NOAA Research and Development Plan

2020-2026

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NOAA
Silver Spring, Maryland

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INTRODUCTION

Mission and Vision

The mission of the National Oceanic and Atmospheric Administration (NOAA) 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." NOAA's mission embodies science, service, and stewardship, and it affects more than one-third of America's gross domestic product[1]. The scientific enterprise is essential to fulfilling NOAA's mission and legislatively mandated responsibilities.

Research and development (R&D) at NOAA are investments in the scientific knowledge and technology that enables the United States to protect lives and property, address environmental challenges, sustain a strong economy, and manage the Nation's fisheries and other natural resources. NOAA's R&D enterprise comprises NOAA-funded and NOAA-conducted R&D, encompassing internal laboratories and science centers, Cooperative Institutes, Cooperative Science Centers, Sea Grant Programs, grant recipients, and contractors. NOAA's scientific activities develop and improve products and services to meet critical stakeholder needs. In meeting those needs, NOAA transitions its R&D into operations, applications, commercialization, and other uses that have a positive impact on the lives of the American people every day. For example, NOAA R&D provides reliable information to citizens, policy makers, emergency managers, and other decision makers by enabling better forecasts, earlier warnings for environmental phenomena, and a greater understanding of Earth systems and natural resources. In turn, NOAA relies on feedback from these customers to improve NOAA products, strengthen decision support services, and build confidence.

The societal benefits of R&D are embodied in NOAA's vision of a future with healthy ecosystems, communities, and economies that are resilient in the face of change[2]. As expressed in NOAA's 20 Year Research Vision (2005-2025), discoveries in science and technology and integration of research across our environment, economic well-being, and human health are key for NOAA products and services to meet urgent demands from a growing global population[3].

Purpose

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. This Seven Year Research and Development Plan (Plan) provides a characterization of the priorities and guidance for NOAA's R&D activities from 2020-2026. The Plan will provide direction on NOAA's R&D and allow for

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[1] National Oceanic and Atmospheric Administration (n.d.). About our agency. Retrieved from https://www.noaa.gov/about-our-agency

[2] National Oceanic and Atmospheric Administration (2008). Our mission and vision. Retrieved from noaa.gov/our-mission-and-vision

[3] National Oceanic and Atmospheric Administration (2005). NOAA 20 Year Research Vision. Retrieved from https://nrc.noaa.gov/sites/nrc/Documents/Reduced%20file%20size_20%20yr%20Research%20Vision.pdf

proactive actions to align NOAA's resources, budget, and functional activities to achieve stated goals. Implementation of the Plan will be captured in NOAA's annual operating plans, the NOAA Research and Development Database, and the annual NOAA Science Report.

The NOAA R&D Plan for 2020-2026 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 Plan is presented as a framework with which NOAA and the public can identify priorities and evaluate progress toward anticipated societal outcomes. It 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. As such, the Plan 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 will use this document for planning and prioritizing projects and guiding investments for NOAA and NOAA-funded R&D areas. Prioritization of the projects and activities that NOAA undertakes, based on budget realities and emerging needs, are captured in Line Office annual guidance and operating plans. NOAA utilizes strategic planning to anticipate future needs and set near-term priorities for meeting those needs. With this R&D Plan, 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. NOAA's progress toward meeting R&D goals and objectives will be evaluated periodically throughout the duration of the Plan.

The Plan communicates the Agency's scientific priorities to employees, partners, and stakeholders. In developing this Plan, NOAA obtained substantial input from 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.

By taking a strategic approach to NOAA's R&D enterprise, NOAA positions itself to coalesce disparate efforts and continue producing world-class science that addresses the agency's mission and the Nation's needs.

Scope

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

Research – Systematic study directed toward a more complete 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.

