovative restoration techniques (e.g., coral propagation and planting on damaged reefs) for coastal and marine ecosystems.
- Expand the ability to predict changes in ecosystems and ecosystem components in response to environmental drivers (e.g., climate, extreme weather, pollution, acidification, altered habitats).

Research Highlight

NOAA is developing advanced unmanned aircraft system (drone) technology to change the way marine mammal surveys are done. NOAA researchers have partnered with GeoThinkTank, Mystic Aquarium to develop drone technology for surveying northern fur seal pups in Alaska's Pribilof Islands. They are combining visual and thermal (multi-spectral) imaging to distinguish seal pups from the rocky shoreline. Field data collected in 2018 will be analyzed to cross calibrate this emerging technique with standard seal pup survey techniques and to determine next steps in developing a custom drone mounted sensor. In addition to reducing disturbance and risk to the seal colonies, successful development of this advanced technique has the potential to reduce the cost and number of staff required to complete the annual survey.

Key Question 2.2: How can healthy and diverse ecosystems be sustained while meeting the needs of indigenous, recreational, and commercial fishing communities?

The domestic seafood sector provides Americans with protein-rich food while contributing jobs and revenue to the Nation's economy. In 2018, commercial landings by U.S. fishermen in the 50 states totaled 9.4 billion pounds valued at $5.6 billion[16]. However, many wild capture fisheries stocks are harvested at their sustainable limits. NOAA R&D will support seafood monitoring and harvests to sustainably meet the needs of commercial, indigenous, and recreational fishing communities.

Research Highlight

The first NOAA Fisheries Stock Assessment Improvement Plan (SAIP) was released in 2001. Since then, the number of stock assessments completed annually has increased from 50 in 2001 to nearly 190 in 2015. Over the same timeframe, the number of stocks experiencing overfishing (annual catch rate too high) or that are overfished (population size is too low) have declined by 30 and 24 percent respectively. In 2018 the Next Generation (NG) SAIP was released. The NGSAIP calls for assessments that are "more holistic and ecosystem-linked" and use "innovative science and technological advancements to improve the data" for stock assessments. With climate change impacting ecosystems, stock assessments need to account for non-equilibrium ecosystem states, shifts in stock productivity, cumulative effects of fishing on multiple overlapping stocks, and socioeconomic drivers. While this can be achieved by expanding the scope of and data inputs to assessments, it must be balanced with agency resource constraints and the need to explain uncertainty. There is a need for more direct calibration of assessment data and more research to better understand and describe fish stock dynamics and the physical, biological, and socioeconomic drivers of those dynamics.

Objectives:

- Develop next-generation fisheries and protected species stock assessments that incorporate the effects of environmental and climate change on stock dynamics, along with spatially specific habitat-quality models, to optimize sustainable commercial, recreational, and subsistence harvest while conserving protected species.
- Improve analytical methods and technologies supporting seafood monitoring, aiming to document and prevent illegally harvested fish from entering U.S. ports and markets and achieve sustainable fisheries globally.
- Develop safe and effective methods to monitor and prevent bycatch of non-target species, including fish, marine mammals, and sea turtles that drive closures of commercial and recreational fisheries.
- Develop environmental and social indicators that facilitate increased ecosystem understanding and sustainable coastal development and recreational fishing.

Key Question 2.3: How can the growth of sustainable aquaculture in the United States be accelerated?

Imports currently account for more than 85 percent of U.S. seafood consumption[17]. Conservative estimates show that if less than 0.01 percent (or less than 500 km^2) of the U.S. exclusive economic zone were used for aquaculture, it could yield up to 600,000 metric tons of additional farmed seafood per year[18]. In addition to increasing supply, investment in aquaculture will provide employment and business opportunities in coastal communities. NOAA R&D in aquaculture production will facilitate safe, sustainable seafood for domestic and international markets.

Objectives:

- Develop models, manuals, and new technologies (e.g., eDNA) to better determine ocean spaces suitable for aquaculture, protect natural ecosystems, and minimize space-use conflicts.
- Improve understanding and develop tools to manage aquaculture's effects on the marine environment, species, and habitats, including measures to minimize disease transfer among aquatic animals.
- Conduct studies for enhancing aquaculture (fish genetics and applied genomics, selective breeding, disease, and hatchery feed stocks) and understanding the impacts of environmental change on aquaculture.
- Develop and improve technologies (e.g., marine aquaculture feeds, automated systems) to reduce costs.

