Research and Development at NOAA
A Five Year Strategic Plan
2013-2017

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Section 1. Introduction: Why Research and Development?

I. Saving lives, protecting property, and providing for the future

Earth's ecosystems support people, communities and economies. Human health, prosperity and well-being depend on the health and resilience of the natural environment.[1] The intimate connection between people and the environment is demonstrated on a daily basis. Yet this connection is not without its challenges. The availability of freshwater, the exposure of people and communities to high impact weather, the stresses due to urbanizing the coasts, the exploitation of ocean and coastal resources, and the pervasive effects of climate change on society and the environment are the central challenges that NOAA must address to improve human welfare and sustain the ecosystems upon which we, as a Nation, depend.[2] These are the challenges that we can foresee, but there are many that we cannot. Sudden events often challenge us as a society and how we exist in the environment that supports and helps to define us. The Deepwater Horizon explosion and subsequent protracted oil spill, the earthquake and tsunami that devastated the northern coast of Japan, triggering nuclear meltdowns and release of radioactivity, the eruptions of Eyjafjallajokull that caused global aviation disruptions - each of these events challenged us but also demonstrated our tremendous capability to respond and adapt.

NOAA is the only federal agency with operational responsibility to protect and preserve ocean, coastal, and Great Lakes resources and to provide critical and accurate weather, climate, and ecosystem forecasts that support national safety and commerce. As social and economic systems evolve and become more complex, the tools and information needed to promote growth, to preserve and improve human and environmental health, to develop and maintain a viable national infrastructure, and to provide security for present and future generations must advance as well.[3] The demands for responsive and forward thinking science, service, and stewardship are reflected in our daily lives:

- A nationwide survey indicates that 96 percent of the U.S. public obtains in total, either actively or passively, 301 billion weather forecasts each year. Based on an average annual household value of $286 placed on weather information, the American public collectively receives $31.5 billion in benefits from weather forecasts each year.[4]
- The commercial and recreational fishing industries depend on healthy and abundant fish stocks, habitats, and marine ecosystems to provide lasting jobs, food and recreational opportunities. In

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[1] National Oceanic and Atmospheric Administration. Next Generation Strategic Plan. December 2010.

[2] National Oceanic and Atmospheric Administration. Next Generation Strategic Plan. December 2010.

[3] National Oceanic and Atmospheric Administration. Research in NOAA: Toward Understanding and Predicting Earth's Environment. January 2008.

[4] J. K. Lazo, R. E. Morss, J. L. Demuth, 300 billion served: sources, perceptions, uses, and values of weather forecasts. Bulletin of the American Meteorological Society, 90(6). (June, 2009)

total, our Nation's fisheries supported 1.5 million full and part-time jobs and contributed $79 billion to GDP.[5]

- Since 2000, the total United States land area affected by drought of at least moderate intensity has varied from as little as 7% of the contiguous United States (August 3, 2010) to as much as 46% of the U.S. land area (September 10, 2002). According to the U.S. Drought Monitor (USDM), more than half the country (56%) experienced drought conditions in June 2012—the largest percentage since the monitor was started 12 years ago.[6]

"It is through research that society gains the understanding to make informed decisions in this increasingly complex world."[7]

Over the next five years, NOAA research and development activities, conducted by NOAA and our partners, will address those societal and environmental challenges and trends that are of increasing importance to decision makers. National and global population growth and migration towards coastal regions, climate variability and change, human and natural alterations of ecosystems, agricultural needs in the face of changing water supply and water quality, economic trends, and other pressing questions are creating an increasing demand for information and services to help people make the best possible decisions.[8]

A. Legislative drivers for NOAA R&D

As an agency of the Executive Branch of the United States government, federal statutes and Executive orders define the framework within which NOAA's research enterprise is executed. While research p*er se* is not necessarily mandated by all of these drivers, the research enterprise provides NOAA the scientific foundation to effectively execute these mandates. These drivers are diverse in scope, ranging from the Ocean Exploration Act, which focuses on unexplored regions of the deep oceans that encompass 95% of the ocean, to the Weather Service Organic act, which provides NOAA with the authority to forecast, record, report, monitor, and distribute meteorological, hydrologic and climate data, to the Magnuson-Stevens Fishery Conservation and Management Act, which requires rebuilding and maintaining the Nation's fishery stocks.[9] Each of these mandates focuses on a specific need, topic, or challenge for the Nation; however, the strength of the NOAA R&D enterprise rests on not only fulfilling those requirements but examining the areas of synergy between focused requirements and integrating required research into a holistic perspective.

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[5] Fisheries Economics of the United States, 2010 (forthcoming, not yet published)

[6] NOAA Testimony, COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY, U.S. HOUSE OF REPRESENTATIVES, July 25, 2012

[7] National Oceanic and Atmospheric Administration. Research in NOAA: Toward Understanding and Predicting Earth's Environment. January 2008.

[8] National Oceanic and Atmospheric Administration. Research in NOAA: Toward Understanding and Predicting Earth's Environment. January 2008.

[9] A full list of mandates and additional drivers is provided in Appendix A.

B. From Knowledge (Research) to Application - Framing NOAA Future R&D

NOAA is America's oldest science agency, and our reach extends from the surface of the sun to the bottom of the sea. We study, monitor, predict, and forecast the Earth's environment, and provide critical environmental information to the nation. We are stewards of our nation's fisheries, coasts and oceans. Our work makes a difference in the lives of each and every American. Every day: businesses large and small depend on NOAA's weather forecasts to make important decisions; fishermen and ship captains go to sea with the benefit of NOAA's charts and forecasts; our nation's ports, through which 90 percent of the nation's imports and exports travel, are safer thanks to NOAA information and services; Americans enjoy fresh seafood caught or grown sustainably in our waters; coastal tourism thrives because of NOAA's work to protect healthy marine ecosystems that support recreational fishing and boating, bird and whale watching, snorkeling on coral reefs and spending time at the beach; and military leaders, emergency managers, farmers, airline pilots, and so many others depend on NOAA for vital information about weather and weather-related disasters. NOAA seeks to maximize the benefits of its research and development investments; by improving decision-making by articulating the inherent uncertainty associated with research; defining and quantifying the value of its research and development; and improving the way it translates that investment into knowledge and services that can be used by decision-makers.

i. Informing Decisions locally and Globally

NOAA's vision for the future - ***healthy ecosystems, communities and economies that are resilient in the face of change*** - has no geographic boundary. A coastal community seeking to mitigate impacts of rising sea level can use predictions derived from global climate models. Improved understanding of the impacts of coastal development are informing local managers and communities of risks to human health and the ecosystem. Long term investments in climate science have dramatically improved our understanding of the variability in the climate system, for example, through the now-operational TAO array whose observations inform models that predict the El Niño-Southern Oscillations (ENSO). ENSO and the resulting climatic variability have demonstrated impact on extreme temperatures, water resources, living resources, and storm activity, and understanding the trends and impacts allow for advance warning and preparation. Models used to understand how, where, and when chemicals and materials are transported through the air have been used to assess post-earthquake/tsunami radioactive particle dispersion in Japan. NOAA will continue to respond to critical questions and challenges on local to global scales, from examining the impacts of dam removal and river flow and subsequent recovery of an ecosystem that had been altered for decades, to contributing to the international, collective knowledge of the state of the climate system and the uncertain future that comes with its evolution.

ii. Supporting Economic Success

NOAA science and technology impact the daily lives of the nation's citizens, and have a significant impact on the national economy. For example, about one-third of the U.S. economy (approximately $3 trillion) is weather sensitive. Industries related to agriculture, energy, construction, health, travel, and transportation are almost entirely weather dependent. Weather data and forecasts play a critical role in these major economic sectors. Federal, state, and local governments and the public use weather warnings to save lives and prevent destruction of property. Accurate and longer range weather forecasts depend on an ongoing program of research and development. U.S. electricity producers save $166 million annually using 24-hour temperature forecasts to improve the mix of generating units that are available to meet electricity demand. Incremental benefits are relevant in assessing the merits of investments that will improve forecast accuracy. The incremental benefit of an improvement in temperature forecast accuracy is estimated to be about $1.4 million per percentage point of improvement per year. For a 1°C improvement in accuracy, the benefit is about $59 million per year (or a $37 million benefit for a 1°F improvement). It is estimated that a perfect forecast would add $75 million to these savings (all values in 2002 dollars).[10] [Need to include climate/oceans/coasts examples]

iii. Quantifying and Communicating Uncertainty

Uncertainty[11] attempts to quantify how much real world events differ from what is expected or predicted. The reason that understanding uncertainty is so important stems from how significant the impacts are based on the magnitude of difference between was does or can occur versus what is expected or predicted to occur. As noted in a 2006 National Academies Study on Characterizing and Communicating Uncertainty, "Whereas decisions with low stakes occur very frequently (e.g., should I carry an umbrella today?), the consequences of the rare decisions with high stakes and thus the importance of transmitting forecasts in those situations in the most effective and socially beneficial way are many orders of magnitude greater."[12] Research results have some degree of inaccuracy associated with them resulting in uncertainty. It is important to understand that uncertainty to inform decisions based on those results. Predictions and forecasts also have uncertainty associated with them. For example, a major cause of forecast uncertainty is not the error (not "inaccuracy") associated with research results that are incorporated in a weather model, but the application to conditions for which the model was not developed. "All prediction...is uncertain."[13] Research is required to understand the size of that uncertainty; what factors contribute to that uncertainty; how to minimize that uncertainty; and how to communicate that uncertainty so that informed decisions can be made. Public understanding of the uncertainty for NOAA's products and services will help the public and decision-makers respond appropriately.

[10] Teisberg, T., Weiher, R., and A. Khotanzad. (2005, December). The Economic Value of Temperature Forecasts in Electricity Generation. Bulletin of the American Meteorological Society, 86(12).

[11] Uncertainty is an overarching term that refers to the condition whereby the state of a system cannot be known unambiguously. Probability is one way of expressing uncertainty. A probabilistic forecast conveys uncertainty in the prediction. The converse is a deterministic forecast, which provides only one prediction of the future state of a system, with no information regarding forecast uncertainty. For example, the track forecast of a hurricane could be represented by a (deterministic) single line or by a cone that more appropriately (and probabilistically) conveys the likely range of forecast tracks. (NAS, 2006)

[12] National Academies of Science. Completing The Forecast: Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts. National Academies Press, Washington, DC. 2006.

[13] National Academies of Science. Completing The Forecast: Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts. National Academies Press, Washington, DC. 2006.

iv. Integrating the Human Dimension

The use of social sciences, such as economics, sociology, and anthropology, allows for improved design and delivery of NOAA's products and services, by identifying how people receive and use the information provided. Using social sciences also enables NOAA to evaluate the benefits of its services, such as the incremental improvement of weather forecasts or the economic effectiveness of resource management policies. Additionally, social scientific investigations are crucial to understanding the value of ecosystem services and in better understanding what people value and why. While NOAA has a robust pedigree in natural sciences, the integration of social sciences into its science, service, and stewardship is limited and dispersed, potentially limiting the effectiveness of NOAA's science investment and service. An example highlighting the need for improved integration of social science lies in NOAA's hurricane forecasting capabilities. The investment in the research and technology to improve hurricane forecasting will protect lives and property, however, the full sociological and economic benefit of this investment has yet to be quantified.[14] Additionally, to truly realize the benefits of this investment in hurricane forecasting improvements, society must understand and respond appropriately to the information provided. NOAA must continue to enhance and expand the integration of social sciences (e.g., economics, sociology) with NOAA's natural sciences to fully understand ecosystems in light of human valuation; determine how to best engage the public; enhance the socio-economic returns of NOAA's research investment; and provide guidance for tailoring technology development and implementation for its most effective use.

v. Translating Our Innovation

NOAA R&D is "outcome-oriented, " focusing on the ultimate use of its investment, such as improved community resiliency in the face of climate change, improved hurricane forecasts and more effective communication forecast information to emergency managers. The result of this evolution is the convergence and integration of multiple disciplines and NOAA targeting most, if not all, research and development to meet mission critical responsibilities to protect people, property, ecosystems, and the promotion of economic well-being. Achieving outcomes depends upon effectively translating the knowledge resulting from NOAA's R&D into applications useful to society. There is no formal definition of "translate," but it includes activities of technology and knowledge transfer, internally and externally, to enable NOAA to improve its products and services, and along with our partners and the public, to create a safer and more sustainable society. Translation is inherently about communication -- a two-way dialog -- such that the science and technology that NOAA produces is not only relevant to society, but also responsive to its needs.

NOAA is continually seeking to improve how it transitions information and technologies by implementing this responsive transition process and capitalizing on its successes. For example, the development and transition of the Harmful Algal Bloom Operational Forecast System, which provides

[14] Lazo, J.K., Waldman, D.M., Morrow, B.H., Thacher, J.A., 2010. Household Evacuation Decision Making and the Benefits of Improved Hurricane Forecasting: Developing a Framework for Assessment. Weather and Forecasting. 25:1:207-219.
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information on the location, extent, and the potential for development or movement of harmful algal blooms in the Gulf of Mexico, required the focused effort of researchers, modelers, and operators from NOAA and its partners to bring the project to fruition. Arenas, such as test beds and proving grounds, for increased collaborations between researchers and operators, and a strong support for continual research and technology infusion into NOAA's operations, will yield a robust enterprise capable of delivering state-of-the-science information and services to the Nation. In addition to technology transition, NOAA continually seeks to provide the critical information necessary to support decision-makers. For example, Regional Integrated Sciences and Assessments (RISA) support integrated, place-based research across a range of social, natural, and physical science disciplines to expand decision-makers' options in the face of climate change and variability at the regional level.

II. Purpose of this document

NOAA's investment in research and development will provide the foundational information and technology to help the Nation adapt and respond to a complex present and dynamic future. This investment, coupled with improvements in how NOAA develops, communicates, and translates new information, can address challenges (e.g., impacts of ocean acidification) and embrace opportunities (e.g., forecasts for renewable wind energy). NOAA's R&D enterprise builds on demonstrated success and capitalizes on the assets and capabilities of the agency and its partners to support NOAA's mission.

This plan is designed to help guide NOAA's research and development activities over the next five years by articulating the key areas of focus and investment for the Agency. The motivation for this plan is found in the NOAA 20 Year Research Vision and linked to the NOAA Next Generation Strategic Plan and its four mission goals focusing on climate, weather, oceans, and coasts. This plan is designed to inform NOAA's partners, Congress, constituents, and the public of the value of NOAA's research and development, and the societal benefits of that R&D.

Within section 2, the research and development questions, objectives, and targets lay out a path forward for NOAA, and describe what we, as an agency, will ***strive to execute,*** with our academic, governmental, NGO, industry, and international partners, to support the Agency's mission. Just like many American families and other government agencies, NOAA is making hard choices and sacrifices in the face of a challenging budget environment. This plan articulates key areas of R&D that merit attention and focus by the Agency. The research and development questions, objectives, and targets are based on NOAA's internal planning process, the Strategic Execution and Evaluation Process (SEE), discussed further in Section 4. The information from this process was then supplemented with input from other strategic documents, NOAA's science challenge workshops, and input from NOAA scientists and partners on the direction of NOAA's R&D. In addition to providing a guide to inform and engage our partners and stakeholders, this document will inform future internal planning efforts directing NOAA's areas of investment in research and development.

Section 2. NOAA's Strategic Approach to Research and Development

I. Introduction

NOAA's R&D enterprise has delivered advancements that have proven integral to informing society, improving decisions, and advancing our operational capacity. This document describes the path ahead to continue that record of achievement and deliver the critical R&D required by a changing society and evolving environment.

A. 20 Year Research Vision and Science Grand Challenges

To fulfill the promise of a science agency that delivers critical and necessary information and services to the public in the short and long-term, in 2005, NOAA looked to the future with the development of a 20 year vision for research. This vision, "Understanding global ecosystems to support informed decision-making,"[15] has helped guide NOAA's investment in research and provide a perspective that addresses the immediate and future needs of the Nation. This premise drives the continued discussion, planning, investment, and implementation of NOAA's research and development enterprise.

NOAA's vision and strategic goals hinge on understanding the complex interrelationships that exist across climate, weather, ocean, and coastal domains. This idea was affirmed by NOAA's senior scientists, when identifying the grand scientific challenges for NOAA for the next five to twenty years. The overarching grand challenge identified for NOAA was to "develop and apply holistic, integrated Earth system approaches to understand the processes that connect changes in the atmosphere, ocean, space, land surface, and cryosphere with ecosystems, organisms and human over different scales."[16] This overarching grand challenge, and supporting major science challenges (Table 1) is an opportunity to integrate NOAA's collective capabilities to achieve major scientific advances that would benefit the Nation.

Table 1. 2010 NOAA Grand Science Challenges[17]

Overarching Grand Challenge: Develop and apply holistic, integrated Earth system approaches to understand the processes that connect changes in the atmosphere, ocean, space, land surface, and cryosphere with ecosystems, organisms and humans over different scales.
Major Science Challenges: Acquire and incorporate knowledge of human behavior to enhance our understanding of the interaction between human activities and the Earth system • Understand and quantify the interactions between atmospheric composition and climate variations and change • Understand and characterize the role of the oceans in climate change and variability and the effects of climate change on the ocean and coasts • Assess and understand the roles of ecosystem processes and biodiversity in sustaining ecosystem services • Improve understanding and predictions of the water cycle at global to local scales

[15] National Oceanic and Atmospheric Administration. 20 year Research Vision. May 2005.

[16] Sandifer, P., Dole, R. 2010.Strengthening NOAA Science: Findings from the NOAA Science Workshop.

[17] http://nrc.noaa.gov/plans_docs/2010/Science_Workshop_WP_FINAL.pdf

• Develop and evaluate approaches to substantially reduce environmental degradation
• Sustain and enhance atmosphere-ocean-land-biology and human observing systems
• Characterize the uncertainties associated with scientific information
• Communicate scientific information and its associated uncertainties accurately and effectively to policy makers, the media, and the public at large.

B. "Use-Inspired Research"

NOAA requires innovative research that pushes the boundaries of scientific understanding and integrates information across scientific disciplines to explore, observe, and understand Earth system dynamics and enable the Nation to make informed decisions about resource management and our changing environment. Investing in this "use-inspired research," which encompasses the traditional definitions of "basic"[18] and "applied"research[19], will create an improved understanding of the Earth system from global to local scales, improve our ability to forecast weather, climate, and water resources, and increase our understanding of ecosystem health. "Use-inspired research"[20], seeks to replace the linear relationship of basic and applied research with a concept that addresses the complexities of research, and the feedbacks between research and application or operation. This term can also encompass the entirety of the research portfolio that underpins NOAA's mission, from the immediate or short-term, such as investments into fisheries stock assessment techniques for immediate application to the longer-term, such as the investigations that identified the presence of the ozone hole in the polar regions, its causes, and ultimately led to mitigation measures, which occurred over many years. Similarly, the discoveries unearthed by exploration of ocean environments provide backdrop for continued efforts in habitat protection, species exploitation, and improved understanding of this yet-largely unknown domain. "Use-inspired research" is research that supports NOAA's mission, in all its facets and across all timescales of interest, from minutes to centuries, and across relevant spatial domains.

C. Research and Development in support of NOAA's Mission

As outlined in NOAA's Next Generation Strategic Plan, NOAA provides "research-to-application capabilities that can recognize and apply significant new understanding to questions, develop research products and methods, and apply emerging science and technology to user needs."[21] These capabilities are brought to bear on the four strategic goals directing NOAA's mission:

- Climate Adaptation and Mitigation-An informed society anticipating and responding to climate and its impacts.

[18] National Science Foundation. Division of Sciences Resources Statistics, 2009. Federal Funds for Research and Development: Fiscal Years 2006-2008.Detailed Statistical Tables 10-303. Arlington, VA.
[19] National Science Foundation. Division of Sciences Resources Statistics, 2009. Federal Funds for Research and Development: Fiscal Years 2006-2008.Detailed Statistical Tables 10-303. Arlington, VA.
[20] Stokes, D. (1997). *Pasteur's quadrant : Basic science and technological innovation.* Washington D.C.: Brookings Institution Press.
[21] National Oceanic and Atmospheric Administration. Next Generation Strategic Plan. December 2010.

- Weather-Ready Nation-Society is prepared for and responds to weather-related events.
- Healthy Oceans-Marine fisheries, habitats, and biodiversity are sustained within healthy and productive ecosystems.
- Resilient Coastal Communities and Economies-Coastal and Great Lakes communities are environmentally and economically sustainable.