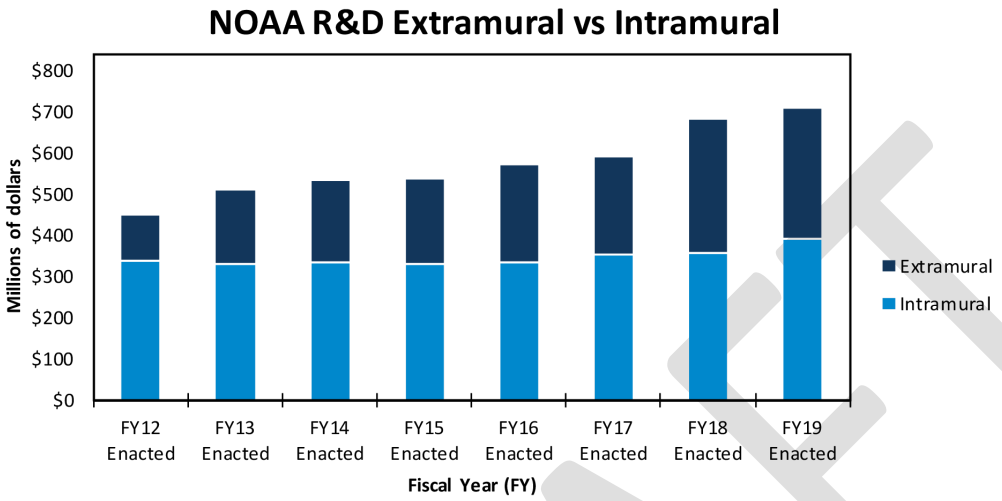

Figure 1. NOAA R&D include intramural and extramural activities. Intramural activities are internal R&D efforts, such as those performed by NOAA laboratories and science centers. Extramural activities include NOAA R&D partnerships and collaborations with non-NOAA entities, such as through grants, contracts, or cooperative agreements. Extramural R&D allow NOAA to leverage additional expertise and capabilities, as well as promote wider use of innovative research results.

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

Over the period 2011-2017, NOAA staff published more than 13,000 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[4]. These articles significantly furthered lines of scientific inquiry in their fields - more than 90 percent were cited by other papers within the scientific literature.

In directing, formulating, and evaluating R&D, NOAA follows eight principles outlined in NOAA Administrative Order (NAO) 216-115A[5]:

[4] Cikanek, H., Cyr, N., Ji, M., Matlock, G., and Thur, S. (2019). 2018 NOAA Science Report. Retrieved from https://repository.library.noaa.gov/view/noaa/19812

[5] NOAA Office of the Chief Administrative Officer (2018). NAO 216-115A: Research and Development in NOAA. Retrieved from https://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/216-115A.html

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".

Transitioning Research into Operations, Application, Commercialization, and other Uses (R2X): NOAA maintains a mission-oriented enterprise that is capable of identifying and applying R&D outputs to new and improved products, services, or more efficient operations. Part of this transition cycle includes the feedback from Operations to Research (O2R) to fill in gaps and improve existing operational products. Transition plans facilitate the transition of R&D to a potential end use. These transition projects are reviewed on a periodic basis[6].

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, and risks.

Partnerships: NOAA engages in interagency, academic, and public-private 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 Cooperative Institutes, the Educational Partnership Program (EPP), the National Oceanographic Partnership Program (NOPP), Cooperative Research and Development Agreements (CRADAs), Memoranda of Agreement (MoA), international engagements, citizen science projects, and communities of practice (e.g. community modeling).

Facilities and Infrastructure: In addition to the "soft" assets described above, successful implementation of the Plan requires NOAA to maintain and improve the "hard" assets that enable R&D. This includes laboratories and science centers, ships, aircraft, high performance computing capacity, satellites, and buoys. These platforms must be maintained and updated to continue to support NOAA's world-class R&D.

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[7].

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[6] NOAA Office of the Chief Administrative Officer (2019). NAO 216-105B: Policy on Research and Development Transitions. Retrieved from https://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/Handbook_NAO216-105B_03-21-17.pdf

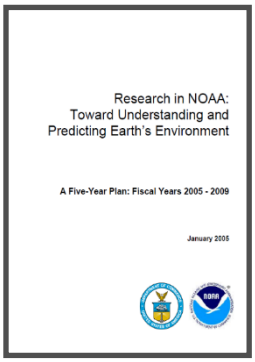
[7] Cikanek, H., Cyr, N., Ji, M., Matlock, G., and Thur, S. (2019). 2018 NOAA Science Report. Retrieved from https://repository.library.noaa.gov/view/noaa/19812

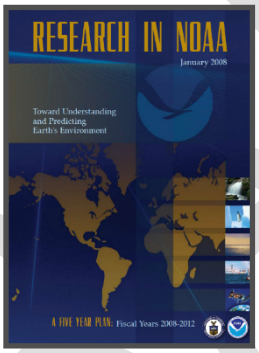
Scientific Integrity: NOAA scientists act with integrity to produce credible and reliable R&D results. To further the culture of scientific excellence at NOAA[8], NOAA's Scientific Integrity Policy, NAO-202-735D, outlines the responsibilities for scientists, those who use scientific results to set policy, and managers.

Accountability: NOAA will regularly evaluate its R&D and adjust activities and priorities as needed.

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[9]. In response to the SAB's recommendation, NOAA created R&D Plans for 2005-2009, 2008-2012, and 2013-2017, and this current Plan.