Research Highlight

NOAA conducts research to advance aquaculture practices and success, and funds the development of better technologies for shellfish aquaculture industry to monitor and respond to corrosive conditions. For example, NOAA researchers helped identify that changing carbonate chemistry due to upwelling and ocean acidification was the cause of larval failures at hatcheries in the Pacific Northwest between 2005 and 2007 that impacted the 35 million dollar oyster industry. With Washington State, university, and industry partners, NOAA researchers determined low pH water pumped into the hatchery made it difficult for oyster larvae to build shells, resulting in large die-offs. Together, researchers devised solutions for oyster production in low pH waters including monitoring the pH of inflow water with ocean observing systems so hatchery staff can buffer the water pH and larval oysters can survive, and exploring whether some strains of oysters are more resilient to ocean acidification and low pH water. The Washington State Blue Ribbon Panel on Ocean Acidification released reports (2012, 2017) documenting further actions to mitigate the effects of ocean acidification in the state. Research is ongoing to understand the physical drivers of low pH waters, biological effects on oysters and other commercially important species, and social impacts on the region.

Key Question 2.4: How can the conservation of coastal and marine resources, habitats, and amenities be balanced with growth in tourism and recreation?

The United States' marine and freshwater coasts are both home to 40 percent of the U.S. population[19] and national treasures that draw millions of people from around the world to enjoy recreational photography, boating, fishing, beachcombing, tide pooling, water contact sports, and other activities. In 2012, nearly 49 million adults participated in ocean and coastal recreation, supporting more than 3.1 million full-time jobs and providing $409 billion in income to businesses[20]. However, human habitation, recreation, and tourism have the potential to degrade marine habitats through such things as marine debris, water pollution, soil erosion, and wildlife disturbance. NOAA R&D aims to inform decision-making on balancing economic growth from coastal communities, tourism, and recreation with maintaining the health of coastal and ocean systems.

Research Highlight

NOAA's harmful algal bloom (HAB) forecasting continues on a path to have region-specific, nationwide capability. Inherent in this effort is timely information on when a bloom will start, how large it will be in biomass and geographic coverage, at what point it will be toxic enough to alert public health officials and coastal resource managers, and when the intensity might abate. Efforts in several regions cover a range of HAB species (e.g., *Karenia brevis, Alexandrium fundyense, Margalefidinium sp.*) that produce a variety of concerns. HAB research focuses on basic understanding of why HAB blooms initiate, how toxins are produced, and how toxins move through food webs and are retained by fish and shellfish consumed by humans. Additional work centers on developing simple and reliable methods to detect and analyze HAB toxins and understand their toxicity to humans and marine organisms. These elements, combined with HAB forecasting, reduces the impact on humans from toxic blooms by providing vital information to coastal managers.

Objectives:

- Improve capabilities for modeling, monitoring, and predicting chronic and acute stressors that degrade coastal habitats and resources (e.g., hypoxia, ocean heat waves), or pose human health risks (e.g., harmful algal blooms, pathogens, rip currents).
- Develop or improve methods and technologies for environmental sensors and monitoring platforms, enhancing capabilities to measure relevant physical and biogeochemical targets better (e.g., accuracy, precision, etc.), faster, and most cost effectively.
- Improve methods for restoring coastal habitat, sustaining ecosystem services, promoting ecotourism, and exploiting nature-based adaptation solutions.
- Understand the processes and impacts of temperature, ocean acidification, sea level rise, and harmful algal blooms on marine organisms, ecosystems, and coastal communities.

Key Question 2.5: How can efficiencies be maximized and safety improved under increasing maritime traffic and larger vessel sizes?

Nearly 12 million registered recreational boaters[21] utilize the U.S. marine transportation system, and many U.S. goods move through American ports. Maritime traffic and commercial cargo sizes are increasing in volume. Increasing maritime traffic multiplies the potential for incidents that could impact those living in nearby coastal communities. New vessel routes are emerging in the U.S. Arctic, making it all the more important for mariners to have access to reliable and efficient navigation products and services. NOAA R&D will provide accurate, integrated weather and oceanic measurements and models that will permit up-to-date nautical predictions, products, and services - facilitating decreased damage and loss and enhancing economic efficiency.