Unified by an overarching vision of resilience, these goals are mutually supportive and complementary. Just as economic prosperity depends upon a healthy environment, the sustainability of ocean and coastal ecosystems depends on society's ability to mitigate and adapt to changing climate and other environmental changes. Similarly, sustainable economic growth along the Nation's coasts, in arid regions, and in countries around the world depends upon climate predictions and projections to inform issues such as coastal development and agriculture. Likewise, the resilience of communities depends on their understanding of and preparedness for high-impact weather and water conditions. By accounting for these interconnections, NOAA can magnify the effect of each goal on its common vision of resilient ecosystems, communities, and economies.[22]

NOAA's Mission: Science, Service, and Stewardship
To understand and predict changes in climate, weather, oceans, and coasts,
To share that knowledge and information with others, and
To conserve and manage coastal and marine ecosystems and resources.

While NOAA's four goals are complementary, they each also have separate and distinct issues and challenges that requires the focused investment of NOAA's research and development enterprise. Addressing the needs of the individuals goals also includes examining and investigating critical science and technology elements that support all of the goals, such as observations, modeling, and computer technologies. Additionally, NOAA seeks to continually improve its research and development and how it is used. Incorporating assessments of how NOAA's science is used by society underpin each of NOAA's goals. Ultimately, the strength of NOAA's research and development rests not solely on addressing specific needs focused on climate or ecosystems, weather or communities, but in the integration of all of these facets. A continuing challenge is to bring together single components into an integrated and holistic Earth system understanding that can be then broadly applied. With an integrated and holistic Earth system perspective, NOAA can address not only the key questions that fall into one particular goal or objective, but those questions that transcend any one goal.

D. Section Structure

By focusing attention on outcomes rather than activities -- ends rather than means -- the outcomes can be used as a basis for making rational investment choices, aligning requirements, and clarifying roles and responsibilities. Goals and desired outcomes, as specified in NOAA's Next Generation Strategic Plan, frame what needs to be known, from which overarching R&D questions are identified. R&D objectives

[22] National Oceanic and Atmospheric Administration. Next Generation Strategic Plan. December 2010.

identify how these overarching questions will be addressed by NOAA. In turn, R&D targets identify the incremental building blocks being pursued over the next five years to achieve the objectives.

LEGEND

Goal: Goals (and Enterprise Objectives) are taken directly from NOAA's Next Generation Strategic Plan (NGSP). They direct all NOAA activities, including R&D.

Key Question: Questions represent the lack of some knowledge or capability that is needed to achieve NOAA's goals. Unanswered questions provide the impetus to do R&D.

Objective for R&D: Objectives in this document are for R&D, not ultimate outcomes or outcomes for regular, even "scientific" operational activities. They represent steps toward answering the question under which they lie.

Target: Targets are discrete end-states after (at least) 5 years, not continuous activities to be conducted over a period of 5 years. They are the means of empirically verifying progress toward the objective.

II. Climate Adaptation and Mitigation: *An informed society anticipating and responding to climate and its impacts*

Projected future climate-related changes include increased global temperatures, melting sea ice and glaciers, rising sea levels, increased frequency of extreme precipitation events, acidification of the oceans, modifications of growing seasons, changes in storm frequency and intensity, air quality, alterations in species' ranges and migration patterns, earlier snowmelt, increased drought, and altered river flow volumes. Impacts from these changes are regionally diverse, and affect numerous sectors related to water, energy, transportation, forestry, tourism, fisheries, agriculture, and human health. A changing climate will alter the distribution of water resources and exacerbate human impacts on fisheries and marine ecosystems, which result in such problems as overfishing, habitat destruction, pollution, changes in species distributions, and excess nutrients in coastal waters. Increased sea levels are expected to amplify the effects of other coastal hazards as ecosystem changes increase invasions of non-native species and decrease biodiversity. The direct impact of climate change on commerce, transportation, and the economy is evidenced by retreating sea ice in the Arctic, which allows the northward expansion of commercial fisheries and provides increased access for oil and gas development, commerce, and tourism.

Key Question 1: ***What is the state of the climate system and how is it evolving?*** Without a sustained observing system, climate is not a science. Integrated global observing systems are the foundation for research critical to understanding the Earth's climate system, improving climate predictions at global and regional scales, and monitoring current climate variations and placing them into historical perspective. Reliable and timely access to climate data and information is essential to improved understanding of key physical processes of the climate system, improving climate prediction and projection models, and regularly producing integrated analyses of the climate system and reporting on the causes and consequences of observed climate variability and extreme events. Data and analysis produced from the climate observing network benefits virtually every sector of the nation's economy as well as across all of NOAA's Mission Goals.

Objective for R&D: ***Sustained climate record.*** NOAA will continue to provide the nation and the world with an unambiguous measure of the state of the climate through uninterrupted, high quality in situ and satellite observations of primary variables describing the ocean and atmosphere. Up-to-date and accurate knowledge of the state of the climate is important for an increasing number of human and ecological services. NOAA must sustain and build out its longstanding climate observations, data management, and monitoring to enhance the fundamental scientific understanding and knowledge for people to make informed decisions. High priority should be given to building observing systems and strengthening synergies between observations and modeling for more effective use of existing resources.

Over the next 5 years, NOAA aims to have:

- Conducted qualitative and quantitative analyses of observing systems to improve the observational and monitoring strategies, and use of the resulting data for better understanding and state estimation.
- Assess climate data (its quality, uncertainty, and implications) and make the climate data available to improve our understanding of climate variability and change for the benefit of society.

Objective for R&D: ***Atmospheric and oceanic observations systems that support climate research and Earth System modeling to better understand how the global climate system is changing.***

Over the next 5 years, NOAA aims to have:

- Integrated short- and long-time scale observations into modeling processes for characterizing the seasonal to multi-decadal scale variation of ocean state and assessing its predictability .
- Developed and test deep ocean floats for the benefit of the global ocean observing community.

Key Question 2: ***What causes climate variability and change on global to regional scales?***

Objective for R&D: ***Improved understanding of key oceanic, atmospheric, hydrologic, biogeochemical, and socioeconomic components of the climate system and impacts.***

Over the next 5 years, NOAA aims to have:

- Assessed the roles of natural variability (solar changes and volcanic eruptions) and changing radiative forcing (from greenhouse gases and aerosols) in causing observed seasonal-to-multidecadal scale changes in the climate system.
- Assessed the causes of the rapid decline in Arctic sea ice and develop the capability for predicting future change on decadal scales
- Assessed the likelihood of changes in climate extremes over the US, including tropical and extratropical cyclones and their associated storm surges, as well as droughts and heat waves.
- Assessed the potential for rapid changes in land-based ice sheets and their impact on global and regional sea level
- Evaluated the relative roles of local and remote forcings and feedbacks in trends in means and extremes.
- Performed model simulations of ocean, atmosphere, and land-surface processes to support development of climate-based hydrologic forecasting capabilities.
- Assessed exchange processes and the predictability of exchange processes for use in Earth system models.
- Assessed the climate influences of AMOC and the Pacific Ocean for decadal predictability research and ENSO predictions.
- Assessed the weather and climate features of the tropical oceans to achieve higher confidence in global and regional climate predictions.
- Assessed the Madden-Julian Oscillation and its impact on short-term climate variability and predictability.
- Assessed the mechanisms that control climate sensitivity to water vapor and clouds, and improved representation of these processes in climate models.

Objective for R&D: ***Identify the causes of regional climate trends and the implications for climate predictions and climate change projections at regional scales.***

Over the next 5 years, NOAA aims to have:

- Explained causes for regional and seasonal differences in U.S. temperature and precipitation trends.
- Identified and diagnosed physical processes key to extreme events to advance understanding of climate-extreme event linkages at regional scales; examine watershed dynamics, variability of water vapor transport, aerosol variability, extreme precipitation, and land surface conditions.

- Determined the implications of findings on causes of regional climate trends and extremes for climate predictions and climate change projections at regional scales.
- Determined mechanisms for Arctic climate change and relationships with other regions.
  - Assessed connections of Arctic climate variability and change with other regions
  - Assessed effects of declining sea ice on extratropical climate.

Objective for R&D: ***Improve understanding of atmospheric composition of greenhouse gases and other climate forcing agents.*** NOAA will Improve understanding of atmospheric composition to reduce uncertainties in climate forcings and feedbacks, including greenhouse gasses, aerosols, and clouds. Analyses of climate-forcing agents will help quantify efforts to reduce greenhouse gas emissions. Lack of understanding and quantification of climate-forcing agents (e.g., greenhouse gasses, aerosols, clouds, and other trace gases), and their dual role in air quality and changes in climate undermines development predictions and projections of future climate and its impacts at local, regional, and global scale.

Over the next 5 years, NOAA aims to have:

- [targets under development]

Key Question 3: ***What improvements in global and regional climate predictions and projections are possible?*** This research is critical to providing climate forecasts for multiple time-scales to enable regional and national managers to better plan for the impacts of climate variability, and provide projections to support policy decisions with objective and accurate climate change information. This research provides the nation with a seamless suite of environmental forecasts (i.e. outlooks and projections) on intraseasonal, seasonal, interannual, and multidecadal timescales and on regional, national, and global spatial scales, to understand and predict abrupt climate change, and to promote credible national and international assessments of future climate trends and change. The global environment includes not only the atmosphere, hydrosphere, cryosphere, biosphere, and lithosphere, but also land/ocean biogeochemical processes, ecosystems, atmospheric chemistry, and air quality. This research bridges weather and climate and provides information that is integrated into ocean and coastal management.

Objective for R&D: ***Earth System Models for seasonal to centennial predictions and projections at regional to global scales.*** Improve the skill of seasonal forecasts and delivery of predictions and projections information products for decadal to centennial time scales with quantified uncertainties. Improve regional outlooks through downscaling approaches, high-resolution global climate model runs, multi-model ensembles, and better representation of key physical processes. Risks of failing to fill the various modeling gaps in key physical processes leave decision makers with insufficient scientific support concerning future climate states to address regional and local planning for the impacts of flooding and drought, siting of critical infrastructure in coastal communities, and managing natural resources.

Over the next 5 years, NOAA aims to have:

- Models capable of simulating regional climate change over the US at scales of approximately 10-20 Km.
- Models capable of simulating the ocean and its climatic impacts at very high resolutions (3-5 Km).
- Assessed predictability and predictive skill for global experimental decadal predictions that account for natural variability and the climate-forcing agents
- Experimental real-time National Multi-Model Ensemble seasonal forecasts that incorporate input from GFDL, NASA, NCAR, the IRI, and NCEP.
- Quantified uncertainties in predictions and projections of Arctic sea-ice extent and thickness, decadal-scale variability.

Key Question 4: ***How can the Nation best adapt to the impacts of climate variability and change?*** The NOAA Climate Program provides information and tools to support decision makers in improving management of risks to the U.S. economy and ecosystems and the critical services they provide in sectors and areas that are sensitive to impacts from weather and climate. This includes annual losses from drought, the negative impacts of strong El Niño and La Niña events, sea level rise, and other high impact climate events.

Objective for R&D: ***Improved and sustained assessments of risks and impacts.***

Over the next 5 years, NOAA aims to have:

- A routine and sustained assessments capability based on engagement of researchers and users.
- Climate-related impacts assessments on water resources, health, agriculture, and coasts that are relevant to local, state, and federal governments

Objective for R&D: ***Key vulnerabilities are identified and used to inform adaptation planning across scales of action.*** NOAA will develop new and enhanced regional climate information products and services based on robust research, including social science, and focusing on four societal challenge areas: weather extremes, water resources (including drought), coastal inundation, and sustaining marine ecosystems. This requires integrating NOAA's climate capabilities and engaging with external partners. NOAA is experiencing a rapidly growing demand for regional climate information concerning present and future conditions by decision and policy makers. Uncertainty in climate science is largest at regional scales. NOAA must improve its observations, research, modeling, and transfer of knowledge at these scales.

Over the next 5 years, NOAA aims to have:

- [targets underdevelopment]

III. A Weather-Ready Nation: Society is prepared for and responds to weather related events

A weather-ready nation is a society that is able to prepare for and respond to environmental events that affect safety, health, the environment, economy, and homeland security. Urbanization and a growing population increasingly put people and businesses at greater risk to the impacts of weather, water, and climate-related hazards. NOAA's capacity to provide relevant information can help create a society that is more adaptive to its environment; experiences fewer disruptions, dislocation, and injuries; and that operates a more efficient economy.

Key Question: ***How can we improve forecasts, warnings and decision support for high-impact weather?***

Objective for R&D: ***Improved Observations***

Over the next 5 years, NOAA aims to have:

- Complete Phase I evaluation of Multi-Purpose Phased Array Radar (?)
- Dual Pol (TBD)
- CASA (TBD)

Objective for R&D: ***Integrated Data and Delivery systems.*** NOAA will develop technologies to provide robust critical infrastructure, providing data and information that are reliable, integrated and rapidly refreshed for seamless, cost-effective weather information. Developing the next-generation integrated data integration and delivery systems (e.g. required to meet Next-Generation Air Transportation goals and facilitate analyses and forecasts of water resources) promotes accurate, timely and reliable delivery of information critical for saving lives and property.

Over the next 5 years, NOAA aims to have:

- Begin experimental real-time production of high resolution rapidly updating analysis system
- Complete Phase I evaluation of Warn On Forecast
- HFIP (TBD)
- NWP targets (TBD)
- Probablistic guidance targets (TBD)

Objective for R&D: ***Integrated real-time analyses of weather conditions.*** NOAA will develop weather radar capabilities (processing algorithms for site-specific information) necessary to take maximum advantage of currently deployed, and other cost-effective weather radar platforms to support forecasts and warnings of high-impact weather. NOAA will develop tools and algorithms needed to integrate NWS and partners' date from diverse observational platforms into rapidly updating, storm-scale information. Integration of available observations from diverse platforms, sensors, coverage, and both internal and external providers is needed to meet goals to provide storm-scale information critical to meeting goals for forecasts and warnings of high-impact weather, including "Warn-on-Forecast" goals.

Over the next 5 years, NOAA aims to have:

- [targets under development]

Objective for R&D: ***Improved Decision Support Tools.*** NOAA will expand activities to accomplish NWS Science and Technology Roadmap objectives: enhancing decision support services through integrating observations, analyses, data assimilation and numerical prediction for field forecasters; collaborative communications of weather, water and climate impacts and risks with decision makers to elicit effective responses; and development of impact-based communications capabilities for real-time support to decision-makers, incorporating quantified forecast uncertainty and risk to facilitate analyses for strategic and tactical preparation and response. Limiting weather-related loss of life and property requires eliciting the most effective response to accurate, reliable warnings and forecasts. Communicating effectively is critical.

Over the next 5 years, NOAA aims to have:

- A prototype of the Forecaster Decision Support Environment
- Implement Integrated Hazards Services
- Implement initial National Impacts Catalog capability

Key Question: ***How does climate affect seasonal weather and extreme weather events?***
In order to be prepared for and respond to weather-related events, warning in advance of these events is critical, and the longer lead time of the warning, the more prepared society can be. While deterministic weather predictions provide information on events out to seven days, it is climate predictions that enable society to adequately prepare for impending changes in the weather well in advance. Knowledge of the state of the climate system provides general guidance on what society can expect during a season as changes in climate patterns affect seasonal weather and extreme events by impacting the frequency and intensity of events. There is thus a need to

improve our understanding of the climate linkages to weather and extreme events, and a need to improve our capability to predict climate in order to improve our ability to enable society to respond to upcoming weather events well in advance of extreme conditions. Our ability to improve prediction and understand the nature of the predictability of events must evolve through research, improved models, observations, and monitoring of the climate, leading to reliable estimates of the confidence in predictions and projections across relevant time and space scales.

With a greater understanding of the climate-weather linkage, all sectors of society will be better prepared for extreme events. Coastal communities and related industries, environmental resource managers, national, regional, state, and local governments, and the American Public will have longer lead times to prepare for the impacts of hazardous weather events. In the past 10 years, knowledge and predictability of climate and its impacts on weather has evolved, but with the changing climate and the recent onslaught of extreme weather events, it is critical to improve our understanding of climate-weather linkages.

Objective for R&D: ***Improved understanding of weather and climate extremes and the weather-climate linkage.***

Over the next 5 years, NOAA aims to have:

- Incorporated knowledge of the physical processes of MJOs, atmospheric rivers, predictability of AO/NAO, and tropical convection, into national and regional operational forecast products

- Incorporated trend analysis techniques for changes in precipitation frequency and amounts, changes in the intensity and frequency of extreme heat events and drought, and changes in El Niño Southern Oscillation (ENSO) events, into service delivery
- Incorporated local and regional climate impacts into extreme meteorological and hydrological event forecasts
- Transformed data from observing systems into climate-quality information for detection of changes of weather and climate extremes
- Expand the Local Climate Analysis Tool (LCAT) to include multiple time and space scales for delivery of information in support of regional and local decision making
- Transition scientific advances from the research community on extreme weather and climate events into dynamical models for improved NOAA forecast products and services

Key Question: ***How can we improve space weather warnings?***

Objective for R&D: ***Improved accuracy of 1-4 day forecasts of geomagnetic storms.*** The energy for geomagnetic storms originates at the sun in the form of a Coronal Mass Ejection (CME). It takes several days to propagate to Earth. Improving the detection and assessment of CME's through observations with operational coronagraphs will greatly improve NOAA's ability to forecast geomagnetic storms, which can disrupt the Nation's power grid. Measuring and tracking the magnetic configuration within the CME will greatly improve the accuracy of the forecasts of the strength of the resulting geomagnetic storm.

Over the next 5 years, NOAA aims to have:

- An operational coronagraph flown and supported within the NOAA satellite program.
- Methods of estimating the magnetic field configuration within a CME

Objective for R&D: ***Localized specification and forecasts of the impacts of geomagnetic storms at ground level.*** Critical customers, such as the electric power companies, have requested specific improvements in space weather forecasts. In particular, customers would like regional specification and forecasts of the impact of geomagnetic storms (currently NOAA/SWPC only provides a global index of the strength of the storm). Research is underway, in partnership with the USGS and NASA, to gather regional information from a network of ground observations and develop maps of the impact of geomagnetic storms. Forecasting these regional impacts requires the introduction of a new Geospace model into operations. R&D activities are underway in collaboration with NASA to evaluate and test models from the research community for transition into operations.

Over the next 5 years, NOAA aims to have:

- Developed and tested the DSCOVR spacecraft (multi-agency support) and ground data processing system to insure continuity of solar wind observations that drive Geospace models.
- Developed regional and local specification of the geomagnetic conditions relevant to Electric Power Grid customers (Research)
- Identified the best Geospace model for forecasting local geomagnetic storm conditions. Begin the transition of this model into operations. (Research)

Objective for R&D: ***Predictions of ionospheric conditions relevant to GPS/GNSS users.*** The observation and modeling of ionospheric structures that modify or block the signals from radio navigation systems such as GPS is critical to providing customers with the services that they are requesting. Global Radio Occultation (RO) observations will provide key inputs to the products and models. Developing a Whole Atmosphere Model (WAM) coupled with an Ionosphere-Plasmasphere-Electrodynamics model (IPE) will provide the necessary framework for forecasting ionospheric conditions.

Over the next 5 years NOAA aims to have:

- Assimilative models for COSMIC II data.
- Coupled the Whole Atmosphere Model (extended GFS) to the Ionosphere Plasmasphere Electrondynamics model (IPE). (Research)
- Assessed the impact of data assimilation in the ionosphere/thermosphere forecast modeling

Objective for R&D: ***Improved specification and forecasts of the radiation environment for satellites and commercial aircraft.*** Satellite operators have requested products that turn localized NOAA satellite measurements of the radiation environment into global actionable information on how the environment may damage satellite systems. Commercial airline operators and crew have requested new products to monitor and forecast radiation exposure for air traffic. These new products require modeling of the radiation environment. Current research models provide some utility but a full assessment of model capability and accuracy is needed.

Over the next 5 years NOAA aims to have:

- Models that predict the radiation environment at aircraft and satellite altitudes.

Key Question: ***How can we improve forecasts for freshwater resource management?*** Managing freshwater quantity and quality is one of the most significant challenges the U.S. must address. Demands for water continue to escalate, driven by agricultural, energy, commercial, and residential usage. Sustained growth requires viable long-term municipal water supplies and, by extension, sophisticated predictions and management practices. The Nation's water resource managers need new and better integrated information to manage water more proactively and effectively in a changing and uncertain environment. The NWS predicts where, when and how much water will come from the skies as rain or snow and move through the rivers and streams. Moreover, NOAA manages the U.S. coastal and marine systems that receive water from the land and rivers as it flows back to the sea. NOAA Line Offices are coordinating their research to operations (R2O) activities in support of improved freshwater resource management. This coordination requires a seamless integration of data, information, and services through a common operating framework across agency boundaries. NOAA and its partners will enhance the integration and utility of water services by developing integrated decision-support tools for water resource managers based on high resolution summit-to-sea data and information. Establishing this framework between NOAA and its Federal partner water agenices will enable the infusion of multi-agency research into NWS operations.