The NOAA R&D Plan 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 Plan also reflects public and internal comments solicited during a public town hall, NOAA Strategic Council meetings, and a Federal Register public comment period. The R&D objectives in this Plan will be adjusted in accordance with resource availability and Congressional appropriations. New priorities may emerge as technologies, resources, and societal needs change. The Plan is

[8] National Oceanic and Atmospheric Administration (2011). NAO 202-735D: Scientific Integrity. Retrieved from https://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_202/202-735-D.html

[9] Moore III, B., Rosen, R.D., Rosenberg, A.A., Spinrad, R.W., Washington, W.M., and West, R.D. (2004). Review of the Organization and Management of Research in NOAA. Retrieved from https://www.sab.noaa.gov/ReportLibrary.aspx#11343184-the-organization-of-and-management-of-research-at-noaa

not intended to encompass the wide breadth of R&D NOAA performs, rather, it focuses on highlighting NOAA's current priorities for the next seven years.

EVALUATION

Evaluations are critical to determining program success, identifying unintended outcomes, drivers, and impacts, and informing decisions about the direction of projects. The results are used to form future strategic plans to continue to strengthen NOAA's scientific enterprise. The R&D Plan will be evaluated following the guidance in the procedural handbook for NOAA Administrative Order (NAO) 216-115a[10] on R&D in NOAA. NOAA utilizes the five types of evaluations listed in the NAO, which are periodic, laboratory/science center/program, ad hoc, progress-to-plan, and portfolio R&D evaluations.

Building upon lessons learned from evaluations of previous NOAA R&D Plans, including the need to apply and communicate the Plan, improve tracking and reporting, and clarify targets, NOAA will leverage the following existing mechanisms to track the progress of R&D Plan objectives.

- The NOAA Research and Development Database (NRDD) is a secure, web-based performance management and business intelligence tool that contains information about the R&D projects conducted and funded by NOAA. The initial round of NRDD data entry and approval was in 2017, which has been followed by annual updates and submissions. NRDD submissions will be used to monitor NOAA's R&D portfolio and progress made on this Plan's objectives.
- NOAA Line Offices create Annual Operating Plans (AOPs) that capture upcoming NOAA projects. The Plan can inform AOP formation, and the AOPs in turn inform R&D Plan progress evaluation.
- 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.
- NOAA conducts reviews of programs, laboratories, and science centers. These reviews will inform progress on this Plan's 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 Plan's objectives.

SUMMARY OF VISION AREAS AND KEY QUESTIONS

NOAA was formed by the Reorganization Plan No. 4 of 1970[11], bringing together, under the U.S. Department of Commerce (DOC), the DOC's Environmental Science Services Administration

[10] NOAA Research Council (2018). NAO 216-115A Procedural Handbook: Research and Development at NOAA. Retrieved from https://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/handbook_NAO-216-115A.pdf

[11] 84 Stat. 2090 (1970). Reorganization Plan of 1970. Retrieved from http://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title5a-node84-leaf179&num=0&edition=prelim

that unified U.S. environmental and earth science agency operations (meteorological, climatological, hydrographic, and geodesic) and the U.S. Department of the Interior's U.S. Fish and Wildlife Service's Bureau of Commercial Fisheries (fisheries science and oceanographic research). This created a single agency to integrate different science disciplines and provide a holistic approach to protect life and property from natural hazards, understand the environment, and explore marine resources.

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 focused disciplines (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 (e.g., biological, physical, economic, social, behavioral sciences), with increased partnerships that research pressing topics to address the needs of the diverse communities NOAA serves. Cross-NOAA R&D includes transdisciplinary efforts that vastly improve the use of new and established observational tools (e.g., advanced satellites, drones) to efficiently characterize and predict the state of the atmosphere, the ocean-air interface, the interface of fresh-salt water, and parameters needed to mitigate the effects of climate change.

Box Text: 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. Through establishment of the fishery management councils and fishery management plans, MSA outlined how to allocate fishery yield, if any, to foreign fishing fleets. Additionally, 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.). 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 research scope, MSA has evolved over time to balance the benefits of U.S. fishery resources to the Nation with the need to protect the ecosystems fishery species depend on.

The context for NOAA R&D evolves over time as guided by the DOC, Federal statutes, and other planning documents. However, the context also evolves as scientific advances, made possible through long-term data collection and R&D, demonstrate the changes, relative to baseline states of the oceans and atmosphere, taking place in the coupled Earth system. For example, advances in the architecture of NOAA's space-based earth observations offer new technologies and improved flexibility and responsiveness in addressing its mission requirements (i.e., actionable and timely data for enhancing weather forecasting and other earth system modeling, improved readiness to hazards from weather and space-related events, and adjustments to changing environmental conditions).