Objectives:

- Improve coastal models and other oceanographic products for major U.S. ports, addressing increased vessel traffic with wider beams and deeper drafts.
- Develop new ocean and sea ice observation and forecasting capabilities (e.g., earth system unified models) to improve prediction of explosive oceanic storms and support polar access, safety, and sustainable use.
- Correct meter-level errors in Arctic positioning and provide a new vertical reference frame to support Arctic navigation.
- Support domestic and international R&D focused on innovative oil spill and other incident response technologies and procedures, particularly those suitable for the Arctic environment.
- Understand the impacts of increased vessel traffic and maritime activity on protected species safety and health.

Research Highlight

In January of 2018, a tanker filled with liquefied natural gas navigated the Northern Sea Route through the winter Arctic Ocean without assistance from an icebreaker. Recent trends in Arctic sea ice extent show year-round declines, with sharp summer declines leading to slower fall ice expansion and decreased multi-year (thicker) ice overall. Decreased sea ice extent and thickness will lead to increased ship traffic through the Arctic. NOAA developed and is evaluating the Coupled Arctic Forecast System (CAFS) to improve ice and snow forecasts, which are critical to coastal communities and safe navigation. CAFS evolved by modifying the Regional Arctic System Model[22] to account for short-term weather forecasts. The experimental modeling system combines multiple component models that account for the atmosphere (WRF3.5.1), land (CLM4.5), ocean (POP2), and ice (CICE5.1). CAFS is currently producing experimental sea ice forecasts.

Key Question 2.6: What exists in the unexplored areas of the ocean?

The ocean covers 71 percent of the Earth's surface, contains the Earth's largest waterfall[23] and longest mountain range[24], and is home to unique organisms. An estimated 91 percent of the ocean species have yet to be classified[25] and, of the 3.4 million square nautical miles of the U.S. Exclusive Economic Zone and 154,000 square nautical miles of U.S. coastal waters, only 41 percent has been mapped at 100-meter grid resolution using modern methods[26]. NOAA R&D increases knowledge and understanding of ocean resources, enabling policy makers, managers, and researchers to make informed decisions for stewardship of these resources and regions.

Research Highlight

NOAA supports global initiatives, such as the U.N. Decade of Ocean Science for Sustainable Development and the Nippon Foundation - GEBCO Seabed 2030 Project, to create high-resolution bathymetric maps of the Earth's seabed. By leading national efforts to explore the U.S. Exclusive Economic Zone (EEZ), and contributing to global programs by sharing data from mapping the seabed in international waters, NOAA is making ocean exploration more accessible and filling knowledge gaps in the scientific understanding of global deep waters and seafloor through mapping and characterization efforts. A key component is in the advancement of new and emerging technologies, such as unmanned systems, that can optimize the acquisition and processing of data to meet mapping objectives in more remote areas of the U.S. EEZ and global oceans. Comprehensive seabed maps are important for: navigation safety; national security; heritage; communications cables; forecasting weather, tsunami, and storm surge events; climate change projections; and defining benthic ecosystems.

Objectives:

- Advance mapping technologies, tools, and methodologies to support maritime commerce, discover archaeological and heritage sites, identify marine hotspots and spawning aggregation sites, and expand scientific understanding of the seafloor for economic activities, such as resource extraction siting.
- Achieve high-resolution mapping of the deeper U.S. exclusive economic zone (EEZ), and Extended Continental Shelf (ECS) to facilitate prudent resource use and industrial activities (e.g., energy development, mineral resource mapping, fisheries characterization).
- Further undersea exploration, using both current and emerging observation platforms and technologies (e.g., autonomous underwater vehicles, remote sensing, eDNA, 'omics), to characterize and map habitats and environmental features.
- Actively engage in mapping and resource monitoring in the Arctic shelf regions, which have been largely unexplored, for baseline data and subsequent recommendations for long term monitoring.

Key Question 2.7: How can NOAA utilize and improve socioeconomic information to enhance the sustainability of ecosystem services, public engagement practices, and economic benefits?

The stewardship and utilization of ocean and coastal resources are influenced by socioeconomic factors, perceptions, and behavior. Human activities directly and indirectly impact the quantity and quality of ecosystem services for current and future generations. In turn, human behavior is shaped by both the risks and opportunities of ocean and coastal phenomena and resources. NOAA conducts social science research to better understand and support decision-making processes for the safety of coastal communities and visitors, the sustainability of ocean resources, and the benefit of the U.S. economy.