Objective for R&D: ***Increased hydrologic forecast skill from low-to-high streamflow conditions to be as good as skill afforded by weather and climate predictions.***

Over the next 5 years NOAA aims to have:

- A unified large-scale hydrological modeling system allowing integrated and multiscale predictions, projections and analyses

Objective for R&D: ***Improved representation and prediction of key hydrometeorological forcings***

Over the next 5 years NOAA aims to have:

- A national water cycle reanlysis, including key components and fluxes that close the water balance.
- High-resolution data assimilation products that directly link atmosphere and land-surface processes and depict the full water cycle over the U.S.

Objective for R&D: ***Physical processes key to storms and floods identified and diagnosed, their roles in forecast errors documented***

Over the next 5 years NOAA aims to have:

- Identified "emergent" behavior in watershed dynamics and quantified associated thresholds.
- Diagnosed the variability of water vapor transport in atmospheric rivers
- Diagnosed extreme precipitation and precursor land-surface conditions that amplify or reduce drought and flood severity.

Objective for R&D: ***Key uncertainties in climate and hydrologic models and their couplings explicitly characterized***

Over the next 5 years NOAA aims to have:

- Establish NOAA "tiger teams" to evaluate selected real-world extreme events aiming to dissect causes and antecedents, assessing forecast skill and utility from hours to weeks.
- A global water cycle reanlysis

IV. Healthy Oceans: Marine fisheries, habitat, and biodiversity are sustained within healthy and productive ecosystems

Ocean ecosystems provide many benefits to humans. They provide food and recreational opportunities, and they support economies. Yet the resources that our marine, coastal, and Great Lakes environments present to us are already stressed by human uses. Habitat changes have depleted fish and shellfish stocks, increased the number of species that are at-risk, and reduced biodiversity. Because humans are an integral part of the ecosystem, declines in ecosystem functioning and quality directly impact human health and well-being. As long-term environmental, climate, and population trends continue, global demands for seafood and energy, recreational use of aquatic environments, and other pressures on habitats and over--exploited species will increase as will concerns about the sustainability of ecosystems and safety of edible fish. Depleted fish stocks and declines in iconic species (such as killer whales, salmon, and sea turtles) result in lost opportunities for employment, economic growth, and recreation along the coasts. In addition, climate change impacts to the ocean, including sea level rise, acidification, and warming, will alter habitats and the relative abundance and distribution of species. Climate change poses serious risks to coastal and marine ecosystems productivity, which, in turn, affects recreational, economic, and conservation activities.

Key Question: ***How do environmental changes affect marine ecosystems?***

Objective for R&D: ***Increased knowledge of the physical and chemical changes in the oceans resulting from atmospheric, climatic, and land-based forcing***

Over the next 5 years, NOAA aims to have:

- [Targets under development]

Objective for R&D: ***Increased knowledge of the mechanisms and impacts of environmental changes on marine species and ecosystems***

Over the next 5 years, NOAA aims to have:

- [Targets under development]

Objective for R&D: ***Integrate ecosystem-level data and improved indicators into LMR assessments and management.*** Understanding the relationship between NOAA's trust species and their environment is a critical research area. Efforts include: conducting science to quantify the relationships between species and their environment; modeling efforts to provide predictive information of the response of these species to climate change; translation of this information into fish and protected species stock assessments; development of additional spatial analytic tools augmenting protected species data collection; and the development of precise, quantitative habitat assessment methodologies.

Over the next 5 years, NOAA aims to have:

- [Targets under development]

Key Question: ***What exists in the unexplored areas of our oceans?***

Objective for R&D: Ocean basin boundaries mapped and characterized

Over the next 5 years, NOAA aims to have:

- [Targets under development]

Objective for R&D: New ocean resources discovered and characterized

Over the next 5 years, NOAA aims to have:

- [Targets under development]

Objective for R&D: [Transition objective under development]

Over the next 5 years, NOAA aims to have:

- [Targets under development]

Key Question: ***How can emerging technologies improve ecosystem-based management?***

Objective for R&D: ***Collect and integrate of multi-disciplinary data.*** **T**he NOAA Fisheries Advanced Sampling Technologies Working Group supports new and innovative uses of ocean and aerial resource observation platforms, technologies, and survey methods to improve the quality of assessments with a focus on population abundance and dynamics, environments, and fishing impacts at a wide range of temporal and spatial sampling scales. This will Increase efficient use of ship-time, improve collection of multi-disciplinary data from LMR surveys; Expand technologies to survey habitats inaccessible to conventional gear.

Over the next 5 years, NOAA aims to have:

- [Targets under development]

Objective for R&D: Quickly transform available data streams into scientific advice. NOAA Fisheries continually refines existing systems, and researches new means to obtain, deliver, archive and provide access, querying tools, and data products in support of management and stakeholder needs. Sound enterprise data management practices are critical in ensuring a solid base for information management and dissemination.

Over the next 5 years, NOAA aims to have:

- [Targets under development]

Key Question: ***How can we ensure aquaculture is sustainable?***

Objective for R&D: ***Develop environmentally sound aquaculture technologies***

Over the next 5 years, NOAA aims to have:

- [Targets under development]

Objective for R&D: ***["Dietary knowledge" Objective under development]***

Over the next 5 years, NOAA aims to have:

- [Targets under development]

Objective for R&D: ***Understand the impacts of ocean acidification on shellfish populations***

Over the next 5 years, NOAA aims to have:

- [Targets under development]

Key Question: ***How is the chemistry of our ocean changing and what are the effects?***

Objective for R&D: ***["nutrient over-enrichment" Objective under development]***

Over the next 5 years, NOAA aims to have:

- [Targets under development]

Objective for R&D: ***Improved understanding of the processes of ocean acidification and its consequences for marine organisms, ecosystems, and dependent human communities.***

Over the next 5 years, NOAA aims to have:

- [Targets under development]

Objective for R&D: ***Improved understanding of land-based sources of pollution.***

Over the next 5 years, NOAA aims to have:

- [Targets under development]

V. Resilient Coastal Communities and Economies: Coastal and Great Lakes communities are environmentally and economically sustainable

The complex interdependence of ecosystems and economies will grow with increasing uses of land, marine, and coastal resources, resulting in particularly heavy economic and environmental pressures on the Nation's coastal communities. Continued growth in coastal populations, economic expansion, and global trade will further increase the need for safe and efficient maritime transportation. Similarly, the Nation's profound need for conventional and alternative energy presents many economic opportunities, but will also result in greater competition for ocean space, challenging our ability to make informed decisions that balance conflicting demands as well as economic and environmental considerations. At the same time, the interdependence of ecosystems and economies makes coastal and Great Lakes communities increasingly vulnerable to chronic—and potentially catastrophic—impacts of natural and human-induced hazards, including climate change, oil spills, harmful algal blooms and pathogen outbreaks, and severe weather hazards.

Key Question: ***What is the value of coastal ecosystems?***

Objective for R&D: ***Improved understanding of the economic and behavioral elements of coastal resileience.*** NOAA will estimate the value of ecosystem services to inform management decisions, apply ocean and coastal economic data to better understand the economic importance of the coast and the dependence of the economy on coastal and ocean ecosystems, produce information on economic losses due to coastal hazards toward the mitigation of negative impacts, and document behaviors related to climate change impacts toward increased community and economic resiliency. The sustainability and resilience of coastal communities and economies depends on healthy ecosystems and a clear picture of the connection between society and ecosystem resources. This research will improve understanding of that connection.

Over the next 5 years, NOAA aims to have:

- [Targets under development]

Key Question: ***How do coastal species respond to habitat loss, degradation and change?***

Objective for R&D: ***Determine combined effects of environmental stressors on coral reefs***

Over the next 5 years, NOAA aims to have:

- Documented the combined effects of multiple stressors on at least one coastal ecosystem and the valued species therein.
- Models that simulate contaminant transport thorugh a holistic "atmosphere-watershed-coastal ocean" approach

Key Question: ***How do we ensure that growing maritime commerce stays safe and sustainable?***

Objective for R&D: ***Improved accuracy of and access to oceanographic products and navigation services.*** NOAA will focus on the evaluation and optimal use of advanced sensors, automation of geospatial and cartographic information for decision support, and oceanographic modeling that support hydrographic surveying and navigation safety, and integrated ocean and coastal mapping. This priority will emphasize techniques for multi-use and multi-sourced mapping data, re-purposing, extension and transition to operations of models, and providing real time, enhanced data streams to meet customer demands. It will also improve the efficiency of operations within NOAA for mapping applications in general. The resulting advances in the state-of-the-art will have immediate application in the marine navigation community as it transitions to all-electronic ship bridges.

Over the next 5 years, NOAA aims to have:

- A comprehensive, integrated inventory of ocean and coastal mapping data, linked to the National Information Management System (NIMS).
- High-resolution shoreline information for coastal development and engineering projects

Key Question: ***How do we reduce the economic and ecological impacts of degraded water quality?***

Objective for R&D: ***Region-specific environmental characterization reports that highlight multiple resource uses and offer options for minimizing resource- and space-use conflicts or impacts of coastal pollution***

Over the next 5 years, NOAA aims to have:

- An assessment of the status of ecological condition and potential stressor impacts throughout coastal-ocean (shelf) waters of the northwestern Gulf of Mexico
- An assessment of the status of ecological condition and stressor impacts throughout targeted Areas of Concern (AOCs) in Great Lakes coastal waters, with an emphasis on information to evaluate changes in the quality of these areas relative to Beneficial Use Impairment (BUI) designations and corresponding remediation action in the AOCs.
- A coupled marsh-physical model to dynamically assess ecological effects of sea level rise in Gulf of Mexico and demonstrate results in at least one National Estuarine Research Reserve, utilizing long-term monitoirng data from the reserve.

Objective for R&D: ***Region-specific, nationwide, operational capability for ecological forecasting.*** NOAA will develop regionally focused, nationwide capability to forecast event-specific harmful environmental conditions, and transitioning the capability into operations and facilitating its management applications. Emphasis will be on improving the modeling architecture and reducing forecast uncertainties. Of necessity, ecological forecasting requires integration of observations, data from experiments, and any theoretical constructs, and efforts are underway to progressively reduce uncertainties over spatial and temporal scales of interest. It will enhance current efforts to document ecosystem response to environmental stressors and transfer that capability to coastal resource managers.

Over the next 5 years, NOAA aims to have:

- Documented uncertainties in ecological forecasts in areas where forecasting capability currently exist
- A concept paper on positive feedback models of toxic algal blooms: influence of increased toxicity under nutrient limitation on bloom formation, persistence, and toxicity
- Characterized the species specific habitat preferences (light, salinity and temperature) for HABs that cause ciguatera fish poisoning in the Caribbean to inform models of their distribution, abundance and seasonality
- Assessed the impacts of land-based sources of contaminants (nutrients, toxic chemicals, and pathogens) for hypoxia in northern Gulf of Mexico

Objective for R&D: ***Improved water quality testing and monitoring technologies***

Over the next 5 years, NOAA aims to have:

- Transferred methods for correctly identifying toxigenic algal species and their toxins to regional managers and stakeholders through education and training programs
- A prototype membrane electrode for detecting algal toxin(s) in the field and routine monitoring applications
- Developed methods for taxonomic differentiation and classification of pathogens found in coastal environments and protected species, and identified factors for their virulence

Objective for R&D: ***Improved understanding of emerging water quality issues, including the sources, environmental fate and ecological consequences of nanoparticles and microplastics***

Over the next 5 years, NOAA aims to have:

- Convened a scientific workshop to identify the environmental significance of nanoparticles, focusing on metal oxides and carbon particles and develop a blueprint for high priority research needs and monitoring protocols
- Assessed NOAA's in-house and partnership capabilities to implement the blueprint
- Establish the relationship between microplastics and toxic chemicals in coastal waters, and the resulting impacts on marine organisms via the food chain

Key Question: ***How is Arctic affected by expanding industry and commerce?***

Objective for R&D: Strengthen oil-spill response capabilities. NOAA will play a scientific advisory and support role to the Federal On-Scene Coordinator during Arctic oil spill and clean-up responses up to par with other U.S. regions. The need for this capacity is urgent due to increased Arctic offshore drilling and maritime transit activities, and events such as the Japanese tsunami.

Over the next 5 years, NOAA aims to have:

- Completed the pilot phase analysis and reporting on distributed biological observatory (DBO) activities and results to date
- Mapping guidelines, standards, vessel of opportunity protocols, and standard operating procedures to facilitate integrated ocean and coastal mapping and acquisition of Arctic hydrographic , shoreline, habitat mapping and water column data
- Characterized the distribution of biological resources and the associated key coastal habitats of the Chukchi Sea with maps of sediment distribution, background levels of oil and gas development-related contaminants, and potential toxicity
- Identified areas of special value and vulnerability to offshore petroleum development and coastal infrastructure by applying Biogeography Assessment Framework
- Applied genomics- and proteomics-based markers of exposure to petroleum and its effects on animals at the molecular level, with emphasis on marine mammals and protected species
- Produced coastal inundation maps for Chukchi Sea based on anticipated storm-surge occurrences
- Documented the likely movement, weathering and fate of crude oil trapped under sea ice, and its likely effects of coastal ecosystems, including epontic communities

VI. Stakeholder Engagement: An engaged and educated public with an improved capacity to make scientifically informed environmental decisions

As the challenges NOAA must address become more complex, the Agency will need increasingly sophisticated organizational mechanisms to understand user needs and engage stakeholders and customers across local, regional, and international levels. Many of the challenges that NOAA helps address do not stem from a lack of information, but from an uneven distribution of information. The best way for NOAA to meet the needs of its stakeholders is often to better deliver data and knowledge to those who have not yet accessed it. NOAA must understand these needs and respond to them. Conversely, NOAA's next breakthrough in research, development, operational improvement, or policy action may depend upon the unique knowledge or needs of a partner or customer. NOAA must fully engage with society to be most effective as a service agency.

Key Question: ***How can we improve the way scientific information and its uncertainty are communicated?***

Objective for R&D: ***Understand how best to convey the information needed for stakeholders and the public to make decisions.*** NOAA's success in performing its mission depends on successful communication of its objectives and scientific information and guidance with stakeholders and the public. Consequently, NOAA needs social science research on how best to communicate the scientific content of its objectives, data, and guidance to achieve its strategic objectives and optimal societal benefit.

Over the next 5 years, NOAA aims to have:

- Assessed emerging communication technologies and methods for improving public comprehension and use of NOAA's scientific information, products, and services.
- Optimized NOAA web presence with respect to communicating NOAA objectives, activities, products, services, and public issues.
- Assessed how the public uses probabilistic information to make decisions.
- Developed decision-support tools to inform stakeholders and the public on the impacts of critical issues, situations, and subsequent actions.

Key Question: ***How can we support informed public response to changing environmental conditions?***

Objective for R&D: ***Identify and implement key social science techniques that are most effective at achieving each of the targeted societal outcomes identified by NOAA's Mission Goals and Enterprise Objectives.*** NOAA's broad mission results in the need for quite different communication approaches with stakeholders and the public, *e.g.* regulatory issues for fisheries, stewardship for marine sanctuaries, and public safety for severe weather. NOAA requires social science research on which techniques are best for specific applications.

Over the next 5 years, NOAA aims to have:

- Conducted risk assessments in support of resilient coastal communities
- Developed protected species and habitat evaluation
- Performed risk assessments of coast inundation
- Conducted risk assessments in support of resilient coastal communities
- Conducted regional climate impact assessments
- Assessed social and economic impacts and tradeoffs of fishery stock assessments

Objective for R&D: ***Identify the best practices for transitioning research to broader application.*** For NOAA to realize return on its research enterprise investments, research and developments must be transitioned to applications/operations. The transition process traditionally has been an organizational challenge; therefore, NOAA needs social science research on how best to effect its transitions.

Over the next 5 years, NOAA aims to have:

- [targets under development]

VII. Accurate and reliable data from sustained and integrated Earth observing systems

NOAA's mission is rooted in in situ and space-based Earth observations. The Nation's efforts to mitigate and adapt to a changing climate require accurate, continuous, and comprehensive climate data records. Weather forecasters require observations of the state of the atmosphere and oceans to initiate and verify the models and to make accurate forecasts. Fisheries cannot be sustained without data on current and historical states of the stocks and their living environment. Coastal communities need observations to understand changing coastal ecosystem conditions and manage coastal resources sustainably. Nautical charting and navigation activities require consistent observations of the depth and surface characteristics of the oceans and Great Lakes, and changes that may occur due to ongoing physical processes. All of these capabilities draw upon diverse observing system assets, including satellites, radar, manned and unmanned aircraft, ground stations, sea-going vessels, buoys, and submersibles. The varied and growing requirements levied upon these systems greatly exceed the current capacity. NOAA's observing system portfolio needs to balance growing demands with continuity concerns and implementation of emerging technologies. Over the long-term, NOAA must sustain and enhance observing systems (atmospheric, oceanic, inland waters, terrestrial, solar, cryospheric [Earth's surface where water is in solid form, including glaciers, sea ice and ice caps], biological, and human)—and their long-term data sets—and develop and transition new observing technologies into operations, while working in close collaboration with its governmental, international, regional, and academic partners.

Key Question: ***What is the best observing system to meet NOAA's mission?***

To achieve optimization, NOAA must develop the capability to comprehensively and objectively assess the mission impact of current observation systems, candidate systems, and system configurations across all of NOAA's needs, including existing and candidate non-NOAA systems, while recognizing that sampling requirements vary depending upon the intended application of the data. Coordination between NOAA's Observing System Council and NOAA's Research Council is required to exploit technology advancements and pursue technology research on developing new ways to satisfy operational requirements.

Objective for R&D: ***Quantitative methodologies for assessing impacts of current and candidate observing systems to NOAA missions and products***
NOAA has the responsibility to optimize the effectiveness of its observing systems, from buoys to satellites, which requires the evaluation of candidate observing systems and deployment strategies in support of weather, physical oceanography, biological and ecological observing requirements. Coherent decision-support tools for sensor/system design, modeling and data assimilation choices, impact priority, and investment considerations are needed.

Over the next 5 years, NOAA aims to have:

- An observation system prioritization tool based on quantitative impact assessments and employ to optimize model predictions and projections of the Earth system
- OSSE studies of potential impact of phased array radar systems on short-term forecasts and other observing systems relevant to prediction of severe local storms
- An end-to-end satellite sensor simulator to fully understand the impact on NOAA applications from each individual satellite data source at various time and spatial scales.

Objective for R&D: ***Amount of information from NOAA observing systems, partnerships, and leveraged non-NOAA observing capabilities is maximized.*** Maximizing the information from NOAA's observing systems is constrained by resources; therefore, reducing life cycle costs of observations through the integration of systems, reducing unnecessary/duplicate capabilities, and leveraging non-NOAA available data to fill gaps is critical.

Over the next 5 years, NOAA aims to have:

- A system architecture that integrates non-NOAA data, optimally exploiting data from the Global Earth Observing System of Systems (GEOSS)
- Evaluated technical options for or modifications to NOAA's current observing system that support understanding, accurate assessments and characterizations, and monitoring, including ecosystem state and processes.
- Assessed the optimal location and density (spatial and temporal) of collected observations, informing the reconfiguration of existing NOAA observing

systems for oceanic, Great Lake, and atmospheric observing systems, including floats, probes, moored arrays, satellite systems.

- Determined the optimal observing system configuration and architecture for Comprehensive monitoring of the Earth's climate system, including climatically-important gases
- Determined the optimal observing system configuration and architecture for Sustainable Arctic observations for near-real, seasonal-interannual, and decadal-centennial time scales, particularly addressing sea ice, atmosphere-ocean-cryosphere interactions, and ocean heat storage, as well as operational dynamical models and regional-scale climate predictions and projections
- Determined the optimal observing system configuration and architecture for Integrated observations of physical and radiative parameters needed to understand the surface energy budget
- Determined the optimal observing system configuration and architecture for Regional soil moisture and snow observations
- Determined the optimal observing system configuration and architecture for Understanding and quantifying the role of water vapor in the upper troposphere/lower stratosphere
- Determined the optimal observing system configuration and architecture for Carbon observations and analysis
- Determined the optimal observing system configuration and architecture for Systematic long-term greenhouse gas (GHG) measurements
- Determined the optimal observing system configuration and architecture for Supporting the renewable energy sector.
- High-altitude (>30,000’) Doppler radar on aircraft, including unmanned systems, for long duration monitoring in support of hurricane modeling.
- Prototyped a tool that optimizes NOAA vessel data collection scheduling while minimizing impact on other missions tasked to that vessel.