NOAA seeks to improve warnings and forecasts for severe weather events to reduce societal and economic impacts. In addition, NOAA R&D informs decisions on the balance of economic growth in aquatic sectors (e.g. aquaculture, domestic fisheries) with conservation of vital ocean and coastal[12] resources. NOAA emphasizes an effective R&D enterprise that successfully transitions R&D to operations, which is vital to meeting priority goals and objectives.

Research and development addressing the first vision area, *reducing societal impacts from severe weather and other environmental phenomena*, is grounded in the physical realm with a focus on environmental phenomena that impact society. These range from local incidence of severe weather (e.g., heat waves, polar vortices, tornadoes, hurricanes, flooding, 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 in the sun (e.g., geomagnetic storms, solar flares, sunspots). While they are separate phenomena they are interconnected. Space weather impacts the different layers of the Earth's atmosphere and influences Earth's climate and weather. Global-scale climate itself also influences the severity of local weather. NOAA's ability to save lives and protect property under these events benefits from understanding how risk communication leads to improved societal response to forecasts of severe weather and changes in environmental phenomenon. Active response to risk improves societal and economic outcomes.

Research and development addressing the second vision area, *sustainable use and stewardship of ocean and coastal resources*, expands to the biological realm, including how physical phenomena impact the biological elements of ecosystems but also how the biological influences the physical. Humans are a part of ecosystems and human activity can alter both biological and physical aspects of the Earth. As such there are interconnections between the drivers of weather and the state of the Earth system that are apparent in the key questions and objectives of the first two vision areas. To better understand ecosystems, NOAA needs to undertake basic R&D, such as exploring uncharted areas of the ocean, and develop the knowledge, tools, and technologies to understand, protect, and restore healthy coastal and marine ecosystems. 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 other maritime commerce. Integral is the ability to understand the socioeconomic effects of these decisions on coastal communities.

Research and development addressing the third vision area, *a robust and effective research, development, and transition enterprise*, focuses on the basic building blocks of the R&D

[12] As defined by 33 U.S. Code § 2802, coastal waters means waters of the Great Lakes, including their connecting waters and those portions of rivers, streams, and other bodies of water having unimpaired connection with the open sea up to the head of tidal influence, including wetlands, intertidal areas, bays, harbors, and lagoons, including waters of the territorial sea of the United States and the contiguous zone. Retrieved from http://uscode.house.gov/view.xhtml?path=/prelim@title33/chapter41&edition=prelim#2802_1_target

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 biological phenomena. These data are used in both simple and complex models (e.g., biogeochemical, physical, biological, economic, ecosystem, integrated, and nested models) developed to simulate systems and predict system changes. NOAA is moving forward in developing models that integrate economic and social science with physical and ecological information. These data sets, where not restricted by legislation mandates or legal requirement, are also made available to the public under the Foundations for Evidence-Based Policymaking Act[13] that codified the Public Access to Research Results executive order, providing opportunity for novel applications developed in the private sector.

While the R&D Plan is divided into the three vision areas, there is intrinsic overlap between them. Each vision area is broken down into key questions. In the body of the Plan, 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 prioritization. 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.

1. Reducing societal impacts from severe weather and other environmental phenomena

Key questions:

- ***1.1. How can forecasts and warnings for severe weather and other environmental phenomena be improved?***
- ***1.2. What is the state of the global climate and how is it affecting local weather, increasing environmental hazards, and affecting water quality and water 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?***

2. Sustainable use and stewardship of ocean and coastal resources

Key questions:

- ***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?***

[13] H.R.4174 — 115 Congress (2017-2018). Foundations for Evidence-Based Policymaking Act of 2018. Retrieved from https://www.congress.gov/bill/115th-congress/house-bill/4174.

- ***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?***

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

Key questions:

- ***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 and their associated platforms be optimized to meet NOAA's needs?***
- ***3.3. How can Big Data and information technology 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 credible social science research?***

Vision Area 1: REDUCING SOCIETAL IMPACTS FROM SEVERE WEATHER AND OTHER ENVIRONMENTAL PHENOMENA

Weather impacts the lives of Americans every day, from daily temperature and precipitation to severe weather events. By receiving accurate and timely information, the public can make informed decisions about how to respond, saving lives and property. NOAA R&D works to improve 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. NOAA R&D focuses across all time scales, from weekly forecasts to sub-seasonal to seasonal predictions to climate predictions for the next century. Further, NOAA R&D seeks to improve space weather products and services to ensure safety and national security. This R&D will ensure society is prepared for and has the information needed to respond to weather and other environmental phenomena.

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

Each year, the United States averages approximately 10,000 thunderstorms, 5,000 floods, 1,300 tornadoes, 27 named tropical storms[14], and widespread droughts and wildfires that collectively cause approximately 650 deaths[15]. 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[16]. NOAA R&D provides foundational models, forecasts, and information products and services to better prepare communities, ecosystems, and economies for high-impact environmental events.