Objectives:

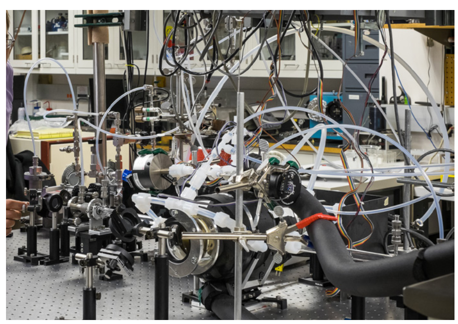
- Provide economic research and associated outreach programming to aquaculture businesses to increase their effectiveness and efficiency.
- Incorporate socioeconomic drivers of fishing behavior into stock assessment models that are used to develop fishery dynamics forecasts, as well as predict future catches and stock status.
- Understand how environmental degradation (e.g., marine debris, oil spills) and coastal hazards impact the economies and social well-being of coastal communities, including direct and indirect costs to society.
- Conduct socioeconomic analyses, including benefit-cost metrics, for ports that implement NOAA's Precision Navigation program.
- Improve information products and outreach efforts that communicate human health risks, and evaluate responses across different groups in society through social media and web metrics after specific events or phenomena (e.g., a harmful algal bloom event or a pollution episode).
- Improve modeling of hazard impact reduction by natural infrastructure and well-functioning coastal ecosystems (e.g., storm surge attenuation by wetlands and corals) to quantify the risk reduction services provided by these systems.

Research Highlight

NOAA is conducting a study to understand how marine debris affects the economies of tourism-dependent coastal communities. Marine debris can affect several economic sectors including aquaculture, fisheries, commercial shipping, recreational boating, local coastal governments, coastal tourism, and emergency response services. The costs associated with marine debris can be direct (i.e., beach cleanups, gear replacement) or indirect (i.e., impacts to biodiversity and ecosystem services). To better understand the impacts of marine debris on tourism around the country, a Regional Pilot Study was conducted as a first attempt to link beach trip choices with estimates of marine debris at beaches. The regions of interest for this work included the Great Lakes (OH), Mid-Atlantic (DE), Gulf of Mexico (AL), and West Coast (CA). Using this information and data from a previous study, the intent is to evaluate changes in tourism spending based on increases or decreases in marine debris, improve our understanding of the economic impact of marine debris, and prioritize areas of the United States where future prevention and removal efforts might be needed.

Vision Area 3: A Robust and Effective Research, Development, and Transition Enterprise

A robust research and development enterprise is vital for reducing the impacts of hazardous weather and enabling the sustainable use and stewardship of ocean and coastal resources. All areas of NOAA R&D require integrated models, optimal observation platforms, and efficient and effective exploitation of Big Data and information technology to best serve NOAA's mission. NOAA relies on Earth observations (both physical and biogeochemical) derived from a variety of sensors and platforms (e.g., satellites, radars, manned and unmanned aircraft, ground stations, sea-going vessels, buoys, submersibles). Employing standardized data management practices ensures that the environmental information provided is appropriately preserved, accessible, and usable for analysis, integration, and sharing to support advances in modeling and spur scientific and commercial innovation. Integrating social sciences into NOAA's data management includes an understanding of human behavior and response to optimize data accessibility, comprehension, and utility.



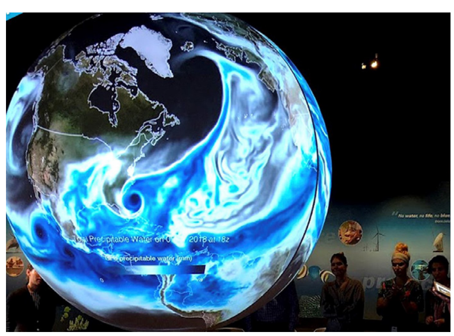



Photo captions (left to right, top to bottom). NOAA Ship PISCES at sunset. Photo credit: NOAA. The kinetics laboratory NOAA/ESRL/CSD. Photo credit: Will von Dauster, NOAA. An Echoboat autonomous surface vehicle surveys a channel to investigate possible shoaling. Photo credit: NOAA. NOAA supercomputing system at a data center in Florida. Photo credit: NOAA. A Science on the Sphere presentation. Photo credi: Anupa Asokan, NOAA. NOAA P-3, N43RF, also known as "Miss Piggy", departing Kangerlussuaq on its way to support an Operation Icebridge mission flight. Photo credit: NOAA/OMAO/AOC.