Objective for R&D: Improved accuracy, coverage, resolution, and effectiveness of observation systems. NOAA aims to improve the accuracy of observational data to meet the needs of all users by leveraging advanced technologies, following best practices, and fostering the use of national/international standards and traceability as embraced by the NOAA calibration center, through collaboration with partner agencies, organizations (such as NIST and NASA), and the scientific community.

Over the next 5 years, NOAA aims to have:

- New ways of sensing NOAA’s required observation parameters for physical, chemical, biological parameters of the deep ocean
- Rapid radar sampling technologies (e.g., Multi-function Phased Array Radar (MPAR) needed to achieve the Warn-On-Forecast objective of producing a robust and useful warning of severe weather out to one hour.

- Enhanced UAS camera systems for marine mammal surveys
- Dropsonde alternatives for the Global Hawk
- Doppler radar alternative for the Global Hawk UAS with at least a 24-hour mission duration.
- A complete Carbon Observing and Analysis System
- Marine sensors and biosensors capable of withstanding the stresses of an aquatic environment while providing accurate and reliable data.
- Next-generation geostationary, GOES-R series, and polar-orbiting, JPSS series, operational environmental satellites
- JPSS User Services free-flyer satellites
- Jason Continuity of Service satellites for altimetry observations of the oceans
- DSCOVR satellite for space weather observations
- Animal-borne observing systems at the scale of NOAA's regional ecosystems

Key Question: How can we best use current and emerging environmental data?
NOAA's vision and strategic goals hinge on understanding the complex interrelationships that exist across climate, weather, ocean, and coastal domains. A holistic understanding of these interrelationships requires a rich, interdisciplinary characterization of the physical, chemical, geological, biological, and social components of ecosystems. NOAA requires observations as the foundation for scientific research and development of core capabilities and capacities, as well as for satisfying its mandates.

Objective for R&D: Emerging data types and capabilities are exploited to address NOAA's observing requirements and increase scientific understanding. NOAA seeks better ways to address its observing requirements, as well as technologies and methodologies that permit the measurement of previously unmeasured/unmeasurable requirements.

Over the next 5 years, NOAA aims to have:

- Automated ice and snow cover data
- Operational polar-orbiting ocean color capability (JPSS-1)
- New polar-orbiting day-night band (JPSS-1)
- Geostationary lightning mapper (GOES-R)
- Prototyped advanced rapid radar sampling technologies (e.g., MPAR) aimed at producing a robust severe weather forecast lead time of one hour
- A conceptual design of an extended range version of the FSV-40 Oscar Dyson class ship ships

Objective for R&D: Exploit environmental data to improve applications and develop new applications, products, and services. NOAA requires full exploitation of its observations for mission-oriented applications in order to obtain return on its observing system investments through the extraction of value by applying the observation data to the Nation's benefit.

Over the next 5 years, NOAA aims to have:

- Demonstrated and transition to applications/operations NOAA's next-generation operational satellite data streams
- Prototyped and demonstrate new/improved observational data products and applications addressing tornadoes, hurricanes, severe storms, floods/droughts, poor air quality, winter weather, fire weather, marine and coastal weather, tsunamis, and short-term climate variability

VIII. An integrated environmental modeling system

To fulfill current and emerging science and service requirements for all of NOAA's strategic goals, the agency must ultimately evolve toward an interconnected and comprehensive Earth system modeling enterprise that links atmospheric, oceanic, terrestrial, cryospheric, ecological, and climatic models. This evolution will advance the ability to provide forecasts that incorporate dynamic responses from natural and human systems, and provide results at spatial and temporal scales capable of assessing impacts on ecosystem services, economies, and communities. NOAA and other Federal Agencies support significant modeling research and development carried out by broad external research communities across the Nation. This objective will transform these existing environmental modeling efforts from disparate enclaves into a coordinated, scientifically robust effort that serves as a foundation for integrated environmental analysis, forecasting, and model-based user support and services. Key benefits of this integrated effort include enhanced service capabilities—a cornerstone of NOAA's decision support efforts—and greater access to, ease-of-use, and reliance on NOAA's models and guidance, providing clearly articulated model confidence; continued advancement of a national environmental prediction and assessment capability; and optimization of NOAA's investments in research, observations, and monitoring.

Key Question: How can modeling be best integrated and improved with respect to skill, efficiency, and adaptability? NOAA requires that its environmental modeling enterprise meet broad but specific agency requirements for an earth system analysis and prediction framework to support near-real-time to decadal, global prediction at appropriate horizontal and vertical resolution including the atmosphere, ocean, land, cryosphere, and space, including advanced data assimilation , forecast model physics, and computational efficiencies. To achieve an enterprise capability, NOAA modeling requires a common framework for integrating models, robust models, optimal data assimilation, and model data sets supporting research. A common modeling framework is needed to ensure that NOAA's entire modeling enterprise is able to share and jointly develop model components, data assimilation schemes, techniques, and proficient ensemble generation techniques.

Objective for R&D: A framework for linking and coupling, nested resolutions, data assimilation, and standards for connectivity, interoperability, and joint development. NOAA requires a framework for connecting and optimally exploiting its environmental models. This framework needs to provide standards for interoperability, the exchange and upgrade of model components, a modeling structure to address the spectrum of spatial and temporal scales, coupling across physical domains, connectivity between physical and ecosystem modeling, and effective data assimilation. This objective serves to: collectively advance computational and environmental numerical prediction science and technology; enhance understanding of the complex earth system in concert with NOAA's research enterprise and other research efforts across the U.S.; extend predictive capability from days to decades based on that enhanced understanding; and identify and quantify uncertainty and risk.

Over the next 5 years, NOAA aims to have:

- Earth System Modeling Framework (ESMF) connectivity for NOAA's operational numerical models
- HWRF simulations at 1km resolution
- Model techniques and capabilities for coupling physical domains and physical-ecosystem domains.
- A modular community regional climate modeling system
- An objective, multi-model approach for coordinating seasonal water supply forecasts between the NWS and the Natural Resources Conservation Service

Objective for R&D: [objective under development]. NOAA requires development, testing, and transition to applications and operations of state-of-the-art Earth system models that address: fundamental processes and relationships relevant to changes in the ocean's physical and biological state; forcing, fluxes, and feedbacks across ocean, atmosphere, cryosphere, and land interfaces; extreme weather events; feedbacks in the global carbon and other biogeochemical cycles; stratospheric and tropospheric changes and interactions with climate; Arctic predictions and climate-related changes; sea-level rise; decadal predictability; as well as space weather prediction.

Over the next 5 years, NOAA aims to have:

- A prototype coupled modeling capability for coastal, estuarine, and river models
- Demonstrated a core data-assimilating coastal hydrodynamical modeling capability
- Prototyped coastal zone modeling capable of tracking coastal geochemical changes on relevant temporal and spatial scales.
- Prototyped optimal nesting between NOAA's operational global, regional, and coastal ocean models, as well as relevant operational ecological models.
- Prototyped a global data-assimilating hydrodynamic ocean modeling capability that includes nutrients, phytoplankton, zooplankton, and detritus (NPZD)
- Prototyped a data-assimilating common core surface and subsurface transport and fate (dispersion) modeling capability for ocean, coastal, and local scales
- Prototyped improved representation of water vapor processes in the upper troposphere/lower stratosphere

- Prototyped modeling of stratospheric ozone depleting potential and global warming potential for candidate replacement chemicals under the Montreal Protocol.
- Demonstrated coupled fire weather - fire behavior modeling system for local firefighting applications
- Prototype an experimental decadal climate prediction system.
- Prototyped modeling of climate-stratospheric chemistry interconnections.
- Prototyped impact scenario models for climate change effects to coastal ecosystems
- predictions of the annual hypoxia plume in the Northern Gulf of Mexico
- Forecast for urban coastal ecosystems the degree and extent of nutrient, contaminant and pathogen input from land and water use practices, land and seascape alterations, and harmful algal blooms
- Prototyped regional predictive ocean models for Pacific and Arctic ecosystems
- Prototype modeling to assess the impacts of water use practices and land-based pollution on marine and Great Lake ecosystems, water quality, and human / animal health.
- Prototyped modeling of the ecological, biogeochemical and socio-economic impacts of ocean acidification.
- Demonstrated modeling for analyzing the vulnerability of coral reef ecosystems to climate impacts
- Prototyped ecosystem-informed management models for California Chinook salmon
- Prototyped initial predictive modeling for use in space weather operations.
- Prototyped modeling of geomagnetic storms

Objective for R&D: Advance data integration and assimilation into Earth system modeling
Data assimilation is a critical element of any environmental modeling system, anchoring model results with observations to enhance representativeness and predictive skill, extracting return on NOAA's investments in its observing system. New data assimilation techniques, new instrumentation and sources, and non-standard or intermittent data, e.g., unmanned aerial and ocean vehicles, integrated ocean observing system instruments, and instrumented marine mammals, require research and development for transitions into NOAA applications and operations. Conduct research on data assimilation for improved representation and predictive skill of: high-impact events (e.g., tornadoes, hurricanes, severe storms, floods/droughts, poor air quality, winter weather, fire weather, marine and coastal weather, short-term climate variability); economic sectors requiring significantly improved forecast services (e.g., aviation, emergency management, renewable energy); aviation-relevant issues (e.g., convection, ceiling, visibility); and fine-scale predictions of near-surface conditions

Over the next 5 years, NOAA aims to have:

- Prototyped coupled data assimilation
- Developed hybrid three-dimensional variational data assimilation and ensemble Kalman filter assimilation methods for standard, non-standard, intermittent observations
- Demonstrated assimilation of non-NOAA IOOS Regional Coastal Ocean Observing System (RCOOS) data in NOAA research and operational models, addressing feasibility, data quality, skill improvement
- Demonstrated assimilation of private sector observations in NOAA research and operational models, addressing feasibility, data quality, skill improvement
- Demonstrated enhanced ocean data integration/assimilation for salinity, ocean color parameters, synthetic aperture radar parameters (e.g. high-resolution winds), and ocean-surface observations that inform the surface energy budget
- Prototyped HF-radar data assimilation
- Identified the most significant data streams for severe weather and prototype enhanced data assimilation, e.g., for hurricanes, blizzards, ice storms, and flash floods
- Determined optimal data assimilation approach for Warn-On-Forecast system
- Demonstrated model ingestion and use of the G-IV Doppler radar data
- Evaluated the impact of assimilation of airborne and ground-based Doppler radar data on hurricane modeling predictive skill.
- Deployed an ensemble Kalman filter data assimilation system for HWRF, NOAA’s operational hurricane regional model system, and FIM, Finite-volume Icosahedral Model
- Prototyped ice-thickness and improved (no person in loop) ice-coverage data assimilation within NOAA's operational suite of forecast models
- Integrated ice observations into modeling to inform the surface energy budget
- Integrated land surface observations into modeling inform the surface energy budget
- Prototyped combining regional climate models and observations
- Initiate data assimilation for space weather modeling

Objective for R&D: Advance the understanding of environmental processes and relationships. Many research and development activities require high-quality long-duration observation datasets. Quality, in part, is determined by how well the data represents the best understanding of the observations. Improved information, understanding, and techniques for retrievals, calibration, sampling, and representation need to be applied to accumulated datasets via reprocessing and reanalysis to ensure that the data represents the best currently possible understanding of the observations.

Over the next 5 years, NOAA aims to have:

- Conducted climate reanalysis of hindcasts and projections employing coupled models, examining differences for enhanced understanding of climate processes and relationships.
- Reanalyzed extended operational satellite observation records to generate calibrated and refined analysis of global and regional climate temperature, precipitation, and related ecosystem changes and trends.

Key Question: What is the uncertainty in NOAA's data, analyses, and predictions?
Decision makers and the public require that NOAA provide information on the uncertainty in its prediction and projection products for use in assessing the significance and utility of the information and for weighting the information with respect to decisions.

Objective for R&D: Ascertain quantified measurement uncertainty for all components of NOAA's observing system, as well as for non-NOAA data sources used operationally. The uncertainty of a prediction/projection depends, in part, on the how well the accuracy of the input data is known; consequently, the uncertainty of the measurements employed in NOAA products, predictions, and projections needs to be determined.

Over the next 5 years, NOAA aims to have:

- Demonstrated an initial integrated satellite calibration and validation system (ICVS) to fully characterize the observational uncertainties from US and foreign satellite data and to make global data more consistent in quality, standards, and intercalibration between instruments

Objective for R&D: Establish quantified uncertainties for NOAA's predictions and projections. Models introduce uncertainty into predictions/projections due to how input data is used, how conditions and processes are modeled, and approximations are employed. Consequently, modeling uncertainties need to be determined and integrated with observation measurement uncertainties to establish prediction/projection uncertainty. Result differences due to model differences, as seen through ensemble modeling, are a measure of the uncertainty associated with specific predictions/projections. The integration of observation and model uncertainties is required to determine the uncertainty of predictions/projections and to provide a more useful decision-making product.

Over the next 5 years, NOAA aims to have:

- Demonstrated initial quantification of model uncertainty and skill for all NOAA operational models
- Quantified understanding of the uncertainties between different climate models in their projections of sea ice, atmosphere-ocean-cryosphere interactions, and ocean heat storage.
- Prototyped an initial ensemble prediction system for probabilistic considerations at multiple spatial and temporal scales.

- Demonstrated initial quantification of prediction/projection uncertainty and skill for NOAA operational forecast products
- the ability to produce objective uncertainty information from the global to the regional scale
- All raw and post-processed probabilistic products easily accessible to the Enterprise at full spatial and temporal resolution.
- Evaluated the accuracy of operational wind, solar, and moisture forecasts

IX. A modern IT infrastructure for a scientific enterprise

NOAA's mission requires a transformed, agile, service-oriented, and secure IT infrastructure to propel its scientific and operational goals with advanced computing capabilities. World-class delivery of reliable and scalable IT services is essential to meet growing demands and to efficiently process and disseminate ever increasing volumes and types of environmental information. High-performance computing (HPC) enables environmental modeling, and thus, all of NOAA's predictive products, including weather forecasts, climate analyses, and the transfer of mature research systems developed into operational capacities in collaboration with academic, private sector and other government partners. Consumer and professional use of social networking sites is becoming increasingly (and inextricably) intertwined. Modern collaborative technologies are essential to enabling NOAA's diverse and widely distributed staff to share knowledge more effectively, and to enable customers and stakeholders to engage with the extended NOAA community transparently and effectively.

Key Question: What information technology developments can help NOAA improve its research and development enterprise?

Objective for R&D: Identify economical IT technical alternatives for computational effectiveness and efficiency. NOAA requires technology solutions, in addition to mission-focused research and development, to enable its science enterprise, particularly for its computationally and communications intensive components, such as numerical predictions.

Over the next 5 years, NOAA aims to have:

- Evaluated GPU technology within NOAA's IT architecture as a computing resource for running NOAA models

Section 3. People, Places, and Things - Assets Supporting NOAA's R&D Enterprise

Articulating NOAA's research and development enterprise requires describing not only where NOAA will invest its efforts, but how it will go about implementing the critical research and development required. Successful implementation involves the engagement of NOAA's diverse infrastructure, including laboratories and programs; personnel, including partners; and research tools, such as observations and models.

I. "Soft" Assets

Achieving NOAA's research and development requires the experience and expertise of NOAA's workforce. The talent and creativity of NOAA's personnel is complemented by extramural research partners who provide expanded scientific, economic, and technical expertise and sources of new knowledge and technologies. [23] NOAA's laboratories, science centers, and programs, support and conduct leading-edge fundamental and applied research on Earth's chemical, physical, and biological systems; this research leads to direct improvements in NOAA's ability to succeed in our mission.[24] NOAA's progress depends on a vibrant scientific enterprise that draws from capabilities in the Office of Oceanic and Atmospheric Research (as its central research organization), NOAA's Line Offices, and the extended community of public, private, and academic researchers with whom NOAA collaborates.

A. People

The most important ingredient for NOAA R&D is the talent of its workforce. Focusing on social and environmental outcomes will require not only the best skills in the scientific and engineering disciplines, but the best skills in interdisciplinary work. Understanding the natural, social, and economic systems that make up a dynamic ecosystem will require increased expertise in social and economic science as well as the physical sciences (Appendix C). As the R&D that NOAA conducts becomes more systems-oriented, the challenge becomes ensuring the right mix of different types of talent and enabling diverse specialists to work together on interdisciplinary teams. NOAA will continue to recruit outstanding professionals with disciplinary, interdisciplinary, and managerial expertise, and cultivate existing and new sources of talent to evolve its workforce capabilities over time. In the current time of fiscal constraint and pending wave of retirements, NOAA must focus on succession planning and strive to attract, hire, train, and retain a new generation of professionals to accomplish its strategic goals. This includes developing a Scientific Career Track program that will serve to identify a career track, to provide a method for promoting and recognizing scientific career development through a standardized process, and to retain its scientific talent.

The scientists and engineers who conduct R&D at NOAA are not exclusively federal employees. In fact, about a third of those conducting NOAA R&D are from academic, private, or not-for-profit institutions. Many are students, recent graduates, or volunteers (Appendix C). A healthy innovation system should be one composed of a community of scientists across organizations such that there is a constant flow of new ideas, and coordination necessary to bring them to fruition. This balance requires strategic investment across all employment categories, ensuring that NOAA benefits from corporate knowledge, application of tactical skill sets, and innovative new ideas.

B. Institutions

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[23] National Oceanic and Atmospheric Administration. Research in NOAA: Toward Understanding and Predicting Earth's Environment. January 2008.

[24] National Oceanic and Atmospheric Administration. Research in NOAA: Toward Understanding and Predicting Earth's Environment. January 2008.

NOAA's laboratories, science centers, programs, and Cooperative Institute, support or conduct leading-edge fundamental and applied research on Earth's chemical, physical, and biological systems. NOAA has 50 organizational units that are responsible for either conducting or funding R&D. These include units such as the NESDIS Center for Satellite Applications and Research (STAR), NMFS science centers, NOS National Centers for Coastal Ocean Science (NCCOS), NWS Office of Science and Technology (OST), OAR Climate Program Office (CPO), National Sea Grant Program, and Earth Systems Research Laboratory (ESRL). (A full list of R&D units with descriptions is provided in Appendix B.)

NOAA also funds research that is conducted by Cooperative Institutes, which are non-federal, non-profit research institutions in a long-term (5-10 year) collaborative partnership with NOAA. Many of the Cooperative Institutes are collocated with NOAA research laboratories, creating a strong, long-term collaboration between scientists in the laboratories and in the university. Cooperative Institutes are located at parent institutions whose geographic expanse extends from Hawaii to Maine and from Alaska to Florida. The CI program has been in existence for 44 years. Currently, NOAA supports 18 Cooperative Institutes consisting of 48 universities and research institutions across 21 states, Puerto Rico and the US Virgin Islands. In FY 2011, NOAA provided $176.4M to Cooperative Institutes, supporting 1211 employees and 485 students.

NOAA's National Sea Grant College Program is a national network of 33 university-based programs dedicated to serving citizens in coastal communities throughout the Nation. Sea Grant helps citizens understand, conserve, and better utilize America's coastal, ocean, and Great Lakes resources. With on-the-ground extension experts located in every coastal and Great Lakes state, Sea Grant translates science into services that benefit coastal residents and their communities. Sea Grant has been in existence for 46 years. In FY 2011, NOAA provided $57.5M to 524 Sea Grant colleges or universities, supporting 2370 employees and 1882 students.

NOAA has other partners that receive support for R&D as well, such as the Educational Partnership Program (EPP) and the National Estuarine Research Reserves. In FY 2011, NOAA provided $76.5M to these partners, supporting 207 employees and 557 students. Further, NOAA awards other grants beyond Sea Grant. The total amount awarded for other R&D grant solicitations in FY 2011 was $36.9M for 36 unique solicitations. The funding awarded in FY 2011 for grants selected in prior years' solicitations (not completed by all programs) was $76.37M.

Through its laboratories and programs, NOAA seeks to balance the activities that benefit from the long-term, dedicated capabilities of federal facilities with those that require the diverse expertise of our external partners. Investment in capital equipment and modernization is critical to address the large research challenges inherent in NOAA's mission and to support NOAA's core competencies. At the same time, supporting our external partnerships provides for an infusion of ideas and nimbleness that is integral to NOAA's mission. Maintaining this balance requires a constant assessment of NOAA's R&D portfolio (see section 4) and targeted direction of resources.