Objectives:

- Produce reliable and timely foundational forecasts of sub-seasonal and seasonal conditions that influence the incidence and severity of droughts, tornadoes, fires, coastal inundation, sea ice conditions, and heat waves.
- Provide tsunami and rip current forecasting capability based on models and measurements, including tsunami inundation models and maps for increasing the preparedness of communities and safeguarding port and harbor operations.

[14] NOAA National Centers for Environmental Information (2018). State of the climate: Hurricanes and tropical storms for annual 2017. Retrieved from https://www.ncdc.noaa.gov/sotc/tropical-cyclones/201713/.
[15] National Oceanic and Atmospheric Administration (n.d.). Weather. Retrieved from https://www.noaa.gov/weather
[16] NOAA Office of the Chief Financial Officer (2018). NOAA By the Numbers. Retrieved from http://www.performance.noaa.gov/wp-content/uploads/NOAA-by-the-Numbers-Accessible-Version-Corrected-17-JUL-18.pdf

- 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.
- Develop and operate next-generation weather and earth system unified models using a community-based approach in concert with advances in high-performance computing.
- Incorporate water quality (including temperature, salinity, and dissolved and suspended constituents) into an integrated water prediction capability with associated decision support services.
- Determine whether a variational, ensemble-based, hybrid, or other data assimilation method yields the best convective-scale analyses and forecasts.
- Evaluate sensitivities to model resolution (via comparison to GOES imagery and radar data) and how to optimize capabilities for predicting specific convective hazards given the resolution that resources will allow.

Research Highlight:

NOAA is integrating the Finite Volume Cubed-Sphere Dynamical Core (FV3), a scalable and flexible dynamical core capable of both hydrostatic and non-hydrostatic atmospheric simulations, into its operational forecasts. The FV3 will soon upgrade the current operational Global Forecast System (GFS) to run as a unified fully coupled system within NOAA's infrastructure, using a Lagrangian vertical coordinate system enabling supreme computational efficiency and an option to improve modeling of resolutions finer than 1 km. Researchers continue to amend cold air bias in the lower atmosphere as well as faster than normal tropical storm tracks, but the FV3 will dramatically improve NOAA's ability to accurately predict severe storms, hurricanes, and winter storm events.

Key Question 1.2: What is the state of the global climate and how is it affecting local weather, increasing environmental hazards, and affecting water quality and water availability?

Global land and ocean temperatures have been above the 20th-century average for 41 consecutive years (1977-2017)[17]. With global climate change comes changes in extreme weather, inundation, fresh water availability, the carbon cycle, sea-ice extent, and temperature[18]. 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 climate change.

[17] NOAA News & Features (2018). 2017 was 3rd warmest year on record for the globe: NOAA, NASA scientists confirm Earth's long-term warming trend continues. Retrieved from https://www.noaa.gov/news/noaa-2017-was-3rd-warmest-year-on-record-for-globe

[18] NOAA Climate Education Resources (2019). Climate change impacts. Retrieved from https://www.noaa.gov/resource-collections/climate-change-impacts

Objectives:

- Assimilate ocean observations and integrate ocean-climate processes research into climate and weather models.
- Advance research on atmospheric chemistry, composition, and processes, identifying their influence on air quality, climate, and weather systems.
- Identify causes for observed regional and seasonal differences in U.S. trends (e.g., temperature, precipitation, visibility, wind, clouds) across latitude, longitude, altitude, and topography to improve predictions and projections, especially for extreme events.
- Assess the roles of natural variability (e.g., solar changes, volcanic eruptions) and changing radiative forcing (from greenhouse gases, trace gases, and aerosols) in causing seasonal-to-decadal changes in the climate system.
- Strengthen the foundational science for understanding and detecting Arctic climate and ecosystem changes.
- Advance research on climate variability and change research, focusing on the impacts of weather extremes and coastal inundation, and changes in freshwater resources and sea ice extent.
- Advance the understanding of the impacts of climate phenomena that affect human health (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 future projections of temperature, precipitation, sea level rise, large-scale climate variability, extreme storms, Arctic change, and ocean acidification. The predictions and projections in the assessment form the basis for informing 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 themselves that work to 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 such as electric power transmission, GPS navigation and timing, high-frequency radio communications, aviation, and satellites. The increasing reliance on precision GPS for activities such as aircraft navigation, oil exploration, construction, and farming has elevated society's vulnerability to and the impacts of space weather. To enhance safety and national security, NOAA R&D will improve space weather warnings and forecasts for GPS customers.