Key Question 3.1: How can unified modeling be integrated and improved with respect to skill, efficiency, and adaptability for service to stakeholders?

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 aim to improve the representativeness and predictive skill of NOAA's models by developing new techniques, employing new or improved parameters, nesting and coupling Earth system modeling and data assimilation, and transitioning R&D to operations and applications.

Objectives:

- Pursue a unified modeling approach to apply a common, physically consistent framework for interoperability across disciplines using collaborative engagement with the external research community.
- Advance data integration, assimilation, and Earth System Modeling Framework (ESMF) connectivity for NOAA's research and operational models that couple the atmosphere, ocean, land, and ice at global and regional scales.
- Quantify model uncertainty and skill for all NOAA operational models and forecast products, including quantified understanding of the uncertainties between different climate models in their projections.
- Develop sound modeling downscaling techniques for climate applications for multiple regional spatial and temporal scales, including an embedded and nested regional Earth system projection capability.
- Integrate environmental data from monitoring assets into high resolution operational models (e.g., hydrodynamic) to produce environmental forecasts (e.g., salinity and temperature) and decision-support tools to facilitate sustainable use of marine resources and identify important habitats.
- Develop and incorporate advanced data assimilation techniques, increased exploitation of observational capabilities, and advanced numerical methods into NOAA models to improve predictive capabilities.

Research Highlight

Beginning in 2019, the Earth Prediction Innovation Center (EPIC), will be established to improve coordination and development of the United States' weather forecasting capabilities and reclaim international leadership in weather prediction to protect life, property, and enhance our nation's economy. EPIC will serve as a center for enabling R&D, leading to rapid development of new models through collaboration between NOAA, its partners, and engagement with community modeling efforts. Through designation of this center, NOAA is developing effective mechanisms for gaining input across the modeling community as recommended by the NOAA Community Modeling Review Committee Report in 2018[27]. Improvements in weather and climate modeling will feed advancements in operational forecast products, impacting many sectors of the United States economy ranging from agriculture and fisheries management to energy markets and inland water management.

Key Question 3.2: How can Earth observations be advanced and their associated platforms be optimized to meet NOAA's needs?

NOAA owns, partners with, and leverages nearly 200 observing systems that provide 1,187 products and services[28]. NOAA observing systems (e.g., satellites, buoys, unmanned systems) generate global environmental data and images that are used to better understand our dynamic Earth, as well as for analyses and forecasts. NOAA R&D will optimize in situ observing systems and satellites by extending the parameters observed and improving their configuration, accuracy, coverage, resolution, and effectiveness, while minimizing observing system cost.

Research Highlight

From 2016-2019, NOAA launched five new satellites, Jason-3, GOES-16, GOES-17, JPSS-1, and COSMIC-2, providing global data for timely and accurate weather forecasts. These satellites enable and enhance NOAA R&D by producing data critical to detecting and observing environmental phenomena. As an example, data from satellites have provided flood maps to the Federal Emergency Management Agency (FEMA) to aid in forecasting, warning, and recovery from major hurricanes. NOAA R&D furthers the power of these observing systems by incorporating artificial intelligence (AI) to better extract information from data, thereby enabling better analyses and predictions from satellite images and data. For example, NOAA scientists have begun exploring ways to use AI to fill spatial and temporal gaps in satellite data, as well as to automatically identify features of interest in a satellite image, such as a developing hurricane. The use of AI has the potential to decrease the time it takes to process the immense volumes of satellite data, potentially increasing the amount of data leveraged for predictions.