C. Partnerships

NOAA takes advantage of its broad national and international network of partners in other agencies, in Sea Grant colleges, external academic institutions and professional societies, in the private sector, non-profit organizations, state, local, and tribal governments, and the international community.[25] Extramural research partners complement NOAA's intramural research by providing expanded scientific, economic, and technical expertise and sources of new knowledge and technologies. NOAA's research partners help maintain its international leadership in environmental research. NOAA employs a variety of mechanisms to fund extramural research within appropriated funding levels and congressional direction. These mechanisms include competitive, merit-based peer-reviewed grants and cooperative agreements. NOAA announces award competitions prior to the start of each fiscal year with a notice of the availability of grant funds for the upcoming fiscal year via a Federal Register notice.

III. "Hard" Assets

The increasingly broad array of societal issues for which NOAA provides decision support requires improving and extending the range of environmental analysis and modeling capabilities, both regionally and globally. Models and data assimilation systems provide the essential forecasting and analysis tools for decision making. These, in turn, rely on a solid base of integrated observations, from which improvements in understanding through analysis can ultimately be translated to better weather, ecosystem, and climate forecasts.[26]

A. Observations and Data

NOAA R&D relies heavily on data on environmental parameters such as air temperature, wind speed, atmospheric pressure, precipitation, geophysical and geospatial data, water vapor, carbon dioxide, ozone, sea level, ocean temperature, ocean salinity, ocean currents, and chlorophyll concentration. To gather data on these parameters, NOAA relies upon satellites, radars, manned and unmanned aircraft, ground stations, sea-going vessels, buoys, and submersibles. The varied and growing requirements levied upon these systems greatly exceed the current capacity; in particular, biological observations are among the most challenging to collect, yet represent a critical need. Much of the data used in NOAA R&D are collected by systems that are dedicated for NOAA's operational functions (for example, the Geostationary Operational Environmental Satellite constellation and the Joint Polar Satellite System). Other data, however, require systems that are intended primarily for R&D. NOAA's observing system portfolio needs to balance growing demands for data with concerns about maintaining existing systems and implementing emerging technologies.[27] Escalating costs to support existing and emerging observations require rigorous analysis and determination of the most effective observing portfolio.

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[25] National Oceanic and Atmospheric Administration. Research in NOAA: Toward Understanding and Predicting Earth's Environment. January 2008.

[26] National Oceanic and Atmospheric Administration. Research in NOAA: Toward Understanding and Predicting Earth's Environment. January 2008.

[27] National Oceanic and Atmospheric Administration. Next Generation Strategic Plan. December 2010.

Many of the challenges that NOAA helps address do not stem from a lack of information, but from an uneven distribution of information. NOAA will need to adopt scalable IT services that will be essential to meeting growing demands to efficiently NOAA collects ever increasing volumes and types of environmental information, and it is essential to manage this information effectively. Standardized data management practices are required to organize and optimize data so that they can be effectively retrieved, preserved, analyzed, integrated into new data sets, and shared across communities and with the public. This includes practices of metadata and curation to make data accessible. The users of the data need to be able to understand the information, to compare and combine data from multiple observing systems, and to cite datasets for usage tracking and reproduce the results.

B. Models

Models are abstract representations of how systems in the real world behave. They define cause-and-effect relationships, often mathematical, between a number of environmental parameters. Along with the observational data that they use as inputs, models are the foundation for predictions of how environmental conditions (such as weather) will evolve, as well as projections of how they might evolve. NOAA's suite of models enable not only operational forecasts, but also the R&D to improve our predictions of weather, air quality, ocean health, short-term and long-term climate, space weather, hydrology and the water cycle, and ecosystems. Through modelling NOAA can better understand changes in the coastal and estuarine waters of the Great Lakes, the effects of global climate change on hurricanes, the impacts of water use and land-based pollution on marine ecosystems and human health. Models improve and are improved by greater understanding of earth system processes. Often, improving model performance requires the inclusion of systems of factors that are already captured by another model, thus one of NOAA's objectives is to make earth system models more highly integrated with each other, and to work with other federal partners to establish standards for doing so.

C. Computing

Information Technology (IT) is critical NOAA R&D. Managing data, conducting analyses, and modeling environmental systems cannot occur without computing platforms, networks, data storage and information analytics. Modeling, in particular, relies on centralized, high-performance computing, but other approaches include cloud computing and virtualization. New high performance computing hardware architectures require scientific applications to run across multiple processors, rather than a single processor, to achieve desired performance. Improvements in modeling techniques have led to environmental models that can utilize many thousands of computer processors, rather than a few hundred, which promises to dramatically increase both the accuracy and speed of environmental predictions.[28] As consumer and professional use of social media sites becomes increasingly (and inextricably) intertwined, NOAA must have secure and flexible environments that stimulate participation by harnessing the power of collaboration tools and portals to promote innovation across NOAA Line Offices and with partners. With the scale, scope, and geographic dispersal of NOAA's various offices, NOAA's IT supports unified communications by efficiently and reliably switching this traffic amongst

[28] http://www.cio.noaa.gov/HPCC/pdfs/HPC_Strategic_Plan.pdf

formats, media and channels. NOAA also supports responsible and sustainable IT development in alignment with NOAA's overall sustainability efforts in "going green."

D. Testbeds and Proving Grounds

NOAA currently operates 10 testbeds or proving grounds to help accelerate the translation of R&D findings into better operations, services, and decision-making. Outcomes from a testbed are capabilities that have been shown to work with operational systems and could include more effective observing systems, better use of data in forecasts, improved forecast models, and applications for improved services and information with demonstrated economic/public safety benefits. A NOAA testbed provides a forum for developmental testing, in a quasi-operational framework among researchers and operational scientists/experts (such as measurement specialists, forecasters, IT specialists) including partners in academia, the private sector and government agencies, aimed at solving operational problems or enhancing operations. A successful testbed involves physical assets as well as substantial commitments and partnerships.[29]

Section 4. Administering NOAA's Research and Development Enterprise

I. Philosophy

NOAA is committed to ensuring its research is of demonstrable excellence and is relevant to societal needs, providing the basis for innovative and effective operational services and management actions.[30] To achieve this, NOAA's R&D enterprise rests on the following fundamental principles.

A. Integrity

For science to be useful, it must be credible. To be credible, NOAA's research must be conducted with the utmost integrity and transparency. NOAA's Administrative Order (NAO) and codes of conduct for scientists and science managers underpin our results and allow us to operate as trusted source for environmental information. The NAO on Scientific Integrity speaks not to a problem facing NOAA, but an opportunity to strengthen the confidence - in a variety of audiences, from scientists to decision-makers, to the general public- in the quality, validity, and reliability of NOAA science and codify NOAA's commitment to a culture of excellence in its science and scientists.[31]

B. Integration

The crux of a holistic understanding of the earth's system comes from both understanding its individual components, such as specific climate change impacts, and understanding and interpreting the way each

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[29] Guidelines for testbeds and proving grounds, 2011; http://www.testbeds.noaa.gov/pdf/Guidelines%20051911_v7.pdf

[30] National Oceanic and Atmospheric Administration. Research in NOAA: Toward Understanding and Predicting Earth's Environment. January 2008.

[31] http://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_202/202-735-D.html

of the components fit together, interrelate and interact. A combined effort of exploration, observations, process studies, modeling, and analysis can yield the improved understanding required to effectively predict, manage and interact with this complex system. NOAA is committed to providing both the discipline-specific foundation and the multi-disciplinary integration required to achieve and use a holistic understanding of the Earth system.

C. Innovation

The business community has long recognized the inherent importance of sustained investment in research and development to promote industrial excellence. General Electric CEO Jeff Immelt, serving as the Chair of the President's Council on Jobs and Competitiveness has said "the mistake we make is by not making enough bets in markets that we're experts in."[32] In the absence of such investment, services become stagnant and unresponsive to the constantly changing demands of the market. For a science-based agency, the argument is even more compelling; in place of market drivers, NOAA must remain responsive to the needs of the Nation, and do so in the face of challenges that cover a diversity of disciplines, time scales, and degrees of impact. Innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations.[33] Ideas and inventions are necessary for innovation, they are not sufficient. Innovation is the process of using ideas and inventions to create value. NOAA is committed to supporting innovation throughout its R&D enterprise to improve the understanding, products and services that support the Nation.

D. Balance

NOAA's R&D enterprise must balance the demand for service and stewardship improvements (the "pull") with the new ideas that could revolutionize how goals are accomplished (the "push").[34] We must not lose sight of the need to advance technology and scientific knowledge (i.e., transformational research) to fuel the Nation's economy and improve our quality of life. Transformational research is an essential component of a well balanced research portfolio and will continue to contribute revolutionary improvements to NOAA's services. NOAA should strive for a balance of incremental, low-risk research investments combined with high-risk, high-reward initiatives. Despite the demands of a system of focused accountability, where outcomes are expected to be defined even before research is conducted, part of NOAA's scientific strength rests on its ability to encourage risk and in doing so, tolerate failure. NOAA is committed to pursuing the breadth of R&D required to address the immediate needs to the Nation and the emerging challenges for the future.

E. Collaboration

[32] http://www.cbsnews.com/8301-504803_162-20117479-10391709.html

[33] Organisation for Economic Co-operation and Development (OECD), 2002. Glossary of Key Terms in Evaluations and Results Based Management. OECD Publications, Paris, France.

[34] Science Advisory Board (SAB). 2004. Review of the Organization and Management of Research in NOAA. A Report to the NOAA Science Advisory Board. The Research Review Team.

Extramural and cooperative research brings with it a flexibility and diversity of expertise and capabilities that would be otherwise unsustainable and unmanageable under a government construct. As noted in the 2004 SAB review of NOAA's research enterprise, extramural research investment brings with it: world class expertise not found in NOAA laboratories; enhanced connection to global science; leveraged external funding sources; multi-institutional coordination; access to external research facilities; and opportunities to engage with graduate and undergraduate students.[35] In the broad context of research, partners are required to not only articulate the needs and requirements driving the enterprise, but also to execute the research questions and to use the research outputs. The users rely on the best possible scientific information to enable their service and stewardship mandates. Each of these elements serves to make NOAA's research enterprise greater than the sum of its parts and yield a wealth of innovation.

II. Keys to Success

As a science agency, a critical component of NOAA's mission is conducting and funding research and development. Strengthening NOAA's science means that the agency conducts the appropriate amount of R&D in the appropriate domains. It means building upon existing best practices to promote scientific and technological excellence and enable scientists and science leaders to pursue the R&D necessary to inform NOAA's service and stewardship responsibilities.

But strengthening science also means something else: managing R&D effectively. This includes actively planning, monitoring, evaluating, and reporting on the agency's R&D to ensure that the Nation obtains a sustained return on its investment pursuant to NOAA's strategic goals and objectives. For R&D, as with all other aspects of NOAA's mission, this is done within the system for Strategy Execution and Evaluation (SEE). Strategy-based performance management is an iterative process of implementation planning, budgeting, execution, evaluation, and the application of evaluation to subsequent planning, budgeting, and execution.

Strengthening science also includes coordinating across NOAA and with NOAA's partners, supporting the exchange of information among scientists, and clear communication of the scope and value of NOAA's R&D to others. A strong scientific enterprise, like any resilient system, is determined not only by the quality of its components, but also in how well connected they are.

A. Portfolio Perspective

Managing NOAA's entire R&D enterprise requires that the agency take a portfolio perspective. R&D activities are investments in the future, and so we must assess tradeoffs among competing investment options in terms of benefits, costs, and risks. Is the activity required to achieve NOAA's near-term objectives or long-term goals? Is NOAA compelled to do it by statute or executive order? What is the

[35] Science Advisory Board (SAB). 2004. Review of the Organization and Management of Research in NOAA. A Report to the NOAA Science Advisory Board. The Research Review Team.

impact of the activity on society or, more directly, on other NOAA capabilities? If it isn't done by NOAA, will it be done at all? If not, how severe would the risk be for NOAA and its stakeholders?

Managing a portfolio of R&D should also take into account how activities fit together as a system of innovation and, therefore, how the set of activities are balanced across a number of dimensions. The table below provides the types of dimensions that are important to NOAA, the options within each dimension. There is no one option that is inherently better or worse; rather, we may choose to be (for example) more radical in one domain and more incremental in another, depending on objectives and circumstances.

Table 2. R&D Balance Dimensions

Portfolio Dimension	Options within Dimension
Disciplinary specialization	Natural, social, multi-, inter-, and trans-disciplinary[36]
Time horizon for result	Short-term, mid-term, or long-term
Degree of change	Incremental or radical
Driver of change	Supply "push" or demand "pull"
Who Executes	Internal or external, intramural or extramural
How it is Organized	Centralized or distributed
Level of Risk	High, medium, or low
Type of Product	Knowledge or technology
Type of Process	Creation or diffusion (of knowledge and technology)

Recent experience and external recommendations suggest that NOAA must rebalance its portfolio in a few of these dimensions. The first is *disciplinary specialization*, within which NOAA must invest a larger proportion of resources into social sciences. Because people both affect, and are affected by the natural environment, NOAA must understand these interactions. NOAA cannot effectively carry out its mission without the research necessary to design and deliver services that match the needs of constituents. This includes understanding who constituents are, how they interpret and respond to regulations, how they use information to make decisions, and how these decisions map into changes in wealth and health. NOAA cannot consistently articulate the value its products and services deliver to the nation, nor can it be sure that its resources are allocated optimally across programs and objectives, without sound and relevant corporate social science.

[36] Nowotny, H., Scott, P., & Gibbons, M. (2001). *Re-thinking science: Knowledge and the public in an age of uncertainty.* Cambridge UK: Polity

The second dimension in need of rebalance is *type of process*, within which NOAA must invest a larger proportion of resources into activities of "transition," which is the transfer of knowledge or technology from a research or development setting to an operational setting. Surmounting the "valley of death" between research and applications is a challenge for many Federal agencies and NOAA is no exception. It involves design and stakeholder engagement in addition to science and engineering. Transition occurs in two phases: demonstration (e.g., the use of test-beds or rapid prototyping) and deployment (e.g., the integration of new people, equipment, or techniques into an operational environment). Demonstration is a part of research and development; deployment is part of operations; both are required for transition to occur. Transition may occur from NOAA-conducted R&D to NOAA application, NOAA-conducted R&D to an external partner's application, or external partner-conducted R&D to NOAA applications.

Less well determined, however, is the right balance along other dimensions, such as *degree of change*, *time horizon*, and *who executes*. Should NOAA be aiming for more radical innovation, or longer term results, or more extramurally conducted R&D? These are questions that demand investigation of what the current balance is and of the expected costs and benefits of changing it. The answers depend upon which goals and objectives NOAA is trying to accomplish. Portfolio balancing does not occur in a vacuum, but with respect to a strategy.

B. Planning R&D

To achieve its mission, NOAA must continually strengthen the quality, relevance, performance of its R&D products, and balance its portfolio of activities required to produce them. The purpose of R&D planning is to establish objectives, priorities, performance expectations, and resource requirements for R&D activities. In so doing, it enables consistent and coordinated management of these activities, both within and across organizational units.

The activities of planning builds a shared understanding of the purpose and direction for an enterprise. NOAA's Science Advisory Board has found that "the major challenge for NOAA is connecting the pieces of its research program and ensuring research is linked to the broader science needs of the agency." And further, that "the overall research enterprise should be viewed as a corporate program. Explicit linkages between research efforts across organizational lines must be forged and maintained for the agency and the nation to obtain the full benefit from research".[37] Planning is the process that forges these necessary linkages.

Effective plans capture the expected cause-and-effect relationships between desired outcomes and the investments that are required to achieve them, thus providing a structure for later monitoring and evaluation. R&D plans can also serve as an important tool to communicate the importance and value of NOAA science to the Administration, the Department of Commerce, the Congress, academia, regulated and user communities, and the public at large. In this capacity, they serve to foster and sustain strategic

[37] Science Advisory Board (SAB). 2004. Review of the Organization and Management of Research in NOAA. A Report to the NOAA Science Advisory Board. The Research Review Team.

partnerships with the external research community, whose valuable contributions are critical to meeting NOAA's mission. They also establish a framework within which stakeholders can expect to have the results of monitoring and evaluation reported.

All R&D at NOAA must be directed toward long-term goals of the agency, and have more specific objectives and more immediate targets. However, this is not to say that it must be planned in the same way as regular operations. One size does not fit all. Lower-risk, incremental advances may require a very sequential progress through a series of stage gates or technical readiness levels. More transformative advances might benefit less from a predefined set hurdles than from multiple opportunities to iterate objectives with leadership and stakeholders as capabilities emerge from the work.[38] The means of planning for R&D should be appropriate for the kind of R&D being planned for (see portfolio dimensions in the previous section), but all R&D can fit within the agency's broad planning framework.

C. Setting Priorities

NOAA plans for R&D as part of the Strategy Execution and Evaluation (SEE) cycle, within which NOAA manages performance. In SEE, Implementation Plans (IPs) indicate how capabilities across the agency are being used to achieve objectives in NOAA's Next Generation Strategic Plan (NGSP), and how progress is expected to occur. The NOAA Administrator's priorities are stated in the Annual Guidance Memorandum (AGM) to focus the agency's attention for the rest of the cycle, starting with an update of IPs. The cycle is multi-annual, so priorities can apply to activities in out-years.

Priorities are choices among options. In the language of SEE, prioritizing something *means* performance in this area takes precedence over those things in other areas. This involves difficult but necessary decisions; if everything is a priority, then nothing is a priority. Priorities at the NOAA-corporate level scale down to priorities at the program level, and vice versa. Potential priorities permeate up from programs to line offices to councils to agency leadership. Leadership then sets priorities with requirements that filter back down. Priorities are best framed as ends rather than means (i.e., outcomes rather than outputs), so that programs have flexibility to pursue the best routes to achieve them.

Priorities are established periodically by analyzing the strategic context for NOAA R&D, and how it may have changed. If the context has changed, if NOAA is positioned to take action, and if this change warrants a change in strategic direction (including, but not limited to shifting investments), then priorities should change accordingly.

Context changes are often external, for example: changes in science, technology, politics, budgets, economic outlook, environmental conditions, and evolving stakeholder needs. Changes can also be

[38] Carleton, T. L. (2010). *The value of vision in radical technological innovation.* Dissertation, Stanford University Department of Mechanical Engineering

internal, for example: programmatic performance with respect to objectives, or a recognized internal need to push for innovation. Context changes can be identified in several ways. Internal changes can be identified through program evaluation (see next section), as well as less formal findings and recommendations of program staff. External changes can be identified by systematically scanning the media environment for emerging trends, as well as simply engaging stakeholders and partners in active dialogue.

D. Evaluating R&D

It is through evaluation that NOAA learns from experience how well R&D works according to plan, and whether or not the assumptions of planning were valid to start. It begins with a model of how a program's work is intended to result in strategic objectives.[39] Based upon this model, NOAA can set performance measures and targets as an empirical means of assessing progress. Assessments can then be made of process effectiveness and efficiency, of intended outcomes, of unintended impacts, and of benefits relative to costs. Through evaluation, NOAA can learn if a program works the way it is intended; identify unknown causes and unanticipated consequences; and make better decisions about whether to continue, halt, or change a program.

Evaluation is the end and the beginning of NOAA's performance management system. The findings and recommendations of program evaluation are the raw materials with which to develop objectives and set priorities, which, once developed and set, are the basis of future evaluations. Learning how to improve R&D involves asking questions such as: What R&D should be conducted to achieve desired outcomes? Is there sound logic connecting the R&D effort to the outcomes expected? Is the design of the program or project optimal? What execution needs are there in terms of time and resources? Did the research conducted achieve the desired outcomes? Did the research conducted have any unexpected results or impacts?

NOAA also values peer reviews of its Laboratories, Programs, and Cooperative Institutes to ensure their quality, relevance and performance. Sea Grant follows a rigorous review of all its National Sea Grant state programs. Formal policy establishes that peer review panels investigate every OAR lab every four years, prepare recommendations, which labs must then address through implementation plans. Similarly, NMFS Program Reviews have a five-year cycle. The first four years are dedicated to programmatic reviews at each NMFS Science Center and the Office of Science and Technology, where each year a specific program theme will be reviewed. The fifth year in the review cycle will focus on strategic planning across the NMFS Science Enterprise. These types of reviews are now required across NOAA.[40]

Evaluation of NOAA R&D complies with, but is not limited to, performance management requirements of Congress and Office of Management and Budget (OMB). In addition to the diverse standards for

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[39] Rogers, P. J., Petrosino, A., Huebner, T. A., & Hacsi, T. A. (2000). Program theory evaluation: Practice, promise, and problems. *New Directions for Evaluation*, 2000 (87), 5-13.