Objectives:

- Develop new communication, navigation, and radiation products to address the requirements of the International Civil Aviation Organization (ICAO) and the establishment of Space Weather Prediction Center (SWPC) as an International Civil Aviation Organization (ICAO) regional Space Weather Warning Center.
- Transition the Whole Atmosphere Model, a coupled ionosphere, plasmasphere, electrodynamics coupled modeling system, to operations, enhancing the product specifications and forecasts for communication and navigation customers. Improve radiation-environment products for the upcoming human exploration initiative and for satellite operations.
- Using new satellite solar observing technology, observe the sun, and develop methods to detect, track, and forecast solar storms.

Research Highlight:

The Space Weather Prediction Center is introducing two new models to specify and forecast the impacts of the very upper atmosphere (the ionospheric) on Global Position System (GPS) and Global Navigation Satellite System (GNSS). The ionosphere can “bend” GPS and GNSS signals making them inaccurate in a manner that is not constant over time. These new models, GLObal Total Electron Content (GloTEC) and Whole Atmosphere Model - Ionosphere Plasmasphere Electrodynamics (WAM-IPE) “correct” the signal so that it has minimal effects on navigation and other uses.

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, reduce property damage and other 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, 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 severe weather by using information based on probabilities, 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 severe 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

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. 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.

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 seafloor while supporting an estimated 25 percent of all known marine species[19] and providing $3.4 billion in value to the U.S. economy each year[20]. 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 of the mechanisms and combined effects of environmental changes resulting from atmospheric, ocean, 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, 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

[19] NOAA Florida Keys National Marine Sanctuary (n.d.). Retrieved from https://floridakeys.noaa.gov/corals/biodiversity.html

[20] NOAA Coral Reef Conservation Program (n.d.). The coral reef economy. Retrieved from https://coralreef.noaa.gov/gallery/cr_economy.html

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 fishers?

The domestic seafood sector provides Americans with protein-rich food while contributing jobs and revenue to the Nation's economy. In 2017, commercial landings by U.S. fishers in the 50 states totaled 9.9 billion pounds valued at $5.4 billion[21]. 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 fishers.

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 indicators that facilitate increased ecosystem understanding and sustainable coastal development and recreational fishing.

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 overfished (population size is too low) have declined by 30 and 24 percent respectively. Combined with efforts to expand data collection and monitoring, improve recreation and commercial fisheries statistics, invest in training future assessment scientist, and support focused working groups and collaboration with various

[21]NOAA National Marine Fisheries Service (2018). Fisheries of the United States, 2017 Report. Retrieved from https://www.fisheries.noaa.gov/resource/document/fisheries-united-states-2017-report

partners, NOAAs' stock assessment enterprise has helped establish the U.S. as a leader in sustainable fisheries management.

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.

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[22]. 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[23]. 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 on fish genetics and applied genomics, selective breeding, disease, and hatchery feed stocks for enhancing aquaculture and understanding the impacts of aquaculture on the natural environment.
- Develop and improve technologies (e.g., marine aquaculture feeds, automated systems) to reduce costs and labor.

[22] NOAA National Marine Fisheries Service (2018). Fisheries of the United States, 2017 Report. Retrieved from https://www.fisheries.noaa.gov/resource/document/fisheries-united-states-2017-report

[23] Nash, C.E. 2004. Achieving policy objectives to increase the value of the seafood industry in the United States: The technical feasibility and associated constraints. Food Policy 29:621- 641. Retrieved from https://spo.nmfs.noaa.gov/sites/default/files/tm103.pdf)

Research Highlight:

NOAA conducts research to advance aquaculture practices and success. For example, NOAA researchers helped identify ocean acidification as 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[24] 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[25]. 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.

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

[24] NOAA Office of Coastal Management and U.S. Census Bureau (2015). American community survey five-year estimates. Retrieved from https://coast.noaa.gov/states/fast-facts/economics-and-demographics.html
[25] NOAA National Marine Fisheries Survey (2018). National survey shows ocean and coastal recreation is big business. Retrieved from https://www.fisheries.noaa.gov/feature-story/national-survey-shows-ocean-and-coastal-recreation-big-business

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.

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 that produce a variety of concerns. Presently, NOAA has operational HAB forecasts for the coasts of Florida and Texas to monitor and predict red tides (caused by dinoflagellate *Karenia brevis*) which can cause respiratory illness and eye irritation in humans and kill marine life. Additional capabilities that will develop into routine operational forecasts are under development for Florida's West Coast (*Karenia brevis*), western Lake Erie (cyanobacteria toxins cause skin irritation and damage to internal organs), Gulf of Maine (dinoflagellate *Alexandrium fundyense* causes paralytic shellfish poisoning), Pacific Northwest (diatom *Pseudo-nitzschia* produces domoic acid causing amnesic shellfish poisoning), Chesapeake Bay (multiple species, including *Margalefidinium*), and Gulf of Alaska (*Pseudo-nitzschia* and *Alexandrium sp.*). 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.