Objectives:

- Evaluate the current business model for observational data and technical capabilities for alternatives (including the use of commercial products) for optimizing NOAA's current and future observing systems, aiming to enhance utility, understanding, accuracy, characterization, and monitoring (including ecosystem state and processes), while minimizing costs.
- Lead innovations in environmental sensors, unmanned systems, and other observing system development and application that increase efficiency and effectiveness and minimize costs, such as miniaturization, compressive sensing, and the exploitation of platforms of opportunity and adaptive sampling.
- Lead development of new and enhanced retrieval of environmental parameters (e.g., moisture, sea ice) from satellite sensors and extend the exploitation of satellite observations in NOAA operations and applications.
- Lead innovation in data processing and artificial intelligence (including such techniques as machine learning) to enhance efficient and effective exploitation of observation data.
- Support the development of real-time data-sharing products in collaboration with regional associations (e.g. U.S. Integrated Ocean Observing System), including contributions from the private sector, academia, and research institutions, to ensure timely and accurate use of ocean and coastal data in NOAA forecasts.
- Explore the exploitation of private sector data networks to improve model initialization.

Key Question 3.3: How can information technology, Big Data, and artificial intelligence be utilized and improved to accelerate and transition R&D efforts and form new lines of business and economic growth?

NOAA generates nearly 20 terabytes of data a day from satellites, radars, ships, weather models, and other sources[29]. As data processing and storage capabilities have improved, NOAA has increasingly used Big Data analytics to create a more detailed and accurate picture of the Earth's systems. In order to be accurate, effective, and useful, Big Data and other large datasets require technological infrastructure, analytical expertise, and data visualization. NOAA R&D will continue to improve data use and access to mitigate errors, accelerate and transition R&D efforts, improve operational efficiency, and provide information for better decision making.

Objectives:

- Advance Big Data and AI analytics and utilize cloud computing platforms to identify, understand, and forecast changes in the Earth system (e.g., circulation patterns, coastal and marine ecosystems, sea level rise).
- Develop methods to improve interoperability and synchronization of data and information across large datasets to promote innovation, utility, and accessibility.
- Incorporate predictive analytics, cognitive and high-performance computing, and automation to combine forecast information with impact information.
- Leverage advanced technologies and leading practices from social science to improve data access and data archiving.
- Develop cost-effective and efficient ways to process and analyze large datasets (e.g., data mining), including image, video, and genomic data.
- Investigate hybrid and commercial cloud computing platforms to support active engagement with the external research community to foster scientific advancements and innovations.

Research Highlight

NOAA's Big Data Project continues to show success through leveraging public-private partnerships to broaden the use and dissemination of NOAA data through modern cloud platforms. As of 2020, more than 100 NOAA datasets have been made available through cloud platforms with Microsoft Azure, Google Cloud Platform, Amazon Web Services, IBM, and Open Commons Consortium. This effort makes NOAA's data more readily accessible and usable by the American public, helping to further business and economic growth.

Key Question 3.4: How can NOAA ensure its investments are informed by focused social science research and application?

NOAA strives for R&D that yields useful applications in addition to improving our fundamental understanding of the world. Integrating social, behavioral, and economic sciences throughout the lifespan of R&D activities is crucial to meeting the needs of NOAA stakeholders and improving the capacity of the public and other decision makers to make scientifically informed choices. NOAA R&D in decision support and public engagement will create more effective communications, products, and services for engaging target audiences and measuring long-term successes and societal impacts.

Research Highlight

Research into human behavior is being incorporated into Fisheries management decisions with FishSET, a Spatial Economics Toolbox for Fisheries. FishSET provides data, modeling, and policy tools that contribute to better understanding the impacts of fisheries management practices, such as closed areas, catch shares, and climate change on fisher behavior. These results will be used to better inform fishery policy decisions.

Objectives:

- Develop and apply research methodologies to assess targeted audiences and engage stakeholder groups at the community level to improve NOAA's capacity to efficiently and effectively inform decision making.
- Use team science to identify and implement approaches and procedures (e.g., confidence, specificity, potential impacts, messaging) that would improve the public's perception of and actionable decisions in response to NOAA bulletins and warnings (e.g., for harmful algal blooms, safe maritime navigation, stewardship of national marine sanctuaries, severe weather warnings).
- Develop methods to integrate climate and ecological data with economic and human-dimension data into coupled models and decision support tools to improve understanding of how people respond to environmental change.
- Increase understanding of the benefits of formal and informal education organizations integrating NOAA-related science content and collaborating with NOAA scientists on developing curricula, exhibits, media, materials, and programs that support NOAA's mission.
- Evaluate the value of NOAA and NOAA-funded projects.
- Evaluate and optimize public participation in NOAA citizen science programs.

Cross-cutting Themes

Many of NOAA's research areas cut across the document's three vision areas. Select cross-cutting activities are referenced in the table, highlighting where these subject areas can be found in the Vision.