[40] http://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/216-115.html

quality research that vary among science and engineering disciplines, NOAA meets or exceeds OMB rules for agencies to conduct peer review for Federal science, according to established standards of quality, relevance, and scope set by the Information Quality Act and Peer Review Bulletin. More broadly, NOAA's program evaluation efforts are consistent with the performance management requirements of the Government Performance and Results Act (GPRA) and the 2010 GPRA Modernization Act.

E. Engaging Stakeholders

NOAA's capacity to achieve the objectives outlined in this plan depends on stakeholder engagement. The role of stakeholder engagement in NOAA's research and development is to identify user needs and help fulfill those needs. NOAA can effectively engage with stakeholder by strategically working with partners and having a two way conversation to better identify society's needs and refine its research and development to meet those needs.

There is no one-size-fits-all approach to stakeholder engagement. The most effective approach will depend on the situation, specific goals, objectives and desired outcome. In general, engaging stakeholders early and often leads to more successful partnerships and more valuable research and development. As a leader in oceanic and atmospheric research and development, NOAA must work with others to meet the needs of society.

NOAA must fully engage with society to be most effective as a service agency. NOAA's next breakthrough in research and development depend upon the unique knowledge or needs of a partner or customer. NOAA's capacity to engage individuals and other organizations effectively will determine its long-term success. Through use-inspired research, which is inherently interdisciplinary, NOAA can help meet the needs of society. Use-inspired research combines 'basic' and 'applied' research by attempting to answer the questions, ""Does it contribute to fundamental understanding?" and "Can it be expected to be useful?" This approach requires stakeholder engagement to be successful.

Stakeholder engagement implies a commitment of service by NOAA through a partnership between NOAA and society based on shared goals, objectives, and resources. Implicit to engagement is a respect for each partner that involves listening, dialogue, understanding, and mutual support. For example, in the areas of weather and climate, NOAA is a major component of the public, commercial, and academic enterprises that provide a full suite of weather products and services to the Nation. In turn, partners have strong and ongoing relationships with such constituent populations as students (from kindergarten through undergraduate programs) and faculty, local governments, businesses and industries, and the general public.

NOAA must be aware of science conducted, funded, and directed by others and must integrate and convert that scientific information into applications used within the Agency. NOAA has strong partner relations with many universities through Sea Grant, Cooperative Institutes, Educational Partnership Programs, the National Estuarine Research Reserve System programs, and numerous others. NOAA partners with organizations including Coastal Ecosystem Learning Centers, industry such as Google, non-governmental organizations such as the Nature Conservancy and National Geographic, and with numerous science centers, museums, zoos, and aquariums. NOAA actively engages such professional societies as National Science Teachers Association, the American Association for the Advancement of Science, the American Geophysical Union and the National Marine Educators Association. NOAA coordinates with other Federal Agencies that have similar engagement missions, including NASA, DOI, EPA, and NSF. At the State and regional level, NOAA's partners include such groups as Western Governors' Association, the Northeast Regional Ocean Council, and the Gulf of Mexico Alliance. Internationally, NOAA works with bodies such as the World Meteorological Organization, the International Maritime Organization, IFREMER, and the International Whaling Commission. NOAA scientists contribute to global efforts such as the International Panel on Climate Change.

Among the many environmental challenges facing the Nation, responding to climate change and the balancing the use of coastal and marine resources are paramount. To address these challenges, NOAA must work with leaders, organizations, institutions, and the public to solve problems that are greater than one agency. The potential accomplishments of NOAA and NOAA stakeholders can be greater than the sum of the parts.

Finally, there is a widening gap between the science most students learn in U.S. schools and the knowledge they will need in the 21st century to foster the Nation's innovation and competitiveness. To support climate, weather, ocean, and coastal science and management needs of the next-generation, NOAA must foster an environmentally literate society and help shape a future environmental workforce. To achieve this objective, NOAA will engage stakeholders and the public at multiple levels to build awareness of environmental science, services, and stewardship responsibilities; foster community dialogue; and to educate citizens and students. To this end, NOAA will work with partners to increase climate, weather, ocean, and coastal literacy through investments in extension, training, education, outreach, and communications; outreach to community leaders and decision makers; through innovative technologies to engage stakeholders and the public; strategic connections with science education communities to advance scientific and technical education opportunities and attract populations who are currently underrepresented in the science workforce; and through education and outreach initiatives of other Agencies, including other Federal scientific and environmental Agencies.

In general, efforts to engage stakeholders may be guided by some common elements, which include:

- Identify goals and objectives for involvement and collaboration;
- Identify any constraints, such as resource constraints;
- Clarify purpose and how input may be considered;
- Identify appropriate participants;
- Use a transparent and accessible process;
- Ensure good faith communication with stakeholders; and,
- Identify areas of strengths and deficiencies associated with the process.

Section 5. Conclusion: Beyond the Plan

I. 5YR Plan as a guide for research and development

Under development

II. 5YR Plan as a tool to evaluate progress

Under development

III. 5YR Plan as a sign-post for the next strategic plan

Under development

Appendix A. Mandates and Drivers

National Sea Grant College Program Act, 33 U.S.C. §§ 1121-1131 - The Act establishes a comprehensive NOAA Sea Grant Program, run by NOAA's Office of Oceanic and Atmospheric Research (OAR). The Act provides that the Secretary of Commerce shall establish a National Sea Grant College Program that shall consist of the financial assistance and other authorized activities that provide support for the elements of the program, including in support of solving coastal problems and developing marine resources. The Secretary of Commerce may make grants and enter into contracts under this Act to assist any sea grant program or project if the Secretary finds that such program or project will implement the objective of the Act and be responsive to the needs or problems of individual states or regions.

Ocean Exploration Authority, 33 U.S.C. §§ 3401-3406 - These provisions establish a comprehensive and coordinated National Ocean Exploration Program. Activities authorized under these provisions include giving priority attention to deep ocean regions, conducting scientific voyages to locate, define and document historic shipwrecks and submerged sites, enhancing the technical capability of the U.S. marine science community and establishing an ocean exploration forum to encourage partnerships and promote communication among experts to enhance the scientific and technical expertise and relevance of the National Ocean Exploration Program. These activities are further highlighted in Public Law 111–11 of 2009.

NOAA Undersea Research Program Act of 2009, 33 U.S.C. §§ 3421-3426 - The Act authorizes a comprehensive NOAA Undersea Research Program. Activities authorized under these provisions include core research and exploration based on national and regional undersea research priorities; advanced undersea technology development to support NOAA's research mission and programs; undersea science-based education and outreach programs to enrich ocean science education and public awareness; development, testing, and transition of advance undersea technology; and discovery, study and development of natural resources and products from ocean, coastal, and aquatic systems.

Federal Ocean Acidification Research and Monitoring Act of 2009, 33 U.S.C. §§ 3701 - 3708 - The Act provides authority to establish and maintain an ocean acidification program to include conducting interdisciplinary and coordinated research and long-term monitoring of ocean acidification. The Secretary of Commerce is directed to establish and maintain an ocean acidification program to include conducting interdisciplinary and coordinated research and long-term monitoring of ocean acidification. The Secretary of Commerce may enter into and perform such contracts, leases, grants or cooperative agreements as may be necessary.

Meteorological Services to Support Aviation Authority, 49 U.S.C. § 44720 - This provision of the Federal Aviation Act of 1958 requires the Secretary of Commerce to cooperate with the FAA in providing meteorological services necessary for the safe and efficient movement of aircraft in air commerce; *i.e.*, to support aviation. The Secretary of Commerce is required to observe and study atmospheric phenomena, and maintain meteorological stations and offices; provide reports that will facilitate safety in air navigation; cooperate with those engaged in air commerce in meteorological services; maintain and coordinate international exchanges of meteorological information; participate in developing an international basic meteorological reporting network; coordinate meteorological requirements in the

U.S. to maintain standards and promote safety and efficiency of air navigation; and promote and develop meteorological science, including support for research projects in meteorology.

Weather Service Organic Act, 15 U.S.C. § 313 - The Act is the implementing statute for NOAA to forecast, record, report, monitor, and distribute meteorological, hydrologic and climate data. The Secretary of Commerce has responsibility for these and other essential weather related duties for the protection of life and property and the enhancement of the Nation's economy.

Tsunami Warning and Education Act, 33 U.S.C. §§ 3201 *et seq*. - The Act establishes a comprehensive program to operate and maintain a Tsunami Forecasting and Warning Program, Tsunami Warning Centers, Tsunami Research Program, and National Tsunami Hazard Mitigation Program. The Act provides authority to operate a Tsunami Forecasting and Warning Program which is charged with providing tsunami detection, forecasting and adequate warnings. This Program includes: operational tsunami detection technology; tsunami forecasting capability; management of data quality systems; cooperative efforts with the U.S. Geophysical Service and NSF; capability for disseminating warnings to at-risk States and tsunami communities; as well as integration of tsunami detection technologies with other environmental observing technologies.

The Clean Air Act (42 U.S.C. § 7401) requires that NOAA identify and assess the extent of deposition of atmospheric pollutants to the Great Lakes and coastal waters; and conduct research, in conjunction with other agencies, to improve understanding of the short-term and long-term causes, effects, and trends of damage from air pollutants on ecosystems;

Data Quality Act (a.k.a. Information Quality Act) P.L 106-554

Global Change Research Act, 15 U.S.C. §§ 2921 *et seq*. - The Act establishes a comprehensive and integrated U.S. research program aimed at understanding climate variability and its predictability. The Secretary of Commerce shall ensure that relevant research activities of the National Climate Program are considered in developing national global change research efforts.

Space Weather Authority, 15 U.S.C. § 1532 - This provision authorizes the Secretary of Commerce to conduct research on all telecommunications sciences, including wave propagation and reception and conditions which affect such; preparation and issuance of predictions of electromagnetic wave propagation conditions and warnings of disturbances in such conditions; research and analysis in the general field of telecommunications sciences in support of other Federal agencies; investigation of nonionizing electromagnetic radiation and its uses; as well as compilation, evaluation and dissemination of general scientific and technical data.

National Climate Program Act, 15 U.S.C. §§ 2901-2908 - The Act authorizes a National Climate Program. The Act grants NOAA the authority to enter into contracts, grants or cooperative agreements for climate-related activities. These activities include assessments of the effect of climate on the natural environment, land and water resources and national security; basic and applied research to improve understanding of climate processes and climate change; methods for improving climate forecasts; global data collection and monitoring and analysis activities; systems for management and dissemination of climatological data; measures for increasing international cooperation in climate research, monitoring, analysis and data dissemination; mechanisms for intergovernmental climate-related studies and services including participation by universities; and experimental climate forecast centers.

Geophysical Sciences Authorities, 33 U.S.C. §§ 883d, 883e - These provisions authorize the Secretary to conduct surveys, research, and investigations in geophysical sciences. In order to improve efficiency and increase engineering and scientific knowledge, the Secretary of Commerce is authorized to conduct developmental work for improvement of surveying and cartographic methods, instruments, and equipment; and to conduct investigations/research in geophysical sciences (including geodesy, oceanography, seismology, and geomagnetism.). 33 U.S.C. § 883d. The Secretary of Commerce is further authorized to enter into cooperative agreements with, and to receive and expend funds made available by State or Federal agency, as well as any public or private organization or individual for purposes of surveying or mapping activities, including special purpose maps. 33 U.S.C. § 883e.

America Competes Act, 33 U.S.C. §§ 893, 893a, 893b - This Act contains provisions for what is commonly referred to as the NOAA education authority. These provisions authorize the establishment of a coordinated program (in consultation with the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA)) of ocean, coastal, Great Lakes, and atmospheric research and development in collaboration with academic institutions and other non-governmental entities. In addition, these provisions authorize formal and informal educational activities to enhance public awareness and understanding.

Establishment of Great Lakes Research Office, 33 U.S.C. § 1268: There is established within the National Oceanic and Atmospheric Administration the Great Lakes Research Office. The Research Office shall conduct, through the Great Lakes Environmental Research Laboratory, the National Sea Grant College program, other Federal laboratories, and the private sector, appropriate research and monitoring activities which address priority issues and current needs relating to the Great Lakes.

Public Health and Welfare – Pollution Prevention and Control, 42 U.S.C. § 7412: The EPA Administrator, in cooperation with the Under Secretary of Commerce for Oceans and Atmosphere, shall conduct a program to identify and assess the extent of atmospheric deposition of hazardous air pollutants (and in the discretion of the Administrator, other air pollutants) to the Great Lakes, the Chesapeake Bay, Lake Champlain and coastal waters. As part of such program, the Administrator shall monitor the Great Lakes, the Chesapeake Bay, Lake Champlain and coastal waters, including monitoring of the Great Lakes and designing and deploying an atmospheric monitoring network for coastal waters; investigate the sources and deposition rates of atmospheric deposition of air pollutants (and their atmospheric transformation precursors); conduct research to develop and improve monitoring methods and to determine the relative contribution of atmospheric pollutants to total pollution loadings to the Great Lakes, the Chesapeake Bay, Lake Champlain, and coastal waters.

Harmful Algal Bloom and Hypoxia Research and Control Act of 1998, , 33 U.S.C. § 145: The National Oceanic and Atmospheric Administration, through its ongoing research, education, grant, and coastal resource management programs, possesses a full range of capabilities necessary to support a near and long-term comprehensive effort to prevent, reduce, and control harmful algal blooms and hypoxia; funding for the research and related programs of the National Oceanic and Atmospheric Administration will aid in improving the Nation's understanding and capabilities for addressing the human and environmental costs associated with harmful algal blooms and hypoxia.

Magnuson-Stevens Fishery Conservation & Management Act (MSA), 16 U.S.C. §§ 1801 *et seq*. - The MSA establishes exclusive Federal management authority over fishery resources of the U.S. Exclusive Economic Zone (EEZ) and requires, among other things, rebuilding of overfished stocks of fish and preventing overfishing while maintaining, on a continuing basis, optimum yield from fisheries. 16 U.S.C. § 303(a). Most fishery management plans are developed by regional fishery management councils and must comply with ten National Standards, 16 U.S.C. §§ 1851(a), 1852. The Secretary is responsible for reviewing and implementing FMPs through regulations. 16 U.S.C. § 1854.

Regional Marine Research Programs, 16 U.S.C. § 1447B. The purpose of this chapter is to establish regional research programs, under effective Federal oversight, to--(1) set priorities for regional marine and coastal research in support of efforts to safeguard the water quality and ecosystem health of each region; and (2) carry out such research through grants and improved coordination." (a) A Regional Marine Research board shall be established for each of the following regions: The Great Lakes Research Office authorized under section 1268(d) of title 33 shall be responsible for research in the Great Lakes region and shall be considered the Great Lakes counterpart to the research program established pursuant to this chapter.

Commerce and Trade, 21 15 U.S.C. § 1511 "Sec. 2901. Findings

The following are hereby transferred to the Secretary of Commerce: (e) Those functions vested in the Secretary of Defense or in any officer, employee, or organizational entity of the Department of Defense by the provision of Public Law 91- 144, 83 Stat. 326, under the heading``... (2) the conception, planning, and conduct of basic research and development in the fields of water motion, water characteristics, water quantity, and ice and snow, and (3) the publication of data and the results of research projects in forms useful to the Corps of Engineers and the public, and the operation of a Regional Data Center for the collection, coordination, analysis, and the furnishing to interested agencies of data relating to water resources of the Great Lakes."

Conservation 16 U.S.C. § 4741 The purposes of this chapter are— (1) to prevent unintentional introduction and dispersal of nonindigenous species into waters of the United States through ballast water management and other requirements; (2) to coordinate federally conducted, funded or authorized research, prevention \1\ control, information dissemination and other activities regarding the zebra mussel and other aquatic nuisance species; (3) to develop and carry out environmentally sound control methods to prevent, monitor and control unintentional introductions of nonindigenous species from pathways other than ballast water exchange; (4) to understand and minimize economic and ecological impacts of nonindigenous aquatic nuisance species that become established, including the zebra mussel; and (5) to establish a program of research and technology development and assistance to States in the management and removal of zebra mussels."

Aquatic Nuisance Species Program, 16 U.S.C. § 4722. The Assistant Secretary, in consultation with the Task Force, shall investigate and identify environmentally sound methods for preventing and reducing the dispersal of aquatic nuisance species between the Great Lakes-Saint Lawrence drainage and the Mississippi River drainage through the Chicago River Ship and Sanitary Canal, including any of those methods that could be incorporated into the operation or construction of the lock system of the Chicago River Ship and Sanitary Canal. The Great Lakes Environmental Research Laboratory of the National Oceanic and Atmospheric Administration shall provide technical assistance to appropriate entities to assist in the research conducted pursuant to this subsection.

Study of Migratory Game Fish; Waters Research 16 U.S.C. § 760e. "The Secretary of Commerce is directed to undertake a comprehensive continuing study of migratory marine fish of interest to recreational fishermen of the United States,….including fish which migrate through or spend part of their lives in the inshore waters of the United States. The study shall include, but not be limited to, research on migrations, identity of stocks, growth rates, mortality rates, variation in survival, environmental influences, both natural and artificial, including pollution and effects of fishing on the species for the purpose of developing wise conservation policies and constructive management activities."

Public Health and Welfare – Pollution, Prevention, and Control, 42 U.S.C. § 7412. The Administrator, in cooperation with the Under Secretary of Commerce for Oceans and Atmosphere, shall conduct a program to identify and assess the extent of atmospheric deposition of hazardous air pollutants (and in the discretion of the Administrator, other air pollutants) to the Great Lakes, the Chesapeake Bay, Lake Champlain and coastal waters. As part of such program, the Administrator shall— (A) monitor the Great Lakes, the Chesapeake Bay, Lake Champlain and coastal waters, including monitoring of the Great Lakes through the monitoring network established pursuant to paragraph (2) of this subsection and designing and deploying an atmospheric monitoring network for coastal waters pursuant to paragraph (4); (B) investigate the sources and deposition rates of atmospheric deposition of air pollutants (and their atmospheric transformation precursors); (C) conduct research to develop and improve monitoring methods and to determine the relative contribution of atmospheric pollutants to total pollution loadings to the Great Lakes, the Chesapeake Bay, Lake Champlain, and coastal waters.

Coral Reef Conservation Act, 16 U.S.C. 6401. The purposes of this title are (1) to preserve, sustain, and restore the condition of coral reef ecosystems; (2) to promote the wise management and sustainable use of coral reef ecosystems to benefit local communities and the Nation; (3) to develop sound scientific information on the condition of coral reef ecosystems and the threats to such ecosystems; (4) to assist in the preservation of coral reefs by supporting conservation programs, including projects that involve affected local communities and nongovernmental organizations; (5) to provide financial resources for those programs and projects; and (6) to establish a formal mechanism for collecting and allocating monetary donations from the private sector to be used for coral reef conservation projects.

The Integrated Coastal and Ocean Observation System (ICOOS) Act of 2009, 33 U.S.C. §3601-3610. This act establishes a national integrated System of ocean, coastal, and Great Lakes observing systems, comprised of Federal and non-Federal components including in situ, remote, and other coastal and ocean observation, technologies, and data management and communication systems. The System is designed to address regional and national needs for ocean information; to gather specific data on key coastal, ocean, and Great Lakes variables; and to ensure timely and sustained dissemination and availability of these data to support a variety of societal benefits. These benefits include supporting national defense; marine commerce; navigation safety; weather, climate, and marine forecasting; energy siting and production; economic development; ecosystem-based management of marine and coastal areas; conservation of ocean and coastal resources; and public safety. The System is also designed to promote research to develop, test, and deploy innovations and improvements in coastal and ocean observation technologies and modeling systems.

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."

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."

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.

Coastal Zone Management Act. The goal of the Coastal Zone Management Act (CZMA) is to encourage states to preserve, protect, develop and, where possible, restore and enhance valuable natural coastal resources. Participation by states is voluntary. To encourage states to participate, the Federal government, through the Secretary of Commerce (Secretary), may provide grants to states that are willing to develop and implement a comprehensive coastal management program (CZMA, section 306). Thirty-four coastal and Great Lakes states have a Federally approved program. This represents 99 percent of the nation's 95,331 miles of ocean and Great Lakes coastline. Illinois is the only potentially eligible state that does not yet have an approved program, and Illinois is currently working towards approval. The CZMA also authorizes the National Estuarine Research Reserve System. Under the CZMA, the Secretary may make grants, not to exceed 50 percent of the cost of the project, which enable coastal states to acquire, develop, and operate estuarine research reserves (CZMA, section 315). Designation of an estuarine reserve requires a state to agree to long-term management of the site for research purposes, and to provide information for use by coastal zone managers.