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[26] utilize the U.S. marine transportation system, and, in 2015 alone, $1.56 trillion worth of U.S. goods moved 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.

[26] U.S. Department of Homeland Security, United States Coast Guard (20018). Recreational Boating Statistics 2017. Retrieved from http://www.uscgboating.org/library/accident-statistics/Recreational-Boating-Statistics-2017.pdf.

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 circulation 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 to 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.

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[27] 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.

Additional NOAA work is contributing to the U.S. Office of Naval Research Departmental Research Initiative, Stratified Ocean Dynamics of the Arctic that addresses the National Science Foundation's (NSF) 10 Big Ideas, Navigating the New Arctic. With support from NOAA, NSF and partners are developing instruments to collect data to better understand what drives oceanic stratification. This information can help improve the skill of sea ice forecast models over longer periods and provide for safer navigation of the Arctic as vessel traffic increases.

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[28] and

[27] Maslowski, W., Clement Kinney, J., Higgins, M., and Roberts, A. (2012). The future of Arctic sea ice. *Annual Review of Earth and Planetary Sciences*, *40*, 625-654.

longest mountain range[29], and is home to unique organisms. An estimated 91 percent of the ocean species have yet to be classified 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[30]. 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.

Objectives:

- Advance coastal and offshore surveying and mapping technologies, tools, and methodologies to ensure safe navigation, 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

Research Highlight:

The majority of the ocean floor has not been mapped. Seabed 2030 (Nippon Foundation, 2017) is a global initiative to create a high-resolution bathymetric map of the Earth's entire seabed. 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. Economic prosperity from the future development of offshore wind energy, fossil fuels, and deep-sea mining capacity must be balanced with the need to protect deep-sea and benthic ecosystems that may be affected by these activities.

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[28] NOAA National Ocean Service (2018). Where is Earth's largest waterfall? Retrieved from https://oceanservice.noaa.gov/facts/largest-waterfall.html

[29] NOAA National Ocean Service (2018). What is the longest mountain range on Earth? Retrieved from https://oceanservice.noaa.gov/facts/midoceanridge.html

[30] Westingon, M., Varner, J., Johnson, P., Sutherland, M., Armstrong, A., and Jencks, J. (n.d.) Assessing sounding density for a Seabed 2030 initiative. Retrieved from https://www.eiseverywhere.com/file_uploads/88d4852d59327aec9aee1f08b5f64e84_AssessingSoundingDensityforaSeabed2030Initiative_CHC20181Meredith.pdf

NOAA supports the Seabed 2030 initiative to expand knowledge of what lies beneath the ocean.

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) impacts the economies 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).

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 the previous Orange County 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 enterprise is vital for being able to reduce the impacts of severe weather and enable the sustainable use and stewardship of ocean and coastal resources. All areas of NOAA R&D require integrated models, optimal observation platforms, and efficient use of Big Data and information technology to best serve NOAA's mission. NOAA relies on environmental data derived from earth observations (both physical and biological) derived through a variety of platforms (e.g., satellites, radars, manned and unmanned aircraft, ground stations, sea-going vessels, buoys, submersibles). Providing environmental information that is accessible and usable through standardized data management practices ensure data are retrieved, preserved, analyzed, integrated, and shared to support advances in modeling and spur scientific and commercial innovation. The integration of the social sciences, which includes an understanding of human behavior and risk, into every research area enables the public to make scientifically informed decisions using NOAA products.

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[31]. 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 framework for interoperability across disciplines with support from the external research community.
- Advance data integration, assimilation, and Earth System Modeling Framework (ESMF) connectivity for NOAA's operational numerical models that couple the atmosphere, ocean, land, and ice at global and regional scales.

[31] NOAA Research Council (2018). 2017 NOAA Science Report. Retrieved from https://repository.library.noaa.gov/view/noaa/19811.

- 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.
- Incorporate ambitious data assimilation (DA) schemes into NCEP architecture that include coupled DA across the Earth System, multi-scale DA across temporal and spatial scales (global to convective), fast and efficient integration of massive increases in the volume of observations, and represent model uncertainty (ensembling), and deal effectively with non-linearity in background and observation errors.

Research Highlight:

Beginning in 2019, the Earth Prediction Innovation Center, or EPIC, will improve the United States' weather and climate models through focused attention and investment throughout the entire modeling community, including short term weather, sub-seasonal and seasonal oscillations, and long term climate patterns. EPIC will serve as a virtual center enabling R&D that leads to rapid development of new models through collaboration between NOAA, its partners, and engagement with community modeling efforts. Through designation of this virtual 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. Improvements in weather and climate models 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 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[32]. NOAA observing systems (e.g. satellites, buoys, unmanned systems) generate global environmental data and images that are used to create analyses and forecasts to better understand our dynamic Earth. 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.