Theme	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	2.5	2.6	2.7	3.1	3.2	3.3	3.4
Climate Science	X	X		X	X	X		X				X	X	X	X
Ecological Forecasting					X			X			X	X			X
Polar Science	X	X	X						X						
Unmanned Systems					X		X	X		X			X		
'Omics					X	X	X	X	X	X					
AI and Machine Learning	X		X		X								X	X	
Big Data	X		X									X	X	X	X

NOAA's R&D enterprise integrates across distinct scientific disciplines to advance understanding of Earth's varied and complex systems. The evolution of NOAA's R&D enterprise can be traced through the three previous Plans, demonstrating the significant effort that goes into directing, formulating, and evaluating R&D. The R&D enterprise supports NOAA's mission to understand and predict changes in climate, weather, oceans, and coasts; to share that knowledge and information with others; and to conserve and manage coastal and marine ecosystems and resources. NOAA continues to work with various partners and stakeholders to achieve its vision of healthy ecosystems, communities, and economies that are resilient in the face of change. This vision, which is unchanged in the face of change, is as relevant today as ever.

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Appendix

List of Plans and Mandates to Inform the NOAA R&D Strategiy

Legislative Mandates, Authorities, and Drivers

Agreements to Aid and Promote Scientific and Educational Activities
America COMPETES Act of 2007 and Reauthorization (2010)
Antarctic Marine Living Resources Convention Act of 1986
Arctic Research and Policy Act of 1984, as amended
Atlantic Coastal Fisheries Cooperative Management Act (1993)
Atlantic Striped Bass Conservation Act
Atlantic Tunas Convention Act
Clean Air Act
Clean Water Act
Coast Guard Authorization Act of 2010, Pub. L. 111-281, Title X (Clean Hulls),
Coastal and Geodetic Survey Act
Coastal Ocean Program (Title II of NOAA Authorization Act of 1992)
Coastal Wetland Planning, Protection, and Restoration Act
Coastal Zone Management Act of 1972
Commerce and Trade
Commercial Engagement Through Ocean Technology Act of 2018
Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
Coral Reef Conservation Act
Customer Option for an Alternative System to Allocate Losses Act of 2011 or COASTAL Act of 2011
Data Quality Act
Deep Seabed Hard Mineral Resources Act
Endangered Species Act
Establishment of Great Lakes Research Office
Estuary Restoration Act of 2000
Federal Insecticide, Fungicide, and Rodenticide Act
Federal Ocean Acidification Research and Monitoring Act of 2009
Federal Water Pollution Control Act
Fish and Wildlife Coordination Act (1934)
Fur Seal Act of 1966
Geophysical Sciences Authorities
Global Change Research Act
Great Lakes Fishery Act of 1956
Harmful Algal Bloom and Hypoxia Research and Control Act of 1998
High-Performance Computing and Communication Act of 1991
Inland Flood Forecasting and Weather System Act of 2002
Integrated Coastal and Ocean Observing System (ICOOS) Act of 2009
International Cooperation in Global Change Research Act of 1990
Investigation and Control of Crown of Thorns Starfish (16 USC 1212)
Jellyfish or Sea Nettles, Other Such Pests, and Seaweed in Coastal Waters; Control or Elimination (16 USC 1202)
Land Remote-Sensing Policy Act of 1992, as amended December 18, 2010
Magnuson-Stevens Fishery Conservation and Management Act (MSA), as amended
Marine Debris Research, Prevention, and Reduction Act
Marine Mammal Protection Act of 1972
Marine Protection, Research, and Sanctuaries Act of 1972
Meteorological Services to Support Aviation Authority
Migratory Bird Conservation Act
National Aquaculture Act
National Climate Program Act
National Coastal Monitoring Act
National Integrated Drought Information System Act of 2017 and NIDIS Reauthorization Act of 2018
National Marine Sanctuaries Act
National Oceanic and Atmospheric Administration Authorization Act of 1992