Endangered Species Act. The Endangered Species Act (ESA) imposes a number of mandatory duties on the Secretaries of Commerce and the Interior. Section 4(a)(2) of the statute provides that the Secretary of Commerce generally exercises these responsibilities for most marine and anadromous species and the Secretary of the Interior for land-based and freshwater species, pursuant to Reorganization Plan No. 4 of 1970 that created NOAA. 16 U.S.C. 1533(a)(2). In 1974, the Directors of the U.S. Fish and Wildlife Services and the National Marine Fisheries Service signed a Memorandum of Understanding that clarified responsibilities based on scientific division of species, but leaving the same general division of responsibilities between the Services intact. Memorandum of Understanding Between the U.S. Fish and Wildlife Service, United States Department of the Interior, and the National Marine Fisheries Service, National Oceanic and Atmospheric Administration, United States Department of Commerce, Regarding Jurisdictional Responsibilities and Listing Procedures Under the Endangered Species Act of 1973 (August 28, 1974). For certain species, including sea turtles and Atlantic salmon, the Services subsequently agreed to exercise joint responsibility. Memorandum of Understanding Defining the Roles of the U.S.

Fish and Wildlife Service and the National Marine Fisheries Service in Joint Administration of the Endangered Species Act of 1973 as to Marine Turtles (July 18, 1977); Memorandum of Agreement Between the Northeast Region, U.S. Fish and Wildlife Service and the Northeast Region, National Marine Fisheries Service, Concerning the Anadromous Atlantic Salmon (March 14, 1994).

Oceans and Human Health Act: 33 U.S.C. § 3101-3104. The Act calls for the coordination of a national research plan by the National Science and Technology Council to study the relationship between human health and the oceans. The Task Force on Harmful Algal Blooms and Hypoxia will aid in designing the ten-year plan, which will: create priorities and goals for federal research into the connections between human health and the oceans; develop specific actions to achieve those priorities and goals; identify Federal agency and department programs, reports, and studies that can contribute to the plan; avoid duplication of Federal efforts, and calculate the funding needed for research.

Clean Water Act. 33 U.S.C. ' 1311. The Clean Water Act (CWA) is the principal statute governing water quality. The Act's goal is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. The CWA regulates both the direct and indirect discharge of pollutants into the Nation's waters. Section 301 of the Act () prohibits the discharge into navigable waters of any pollutant by any person from a point source unless it is in compliance with a National Pollution Discharge Elimination System (NPDES) permit. Section 311 of the CWA (33 U.S.C. ' 1321) regulates the discharge of oil and other hazardous substances into navigable waters and waters of the contiguous zone, as well as onto adjoining shorelines, that may be harmful to the public or to natural resources (CWA section 311(b)(1)). The Act allows the Federal government to remove the substance and assess the removal costs against the responsible party (CWA section 311(c)). The CWA defines removal costs to include costs for the restoration or replacement of natural resources damaged or destroyed as a result of a discharge of oil or a hazardous substance (CWA section 311(f)(4)).

National Marine Sanctuaries Act. 16 U.S.C. ' 1433. The National Marine Sanctuaries Act (NMSA) provides the Secretary of Commerce with the authority to protect and manage the resources of significant marine areas of the United States. NOAA's administration of the marine sanctuary program involves designating marine sanctuaries and adopting management practices to protect the conservation, recreational, ecological, educational, and aesthetic values of these areas.

The NMSA states that the Secretary of Commerce may designate any discrete area of the marine environment as a national marine sanctuary and promulgate regulations implementing the designation, if the Secretary determines the designation will fulfill the purposes of the Act and the designation meets certain criteria. The Act spells out factors for the Secretary to consider in making a designation, and requires consultation with Congress. The Secretary is required to evaluate periodically the implementation of each sanctuary's management plan and goals for the sanctuary. The Secretary is required to conduct research monitoring, evaluation, and education programs as are necessary and reasonable to carry out the purposes and policies of the NMSA. The Act states the Secretary may establish advisory councils to provide assistance regarding the designation and management of national marine sanctuaries.

Marine Mammal Protection Act. The Marine Mammal Protection Act (MMPA) was enacted to protect certain species and stocks of marine mammals and to achieve healthy populations of marine mammals. Pursuant to the MMPA, the Secretary of Commerce (Secretary) maintains jurisdiction over cetaceans (whales, dolphins, and porpoises) and pinnipeds (seals and sea lions). The Secretary of the Interior maintains jurisdiction over all other marine mammals, e.g., polar bears, walrus, and manatee. The MMPA generally prohibits taking and importation of all marine mammals, except under limited exceptions. These exceptions include, but are not limited to, the following: (1) taking incidental to specified activities such as construction projects, military activities, or oil and gas development; (2) taking incidental to commercial fishing operations; (3) taking by Federal, State or local government official duties; and (4) the intentional lethal taking of individually identifiable pinnipeds which are having a significant negative impact on the decline or recovery of at-risk salmonids. In addition, the Secretary may issue permits to authorize the taking or importation of any marine mammal as part of scientific research, public display, or to enhance the survival or recovery of a species or stock (MMPA ' 1374).

Coastal Ocean Program. Section 201(c) authorizes a Coastal Ocean Program. The Coastal Ocean Program is now called the National Center for Sponsored Coastal Ocean Research. ASuch 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. The Coastal Ocean Program sponsors multiple-year, competitive research projects, pulling together expertise from all NOAA line offices, and partnering with state, local, and Federal government agencies and private organizations.

National Environmental Policy Act. The National Environmental Policy Act (NEPA) requires Federal agencies to take certain steps in their decision making processes to ensure consideration of environmental impacts and alternatives. NEPA requires that agency decision makers consider certain specific factors whenever deciding whether to undertake a major federal action. In addition to the analytical requirements, NEPA also requires agency decision makers to utilize a systematic, interdisciplinary approach integrating natural and social sciences and environmental design in planning and decision-making; identify methods to ensure that unquantified environmental amenities and values may be given appropriate consideration in decision-making along with economic and technical considerations; study, develop, and describe appropriate alternatives to recommended courses of action in any proposal which involves unresolved conflicts concerning alternative uses of available resources; recognize the worldwide and long-range character of environmental problems and, where consistent with the foreign policy of the United States, lend appropriate support to initiatives, resolutions, and programs designed to maximize international cooperation in anticipating and preventing a decline in the quality of mankind's world environment; make available to states, counties, municipalities, institutions, and individuals, advice and information useful in restoring, maintaining, and enhancing the quality of the environment; and initiate and utilize ecological information in the planning and development of resource-oriented projects.

Water Pollution Prevention and Control Act. These Acts are intended to manage the adverse impacts of aquatic nuisance species (ANS) by preventing their unintentional introduction and dispersal into the waters of the United States through ships' ballast water and other means. They also provide for the management of those ANS which have already become established and for research and development. The Nonindigenous Aquatic Nuisance Prevention and Control Act establishes an interagency Aquatic

Nuisance Species Task Force. The Under Secretary of Commerce for Oceans and Atmosphere is mandated to serve as the co-chairperson of this Task Force. The Task Force, in general, is required to develop and implement a program for U.S. waters to prevent the introduction and dispersal of ANS; to monitor, control, and study such species; and to disseminate related information. The Under Secretary is authorized to issue rules and regulations as are necessary for accomplishing the objectives of the Task Force. The Task Force is required to allocate funds for competitive research grants to study all aspects of ANS. This grant program shall be administered through the National Sea Grant College Program and the Cooperative Fishery and Wildlife Research Units; however, to date, it has been administered exclusively by Sea Grant.

Non-Legislative Drivers

Climate Change Science Program: The Interagency Climate Change Science Program has oversight over U.S. Global Change Research Program (USGCRP) and Climate Change Research Initiative (CCRI) activities, with a single interagency committee responsible for the entire range of science projects sponsored by both programs. The Interagency Climate Change Science Program retains the responsibility for compliance with the requirements of the Global Change Research Act of 1990, including its provisions for annual reporting of findings and short-term plans, scientific reviews by the National Academy of Sciences/National Research Council, and periodic publication of a ten-year strategic plan for the program.

U.N. Framework Convention on Climate Change: The Convention on Climate Change sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. It recognizes that the climate system is a shared resource whose stability can be affected by industrial and other emissions of carbon dioxide and other greenhouse gases.

Global Earth Observation System of Systems

Montreal Protocol on Substances that Deplete the Ozone Layer

NARA Records and Guidelines: Provide long-term preservation of the Nation's climate Record. Provide NOAA customers access to Climate Data and Information (timely, easy, and convenient) related to the state and changing state of the climate system in a variety of formats

ICSU World Data Center Guidelines and Policy: Provide long-term preservation of the Nation's climate Record. Provide NOAA customers access to Climate Data and Information (timely, easy, and convenient) related to the state and changing state of the climate system in a variety of formats

Great Lakes Water Quality Agreement of 1978.—Amended 1987

International Agreement between Canada and the United States which involves restoring and enhancing water quality in the Great Lakes System "Implementation: The Parties, in cooperation with State and Provincial Governments, shall conduct research in order to: a) Determine the mass transfer of pollutants between the Great Lakes basin Ecosystem components of water, sediment, air, land and biota, and the processes controlling the transfer of pollutants across the interfaces between these components in accordance with Annexes 13,14, 15, and 16; b) Develop load reduction models for pollutants in the Great Lakes System in accordance with the research requirements of Annexes 2, 11, 12, and 13; c) Determine the physical and transformational processes affecting the delivery of pollutants by tributaries to the Great Lakes in accordance with Annexes 2,11,12,13; d) Determine cause-effect inter-relationships of productivity and ecotoxicity, and identify future research needs in accordance with

Annexes 11, 12, 13 and 15; e) Determine the relationship of contaminated sediments on ecosystem health, in accordance with the research needs of Annexes 2, 12 and 14; f) Determine the pollutant exchanges between the Areas of Concern and the open lakes including cause-effect inter-relationships among nutrients, productivity, sediments, pollutants, biota and ecosystem health, and to develop in-situ chemical, physical and biological remedial options in accordance with Annexes 2, 12,14, and sub-paragraph 1(f) of Annex 3; g) Determine the aquatic effects of varying lake levels in relation to pollution sources, particularly respecting the conservation of wetlands and the fate and effects of pollutants in the Great Lakes Basin Ecosystem in accordance with Annexes 2, 11, 12, 13, 15, and 16; h) Determine the ecotoxicity and toxicity effects of pollutants in the development of water quality objectives in accordance with Annex 1; i) Determine the impact of water quality and the introduction of non-native species on fish and wildlife population and habitats in order to develop feasible options for their recovery, restoration or enhancement in accordance with sub-paragraph 1(a) of Article IV and Annexes 1,2,11 and 12; j) Encourage the development of control technologies for treatment of municipal and industrial effluents, atmospheric emissions and the disposal of wastes, including wastes deposited in landfills; k) Develop action levels for contamination that incorporate multi-media exposures and the interactive effects of chemicals; and l) Develop approaches to population-based studies to determine the long-term, low level effects of toxic substances on human health.

OMB Circular A-16. The Office of Management and Budget (OMB) Circular A-16, "Coordination of Geographic Information and Related Spatial Data Activities," provides for improvements in the coordination and use of spatial data, and describes effective and economical use and management of spatial data assets in the digital environment for the benefit of the Federal Government and the Nation. This Supplemental Guidance document further defines and clarifies selected elements of OMB Circular A-16 to facilitate the adoption and implementation of a coordinated and effective Federal geospatial asset management capability that will improve support of mission-critical business requirements of the Federal Government and its stakeholders.

Appendix B: R&D Units

Below is a list of the NOAA organizational units, by Line Office, that either fund or conduct R&D. This list is based on FY 2011 budget appropriation and, as such, only includes those units with appropriated funds for R&D in FY 2011. In later years, additional organizations may have declared R&D dollars (e.g., NCDC, IOOS).

NOAA National Environmental Satellite Data and Information Service (NESDIS)

CENTER FOR SATELLITE APPLICATIONS AND RESEARCH (STAR)
STAR is the science arm of NESDIS. The mission of STAR is to use satellite-based observations to create products of the land, atmosphere, and ocean, and transfer them from scientific research and development into NOAA's routine operations. STAR is a leader in planning future satellite observing systems to enhance the nation's ability to remotely monitor the environment. STAR also calibrates the Earth-observing instruments of all NOAA satellites.

NOAA National Marine Fisheries Service (NMFS)

ALASKA FISHERIES SCIENCE CENTER (AKFSC)
AFSC is responsible for research in the marine waters and rivers of Alaska. The AFSC develops and manages scientific data and provides technical advice to the North Pacific Fishery Management Council, the NMFS Alaska Regional Office, state of Alaska, Alaskan coastal subsistence communities, U.S. representatives participating in international fishery negotiations, and the fishing industry and its constituents. The AFSC also conducts research on marine mammals worldwide, primarily in coastal California, Oregon, Washington, and Alaska. This work includes stock assessments, life history determinations, and status and trends. Information is provided to various U.S. governmental and international organizations to assist in developing rational and appropriate management regimes for marine resources under NOAA's jurisdiction. The AFSC is engaged in cutting-edge research on emerging issues such as global warming and the loss of sea ice in the Bering Sea.

ALASKA REGION, NMFS (AKR)
NMFS Regional Offices receive R&D funding to support their management activities. However, NMFS Regional Offices (RO) do not conduct substantial research. Instead, ROs use the funding to support R&D activities at fisheries science centers, universities, and other institutions, as needed.

NORTHEAST FISHERIES SCIENCE CENTER (NEFSC)
NEFSC manages a multidisciplinary program of basic and applied research to better understand living marine resources of the Northeast Continental Shelf from the Gulf of Maine to Cape Hatteras. NEFSC works to describe and provide to management, industry, and the public, options for the conservation and utilization of living marine resources, and for the restoration and maintenance of environmental quality. Research conducted at various laboratories located around the region include research in ecology, aquaculture and habitat-related work,

oceanography, and studies on the demography and ecology of shark populations,   The Office of Marine Ecosystem Studies (OMES) develops technologies and conducts ecosystem-based research and assessments of living marine resources and their environments to promote recovery and long-term sustainability of fish stocks and protected species; restore and preserve essential habitats to secure ecosystem health; and enhance and ensure long-term social and economic benefits to society from their use. The Large Marine Ecosystems Program Office continues to develop a concept for ecosystem based management . The NEFSC also describes and provides to management authorities, industry, and the public, options for the conservation and utilization of living marine resources.

NORTHEAST REGION, NMFS (NER)

NMFS Regional Offices receive R&D funding to support their management activities. However, NMFS Regional Offices (RO) do not conduct substantial research. Instead, ROs use the funding to support R&D activities at fisheries science centers, universities, and other institutions, as needed.

NORTHWEST FISHERIES SCIENCE CENTER (NWFSC)

NWFSC conducts multidisciplinary research to provide fisheries management information and technical advice. . The NWFSC studies living marine resources (e.g., salmon, groundfish, and killer whales) and their habitat in the Northeast Pacific Ocean – primarily off the coasts of Washington and Oregon and in freshwater rivers and streams in Washington, Oregon, Idaho, and Montana. Such information supports national NMFS programs, responds to the needs of the Pacific Fishery Management Council, and supports other constituencies along the U.S. West Coast. The Center's 500 scientist and staff conduct research in five primary areas: Stock assessments on West Coast groundfish and salmon stocks, toxicology of the habitat and its impacts, on salmon, marine fish, and marine mammals, the physical and biological processes that influence aquatic, marine, and estuarine ecosystems, recovery and rebuilding species, and the use of innovation and technology that can lead to new or better ways to conduct research and understand species and their habitats.

NORTHWEST REGION, NMFS (NWR)

NMFS Regional Offices receive R&D funding to support their management activities. However, NMFS Regional Offices (RO) do not conduct substantial research. Instead, ROs use the funding to support R&D activities at fisheries science centers, universities, and other institutions, as needed.

OFFICE OF HABITAT CONSERVATION (OHC)

The Habitat program receives R&D funding to support their management activities. However, the NMFS Habitat Program does not conduct substantial research. Instead, it uses the funding to support R&D activities at fisheries science centers, universities, and other institutions, as needed.

OFFICE OF SCIENCE AND TECHNOLOGY (S&T)

The NMFS Office of Science and Technology provides headquarters-level coordination and oversight of NOAA Fisheries scientific research and technology development. The Office serves as the focal point within NOAA Fisheries for the development and evaluation of science and technology strategies and policies, and evaluation of NOAA Fisheries scientific mission. The Office also has primary responsibility for national Commercial and Recreational Fisheries Statistics Programs including research on improving data collection and estimation procedures. Other active research includes development of advanced sampling technologies, creation of catch share performance measures, design of non-market valuation methods, improvement to stock and protected resource assessments methods, development of ecosystem-based approaches to assessment and management, and implementation of an Enterprise Data Management strategy for the agency.

PACIFIC ISLANDS FISHERIES SCIENCE CENTER (PIFSC)

PIFSC conducts research on fisheries, coral reefs, protected species, and the oceanographic and ecosystem processes that support them. PIFSC conducts biological, ecological, and socio-economic research in support of fishery management plans and protected species recovery plans. Research and analysis of the resulting fisheries data support fisheries policy and management; protected species efforts examine the status and problems affecting the populations of the Hawaiian monk seal and the sea turtles. PIFSC activities support the Western Pacific Regional Fishery Management Council, the NMFS Pacific Islands Regional Office, and international commissions on Pacific tuna.

PACIFIC ISLANDS REGION, NMFS (PIR)

NMFS Regional Offices receive R&D funding to support their management activities. However, NMFS Regional Offices (RO) do not conduct substantial research. Instead, ROs use the funding to support R&D activities at fisheries science centers, universities, and other institutions, as needed.

SOUTHEAST FISHERIES SCIENCE CENTER (SEFSC)

SEFSC conducts research in the southeastern United States, as well as Puerto Rico and the U.S. Virgin Islands. SEFSC develops scientific information required for fishery resource conservation, habitat conservation, and protection of marine mammals, sea turtles, and endangered species. The research addresses specific needs in population dynamics, fishery biology, fishery economics, engineering and gear development, and protected species biology. The SEFSC also conducts impact analyses and environmental assessments for international negotiations and for the South Atlantic, Gulf of Mexico, and Caribbean Fishery Management Councils.

SOUTHEAST REGION, NMFS (SER)

NMFS Regional Offices receive R&D funding to support their management activities. However, NMFS Regional Offices (RO) do not conduct substantial research. Instead, ROs use the funding to support R&D activities at fisheries science centers, universities, and other institutions, as needed.

SOUTHWEST FISHERIES SCIENCE CENTER (SWFSC)

SWFSC is the research arm of NOAA's National Marine Fisheries Service in the Southwest Region. Center scientists conduct marine biological, economic, and oceanographic research, observations, and monitoring on living marine resources and their environment throughout the Pacific Ocean and in the Southern Ocean off Antarctica. The ultimate purpose of these scientific efforts is for the conservation and management of marine and anadromous fish, marine mammal, sea turtle, and other marine life populations to ensure that they remain at sustainable and healthy levels. Key research areas including managing the U.S. Antarctic Marine Living Resources Program, the distribution of environmental index products and time series data bases to cooperating researchers, describing the links between environmental processes and population dynamics of important fish stocks, conducting research on the ecology of groundfish, economic analysis of fishery data, Pacific salmon studies (including 10 endangered salmon and steelhead runs), and coastal habitat issues affecting the San Francisco Bay and the Gulf of Farallones, the assessing the biomass of valuable coastal pelagic fish stocks and evaluations the biological and environmental factors that affect their distribution, abundance, and survival, and the conservation and management of U.S. and international populations of marine mammals and their critical habitat.

SOUTHWEST REGION, NMFS (SWR)
NMFS Regional Offices receive R&D funding to support their management activities. However, NMFS Regional Offices (RO) do not conduct substantial research. Instead, ROs use the funding to support R&D activities at fisheries science centers, universities, and other institutions, as needed.

The NOAA National Ocean Service (NOS)

CENTER FOR COASTAL ENVIRONMENTAL HEALTH (CCEHBR)
CCEHBR conducts research related to coastal ecosystem health, environmental quality, and public health. Chemical, biomolecular, microbiological, and histological research is conducted to describe, evaluate, and predict significant factors and outcomes of influences on marine and estuarine habitats. The Cooperative Oxford Laboratory in Oxford, MD, is part of CCEHBR.