Objectives:

[32] OSC Report on the State of NOAA Observing Systems

- 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 understanding, accuracy, characterization, and monitoring (including ecosystem state and processes), while minimizing costs.
- Lead innovation in environmental sensor, unmanned system, 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.
- Lead innovation in data processing, machine learning, and artificial intelligence 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 regional forecasts.
- Explore the use of acquisition and sharing of private sector data networks to improve model initialization.

Research Highlight:

In the last four years, NOAA has launched three new satellites, GOES-16, GOES-17, and JPSS-1, that are providing global data to develop timely and accurate weather forecasts. NOAA R&D both contributed to the development of these satellites and their products and is enhanced by the data the satellites produce, which are critical to detecting and observing environmental phenomena. For example, since their launch, these 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) and machine learning techniques to make better predictions from satellite images and data. For example, NOAA scientists have begun exploring ways to use AI to fill 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 and machine learning has the potential to decrease the time it takes to process the immense volumes of satellite data, which will potentially increase the amount of data leveraged for predictions.

Key Question 3.3: How can Big Data and information technology 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[33]. As data processing and storage capabilities have improved, NOAA

[33] National Oceanic and Atmospheric Administration (n.d.). Big data project. Retrieved from https://www.noaa.gov/big-data-project

has increasingly used Big Data analytics to create a more detailed and accurate picture of the Earth's systems. In order to be accurate and effective, 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 in order to mitigate errors, accelerate and transition R&D efforts, improve operational efficiency, and provide information for better decision making and economic growth.

Objectives:

- Advance Big Data analytics and utilize cloud computing platforms to identify and forecast changes in the ocean environment, including ocean circulation, coastal and marine ecosystems, and sea level rise.
- Develop methods to improve interoperability and synchronization of data and information across large datasets to promote innovation and consistent messaging.
- Incorporate predictive analytics, cognitive computing, and automation to combine forecast information with impact information.
- Leverage advanced technologies to improve data access and data archiving.
- Develop cost-effective and efficient ways to process and analyze large datasets, 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. To date, more than 40 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 credible social science research?

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.

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.
- 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 the development of exhibits, media, materials, and programs that support NOAA's mission.
- Evaluate the value of NOAA and NOAA-funded projects, as tracked through the lifespan of the projects, from conception to application.

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 can better understand 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.

Cross-cutting Themes

Many of NOAA's research areas cut across the three vision areas presented in the Plan. Several of these cross-cutting activities are referenced in the table below to demonstrate where these subject areas can be found in the Plan.

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
Ecological Forecasting					x			x			x	x			x
Polar Science	x								x						
'Omics					x	x	x	x	x	x					
AI and machine learning	x				x								x	x	

Data	x											x	x	x	x

NOAA R&D enterprise has evolved over several decades to integrate across distinct scientific disciplines and advance understanding of Earth's varied and complex systems. These changes can be traced through the three previous versions of this Plan and demonstrate 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 has not changed in the face of change, is as relevant today as ever.

Appendix A - List of Plans and Mandates to Inform the R&D Plan

Department of Commerce 2018-2022 Strategic Plan

FY2019 President's Budget Request

Legislative Mandates, Authorities, and Drivers

Agreements to Aid and Promote Scientific and Educational Activities
America Competes Act
Ocean and Atmospheric Research and Development (The America COMPETES Reauthorization Act of 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
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
Crown of Thorns Starfish
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
Fisher and Wildlife Coordination Act (2934)
Fur Seal Act of 1975
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
Jellyfish or Sea Nettles, Other Such Pests, and Sea Weed in Coastal Waters; Control or Elimination
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
    Save Our Seas Act of 2018
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 2006
National Marine Sanctuaries Act
National Oceanographic and Atmospheric Administration Authorization Act of 1992
National Oceanographic Partnership Act
National Sea Grant College Program Act
    National Sea Grant College Program Act Amendments of 2002
National Weather Modification Policy Act of 1976
NOAA Undersea Research Program Act of 1009
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 Act
Ocean Satellite Data
Oceans and Human Health Act
Oil Pollution Act
Outer Continental Shelf Lands Act
Pacific Salmon Treaty Act of 1985
Preservation of Fishery Resources
Public Health and Welfare - Pollution Prevention and Control
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
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

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 (to be released by OSTP)
National Strategic Plan for Aquaculture Research

NOAA Administration Priorities for Research

Implementing the Weather Act
Blue Economy White Paper
Transitioning Research to Operation, Application, and Commercialization

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. § 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 USC 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.