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National Oceanographic Partnership Act
National Sea Grant College Program Act, and amendments
National Weather Modification Policy Act of 1976
NOAA Undersea Research Program Act of 2009
Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 and National Invasive Species Act of 1996
North Pacific Anadromous Stocks Act of 1992
Ocean and Coastal Mapping Integration Act
Ocean Dumping Act
Ocean Exploration Program (33 USC 3401)
Ocean Satellite Data (33 USC 883)
Oceans and Human Health Act
Oil Pollution Act
Outer Continental Shelf Lands Act
Pacific Salmon Treaty Act of 1985
R.M.S Titanic Maritime Memorial Act of 1986
Regional Marine Research Programs
Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act of 2012
Save Our Seas Act of 2018
Shark Finning Prohibition Act
Space Weather Authority
Special Studies and Joint Projects
Study of Migratory Game Fish; Water Research
The Whaling Convention Act of 1949
Tsunami Warning and Education Act
Tuna Conventions Act of 1950
Water Pollution Prevention and Control Act
Weather Research and Forecasting Innovation Act of 2017
Weather Service Modernization Act
Weather Service Organic Act
Western and Central Pacific Fisheries Convention Implementation Act

Non-Legislative Drivers

Department of Commerce 2018-2022 Strategic Plan
FY2019 President's Budget Request
Climate Change Science Program
Global Earth Observation System of Systems
Great Lakes Water Quality Agreement of 1978 - amended 1987
ICSU World Data Center Guidelines and Policy
Montreal Protocol on Substances that Deplete the Ozone Layer
NARA Records and Guidelines
OMB Circular A -16
U.N. Framework Convention on Climate Change

National and Interagency Strategic Plans

Science and Technology for America's Oceans: A Decadal Vision
National Strategic Plan for Aquaculture Research

NOAA Administration Priorities for Research

Reducing impacts of extreme weather and water events
Maximize the economic contributions of ocean and coastal resources
Innovation of NOAA's space based Earth observations architecture to better serve NOAA's operational needs and end-user requirements

Relevant Legislation Also Includes

§ High-Performance Computing and Communication Act of 1991: "NOAA shall conduct basic and applied research in weather prediction and ocean sciences, particularly in development of new forecast models, in computational fluid dynamics, and in the incorporation of evolving computer architectures and networks into the systems that carry out agency missions."

§ United States Code Title 33, Chapter 17, Section 883j "Ocean Satellite Data": "The Administrator of the National Oceanic and Atmospheric Administration … shall take such actions, including the sponsorship of applied research, as may be necessary to assure the future availability and usefulness of ocean satellite data to the maritime community."

§ Global Change Research Act of 1990, 15 U.S.C.

Appendix

§ 2921 *et seq*.: "Under section 2938, the President, the Chairman of the Council, and the Secretary of Commerce shall ensure that relevant research activities of the National Climate Program, established by the National Climate Program Act (15 U.S.C. § 2901 et seq.), are considered in developing national global change research efforts."

§ Oceans and Human Health Act, 33 U.S.C. §§ 3101 – 3104: "… interdisciplinary research and activities to improve understanding of processes within the ocean that may affect human health, and the development of predictive models based on indicators of marine environmental health or public health threats."

§ Coastal Ocean Program (201(c) of PL 102-567) Section 201(c) of PL 102-567: The National Oceanic and Atmospheric Administration Reauthorization Act authorizes a Coastal Ocean Program, and is therefore basic authorizing legislation for NCCOS. In the words of the law: "Such program shall augment and integrate existing programs of the National Oceanic and Atmospheric Administration and shall include efforts to improve predictions of fish stocks, to better conserve and manage living marine resources, to improve predictions of coastal ocean pollution to help correct and prevent degradation of the ocean environment, to promote development of ocean technology to support the effort of science to understand and characterize the role oceans play in global climate and environmental analysis, and to improve predictions of coastal hazards to protect human life and personal property."

§ Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. 1801 *et seq*.): The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) establishes exclusive federal management authority over fishery resources of the Exclusive Economic Zone. It is the principal Act governing U.S. fisheries policy. NCCOS research on ecosystem health, on the role of estuaries in nurseries for commercial fisheries, and on contaminants, such as bacteria or harmful algae, of commercial fisheries are key components in supporting NMFS in managing the Nation's fishery stocks.

§ National Coastal Monitoring Act (Title V of 33 USC 2801-2805): The Act requires the Administrator of the Environmental Protection Agency and the NOAA Under Secretary, in conjunction with other federal, state, and local authorities, jointly to develop and implement a program for the long-term collection, assimilation, and analysis of scientific data designed to measure the environmental quality of the nation's coastal ecosystems.

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