CENTER FOR COASTAL FISHERIES AND HABITAT (CCFHR)
CCFHR is jointly sponsored by the NOS and NMFS. The CCFHR conducts laboratory and field research on estuarine processes, the biological productivity of near-shore and ocean ecosystems, the dynamics of coastal and reef fishery resources, and the effects of human influences on resource productivity.

CENTER FOR COASTAL MONITORING & ASSESSMENT (CCMA)
CCMA assesses and forecasts coastal and marine ecosystem conditions through research and monitoring. CCMA provides the best available scientific information for resource managers and researchers, as well as technical advice and data access. CCMA addresses pollution, land and resource use, invasive species, climate change, and extreme events.

CENTER FOR HUMAN HEALTH RISK (CHHR)
Center for Human Health Risk NOAA's component of a multi-institutional, inter-disciplinary institution providing science and biotechnology applications to sustain, protect, and restore coastal ecosystems, emphasizing linkages between environmental and human health.

CENTER FOR SPONSORED COASTAL OCEAN RESEARCH (CSCOR)
CSCOR is a federal-academic partnership to develop predictive capabilities for managing coastal ecosystems. High-priority research and interagency initiatives support quality science relevant to coastal policy decisions including issues directly supporting NOAA's overall mission.

COAST SURVEY DEVELOPMENT LABORATORY (CSDL)
CSDL explores, develops, and transitions emerging cartographic, hydrographic, and oceanographic technologies and techniques to provide products and services to Coast Survey, NOS, and NOAA partners and customers in the coastal community. These products support safe and efficient marine navigation and a sustainable coastal environment. CSDL consists of three components: Cartographic and Geospatial Technology Programs (CGTP), Hydrographic Systems and Technology Programs (HSTP), and Marine Modeling and Analysis Programs (MMAP).

ENGINEERING DIVISION (ED)
The Center for Operational Oceanographic Products and Services' OSTEP introduces new and improved oceanographic and marine meteorological sensors and systems to improve quality, responsiveness, and value of individual sensors or integrated sensor systems. In addition to the testing, evaluation, and integrating phases, OSTEP performs continuous research and awareness of technology offerings and their application to navigation safety.

GEOSCIENCES RESEARCH DIVISION (GRD)
The NGS Geosciences Research Division performs fundamental research in applications of GNSS (Global Navigation Satellite System) technology to Earth science and in development of gravity measurement systems.

NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE / HEADQUARTERS (NCCOS HQ)
The National Centers for Coastal Ocean Science (NCCOS) conducts and supports research, monitoring, assessments, and technical assistance to meet NOAA's coastal stewardship and management responsibilities. Left alone, stressors change ecosystems. NCCOS conducts and funds research to define these stressors and assess their consequences to ecosystem health and natural resource abundance. Based upon these studies, NCCOS forecasts the anticipated effects of alternate management strategies on ecosystems. By using science to predict potential consequences of different actions, coastal managers have the information necessary to make more informed decisions.

NATIONAL ESTUARINE RESEARCH RESERVES SYSTEM (NERRS)
NERRS is a network of 28 areas representing different biogeographic regions of the United States. The reserves are protected for long-term research, water quality monitoring, education, and coastal stewardship. The NERRS serve as living laboratories for on-site staff, visiting scientists and graduate students who study coastal ecosystems. In this capacity, the reserves serve as platforms for long-term research and monitoring, as sites to better understand the effects of climate change, and as reference sites for comparative studies. The goals of the Reserve System's research and

monitoring program include (1) ensuring a stable environment for research through long-term protection of Reserve resources; (2) addressing coastal management issues through coordinated estuarine research within the System; and (3) collecting information necessary for improved understanding and management of estuarine areas, and making the information available to stakeholders.

NOS ASSISTANT ADMINISTRATOR (NOS AA)
This is where the Ocean and Human Health Initiative is executed and where the NOS Chief Science Advisor is located. OHHI investigates the relationship between environmental stressors, coastal condition and human health to maximize health benefits from the ocean, improve the safety of seafood and drinking waters, reduce beach closures, and detect emerging health threats.

OFFICE OF COAST SURVEY (OCS)
Hydrographic Science and Technology (used to fund the Joint Hydrographic Center)

OFFICE OF RESPONSE AND RESTORATION (OR&R)
OR&R is a center of expertise in preparing for, evaluating, and responding to threats to coastal environments, including oil and chemical spills, releases from hazardous waste sites, and marine debris.

REMOTE SENSING DIVISION (RSD)
The NGS Remote Sensing Research Group conducts research and development in emerging remote sensing technologies, including platforms, sensors, and processing and analysis hardware and software, with the goal of increasing the quality, quantity, and timeliness of information available for Integrated Ocean and Coastal Mapping (IOCM).

NOAA National Weather Service (NWS)

NATIONAL CENTERS FOR ENVIRONMENTAL PREDICTION (NCEP)
NCEP delivers reliable, timely and accurate national and global weather, water, climate, and space weather guidance, forecasts, warnings, and analyses to a broad range of users and partners. These products and services respond to user needs to protect life and property, enhance the nation’s economy, and support the nation’s growing need for environmental information. In developing its products and services, NCEP’s constituent centers undertake and/or support the research needed to maintain its ranking as a world leader in operational environmental prediction.

OFFICE OF HYDROLOGIC DEVELOPMENT (OHD)
OHD enhances NWS products by infusing new hydrologic science, developing hydrologic, hydraulic, and hydrometeorologic techniques for operational use, managing hydrologic development by NWS field offices, and providing advanced hydrologic products to meet needs identified by NWS customers. OHD also performs studies to update precipitation frequency climate normals.

OFFICE OF SCIENCE AND TECHNOLOGY (OST)

OST plans, develops, tests and infuses advanced science and technology into NWS operations. These include advanced techniques and technologies for observations, numerical guidance, forecast techniques, preparation, collaboration and dissemination technologies; and decision support tools and techniques required for NWS Operations. OST furnishes a full spectrum of forecast guidance, provides interactive tools for decision assistance and forecast preparation, and conducts comprehensive evaluations of NWS Products.

NOAA Office of Oceanic and Atmospheric Research (OAR)

AIR RESOURCES LABORATORY (ARL)

ARL conducts research on processes that relate to air chemistry, atmospheric dispersion, the atmospheric boundary layer, and climate, concentrating on the transport, dispersion, transformation, and removal of trace gases and aerosols, their climatic and ecological influences, and exchange between the atmosphere and biological and non-biological surfaces. Key activities include the development, evaluation, and application of air quality models; improvement of approaches for predicting atmospheric dispersion of hazardous materials and low-level winds; the generation of new insights into air-surface exchange and climate variability and trends; and the development of reference climate observation systems. The time frame of interest ranges from minutes and hours to that of the global climate. ARL provides scientific and technical advice to elements of NOAA and other Government agencies on atmospheric science, environmental problems, emergency assistance, and climate change. The goal of this work is to improve the nation’s ability to protect human and ecosystem health while also maintaining a vibrant economy.

ATLANTIC OCEANOGRAPHIC & MET LAB (AOML)

AOML conducts research in physical oceanography, tropical meteorology, oceanic biogeochemistry, and modeling. Research at AOML improves the understanding and prediction of hurricane track and intensity, the ocean’s role in annual to multi-decadal climate variability, and human impacts on coastal ecosystems. AOML is a primary partner in the development of a sustained Ocean Observing System for Climate and a center for hurricane research and Observing System Simulation Experiments for the atmosphere and ocean.

CLIMATE PROGRAM OFFICE (CPO)

CPO provides strategic guidance and oversight for the agency's climate science and services programs. Designed to build knowledge of climate variability and change—and how they affect our health, our economy, and our future—the CPO's programs have three main objectives: Describe and understand the state of the climate system through integrated observations, monitoring, and data management; Understand and predict climate variability and change from weeks to decades to a century into the future; and Improve society's ability to plan and respond to climate variability and change. CPO funds high-priority climate research to advance understanding of atmospheric and oceanic processes as well as climate impacts resulting from drought and other stresses. This research is conducted in most regions of the United States and at national and international scales, including in the Arctic. Recognizing that climate science literacy is a prerequisite for putting this new knowledge into action at all levels of society, the CPO also helps to lead NOAA's climate communication, education, and professional development and training activities.

EARTH SYSTEM RESEARCH LABORATORY / DIRECTOR'S OFFICE (ESRL DIR)

In addition to providing oversight, management, and support services to the ESRL divisions, the Director's office serves as a program development center where nascent activities that cross-cut the ESRL divisions can be undertaken. Current initiatives include the NOAA Unmanned Aircraft Systems (UAS) program, the NOAA Renewable Energy Program, the Advanced Networking Group (NWave), and the NOAA Environmental Software Infrastructure and Interoperability (NESII) project.

ESRL/CHEMICAL SCIENCES DIVISION (CSD)

ESRL-CSD's mission is to discover, understand, and quantify the processes that control the chemical makeup of Earth's atmosphere to better understand the atmosphere's future, thereby providing the sound scientific basis for decisions and choices made by industry, government, and the public. ESRL-CSD's research is centered on three major environmental issues and the linkages between them: climate change, ozone layer depletion, and air quality degradation. Through laboratory investigations in atmospheric chemistry, intensive field measurement campaigns in a variety of environments, and diagnostic analyses and interpretations, ESRL-CSD advances understanding of chemical reactions and radiative processes (heating, cooling, and initiation of reactions) that drive atmospheric change. CSD provides explanations of our research in user-friendly, policy-relevant formats, such as assessments, which may be used to help develop informed decisions.

ESRL/GLOBAL MONITORING DIVISION (GMD)

ESRL-GMD conducts sustained observations and research related to global distributions, trends, sources, and sinks of atmospheric constituents that are capable of forcing change in Earth's climate and environment. This research advances climate projections and provides scientific, policy-relevant decision-support information to enhance society's ability to plan and respond by providing the best possible information on atmospheric constituents that drive climate change, stratospheric ozone depletion, and baseline air quality. ESRL-GMD supports several components of the U.S. Global Change Research Program, much of the World Meteorological Organization Global Atmospheric Watch program, which aims to coordinate long term, climate-relevant measurements worldwide, and other international programs, including the Global Climate Observing System, the Baseline Surface Radiation Network, and the Global Earth Observing System of Systems.

ESRL/GLOBAL SYSTEMS DIVISION (GSD)

ESRL-GSD conducts research and development to provide NOAA and the nation with observing, prediction, computer, and information systems that deliver environmental products ranging from local to global predictions of short-range, high impact weather and air quality events to longer-term intraseasonal climate forecasts.

ESRL/PHYSICAL SCIENCES DIVISION (PSD)

ESRL-PSD conducts weather and climate research to provide the observation, analysis, and diagnosis of weather and climate physical processes necessary to increase understanding of Earth's physical environment, including the atmosphere, ocean, cryosphere, and land, and to enable improved weather and climate predictions on global-to-local scales.

GEOPHYSICAL FLUID DYNAMICS LABORATORY (GFDL)

GFDL conducts comprehensive long-lead time research fundamental to NOAA's mission of understanding climate variability and change. GFDL scientists initiate, develop and apply mathematical models and computer simulations to advance our understanding and ability to project and predict the behavior of the atmosphere, the oceans, and climate. GFDL scientists focus on model-building relevant for society, such as hurricane research, prediction, and seasonal-to-decadal prediction, and understanding global and regional climate variations and change arising from natural and human-influenced factors. GFDL research encompasses the predictability and sensitivity of global and regional climate; the structure, variability, dynamics and interaction of the atmosphere and the ocean; and the ways that the atmosphere and oceans influence, and are influenced by various trace constituents. The scientific work of the Laboratory incorporates a variety of disciplines including meteorology, oceanography, hydrology, physics, fluid dynamics, atmospheric and biogeochemistry, applied mathematics, and numerical analysis.

GREAT LAKES ENVIRONMENTAL RESEARCH LAB (GLERL)

GLERL conducts research and provides scientific leadership to understand, observe, assess, and predict the status and changes of Great Lakes and coastal marine ecosystems to educate and advise stakeholders of optimal management strategies. GLERL houses a multidisciplinary scientific core focusing on research that leads ecosystem forecasts on physical hazards, water quality and quantity, human health, invasive species, and fish recruitment and productivity. GLERL places special emphasis on a systems approach to problem-oriented research to develop environmental service tools. It houses NOAA's National Invasive Species Center and the NOAA Center of Excellence for Great Lakes and Human Health.

NATIONAL SEA GRANT COLLEGE PROGRAM (SeaGrant)

The National Sea Grant Program works closely with the 30 state Sea Grant programs located in every coastal and Great Lakes state and Puerto Rico. Sea Grant provides a stable national infrastructure of programs serving as the core of a dynamic, national university-based network of over 300 institutions involving more than 3,000 scientists, engineers, educators, students, and outreach experts. This network works on a variety of topics vital to human and environmental health—topics such as healthy coastal ecosystems, hazard resilience in coastal communities, a safe and sustainable seafood supply and sustainable coastal development. Through their research, education, and outreach activities, Sea Grant has helped position the United States as the world leader in marine research and the sustainable development of coastal resources. Sea Grant activities exist at the nexus of local, state, national, and sometimes international interests. In this way, local needs receive national attention, and national commitments are fulfilled at the local level.

NATIONAL SEVERE STORMS LABORATORY (NSSL)

NSSL investigates all aspects of severe weather. Headquartered in Norman, OK, and in partnership with the NWS, NSSL is dedicated to improving severe weather warnings and forecasts in order to save lives and reduce property damage. NSSL conducts research to improve accurate and timely forecasts and warnings of hazardous weather events such as blizzards, ice storms, flash floods, tornadoes, and lightning. NSSL accomplishes this goal through a balanced program of research to advance the understanding of weather processes, research to improve forecasting and warning techniques, development of operational applications, and transfer of understanding, techniques, and applications to the National Weather Service and other agencies.

OCEAN ACIDIFICATION PROGRAM (OA)

The NOAA Ocean Acidification Program (OAP) was established by SEC. 12406. of the 2009 Federal Ocean Acidification Research and Monitoring Act (FOARAM) to coordinate research, monitoring, and other activities to improve understanding of ocean acidification. The OAP maintains a long-term OA monitoring; conducts research designed to enhance conserving marine ecosystems sensitive to OA; promote OA educational opportunities; engage national public outreach activities related to OA and its impacts; and coordinate OA activities across other agencies and appropriate international ocean science bodies. As part of its responsibility, the OAP provides grants for critical research projects that explore the effects on ecosystems and the socioeconomic impacts.

OFFICE OF OCEAN EXPLORATION AND RESEARCH (OER)

The NOAA Ocean Exploration (OE) program was established in 2001 in response to the report of the President's Panel on Ocean Exploration and focuses on: (1) mapping and characterizing the 95 percent of the ocean that is currently unexplored; (2) investigating poorly known ocean processes at multiple scales; (3) developing new sensors and systems; and (4) engaging stakeholders in new and innovative ways. OE investigates unknown ocean areas and phenomena, and employs an interdisciplinary scientific approach to ensure broad and comprehensive results that catalyze future research. The program invests in: (1) extramural grants; (2) telepresence-enabled expeditions using the Nation's only dedicated ship of exploration, the NOAA Ship Okeanos Explorer; (3) interagency partnership expeditions; and (4) participation in major national and international initiatives. Other key areas of investment include data and information management and product development, and education and outreach, which ensure the information derived from each expedition and project is widely distributed. OE continues to break new ground in the research, development, testing and evaluation, and application of undersea, ship-based, and communications technologies. The NURP component of OER provides NOAA with the unique ability to engage scientists in cutting edge research required to follow up on discoveries made during the course of exploration. NURP centers include the Hawaii Undersea Research Lab at the University of Hawaii, the West Coast and Polar Regions Center at the University of Alaska Fairbanks, and the Cooperative Institute for Ocean Exploration, Research and Technology operated by the Harbor Branch Oceanographic Institute at Florida Atlantic University and the University of North Carolina Wilmington. NURP supports the National Institute of Undersea Science and Technology at the University of Mississippi. NURP, through the University of North Carolina Wilmington, also operates the NOAA-owned Aquarius Undersea Habitat, the only manned undersea research facility, located in the Florida Keys. NURP provides extramural grants to both the federal and non-federal research community, while assisting scientists in acquiring data and observations that provide the information necessary to further NOAA's priority goals specific to increasing our knowledge of the oceans.

OFFICE OF WEATHER AND AIR QUALITY (OWAQ)

The OWAQ Program helps provide improved weather forecast information and products to the Nation by facilitating, coordinating, and transitioning into applied weather and air quality research in NOAA. OWAQ programs provide outreach, linkage, and coordination between NOAA, other government agencies, and the academic and private sectors, both within the U.S. and internationally. OWAQ strives to ensure NOAA is optimally leveraging weather and air quality research capacity. OWAQ manages the overall U.S. Weather Research Program (USWRP) effort in support of research for air quality forecasting, societal benefits, and related weather research through projects with such internal and external partners as the National Center for Atmospheric Research (NCAR) and NOAA's cooperative institutes. NOAA's USWRP seeks to improve weather and air quality forecast information and products by funding, facilitating, and coordinating cutting-edge research to improve weather and air quality predictions to protect lives and property of the American public and inform weather sensitive U.S. industry.

PACIFIC MARINE ENVIRONMENTAL LABORATORY (PMEL)

PMEL carries out interdisciplinary investigations in oceanography and atmospheric science and develops and maintains efficient and effective ocean observing systems. Results from PMEL research activities contribute to improved scientific understanding of the changing climate systems and its impacts, improved tsunami forecast capabilities, and improved understanding of the impacts of climate and ocean conditions on marine ecosystems. PMEL cultivates innovative technologies to improve research and observing capabilities that can be transferred to operations and private industry.

RESEARCH TECHNOLOGY AND APPLICATIONS (ORTA)

ORTA is responsible for two Congressionally mandated programs: The Technology Transfer Program, under the Federal Technology Transfer Act (FTTA) of 1986, and the Department of Commerce Small Business Innovation Research (SBIR) Program in accordance with the Small Business Innovation Research Program Reauthorization Act of 2000. The ORTA Technology Transfer functions are to assist NOAA laboratories with patent applications and licensing; advise on Cooperative Research and Development Agreements (CRADAs); maintain NOAA records on patent and licenses; and manage NOAA's account with the Patent and Trademark Office. The SBIR program prepares, coordinates, and disseminates the annual program schedule; recommends Phase 1 and Phase 2 funding limits and number of awards for each; obtains research topics from NOAA scientists; prepares and disseminates the annual NOAA solicitation; manages the proposal process (through peer review, selection, and award phases); monitors the Phase 1 and Phase 2 review process; de-briefs offerors; and chairs meetings of the NOAA/SBIR Working Group.

NOAA Office of Marine and Aviation Operations (OMAO)

MARINE AND AVIATION OPERATIONS CENTERS (MOC)

OMAO operates a wide variety of specialized aircraft and ships to complete NOAA's environmental and scientific missions. NOAA's ship fleet provides hydrographic survey, oceanographic and atmospheric research, and fisheries research vessels to support NOAA's research activities. NOAA also operates a fleet of fixed-wing and aircraft that collect the environmental and geographic data essential to NOAA hurricane and other weather and atmospheric research; provide aerial support for remote sensing projects; conduct aerial surveys for hydrologic research to help predict flooding potential from snow melt;, and provide support to NOAA's fishery and protected species research. To complement NOAA's research fleet, NOAA's ship and aircraft support needs are met through contracts for ship and aircraft time with other sources, such as the private sector and the university fleet.

Appendix C. Supporting Information

Table 1. Number of NOAA bench scientists by discipline[41] (source?)

Specialization	**Number of People**
Natural Resources Management and Biological Sciences	1296
Physical Sciences	1063
Mathematics and Statistics	128
Engineering and Architecture	80
Social Science, Psychology, and Welfare	67
Information Technology	16
Other	70

Table 2. Number of NOAA bench scientists by employment status[42]

Employment Status	**Number of People**
Federal employees	1724
University, non-profit employees	474
Contractors and consultants	379
Post-docs or fellows	85
Other	58

[41] Numbers of bench scientists were provided by the managers of each research unit, who judged which people within occupational groups were "expected or encouraged to publish" or otherwise integral to scientific and technical activities. The exception to this was NMFS, which based its estimates on job series and grade, and therefore probably overestimated the number of bench scientists compared with other line offices. Non-NOAA scientists who working off-site people are not included.

[42] See footnote above.

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