Research and Development at NOAA: Environmental Understanding to Ensure America's Vital and Sustainable Future

A Five Year Strategic Plan
2013-2017

DRAFT 2
For NOAA and Affiliate Review

Table of Contents

Section 0. Preface

Research and development (R&D) at NOAA is an investment in the scientific knowledge and technology that will allow the Nation to adapt and respond to change in a complex world. Key to meeting the challenges and embracing the opportunities of a dynamic future is not only the quality of the R&D, but its responsiveness to National needs. This means that NOAA R&D is intended to improve environmental data sets and numerical models, as well as how information is communicated to customers, how advances in science and technology are translated into new applications, and how well we know what value NOAA creates through its offerings of science, service, and stewardship.

Purpose of the Plan

This plan is designed to guide NOAA's research and development activities over the next five years. It is also intended to provide a common understanding -- between NOAA's leadership, its workforce, its partners, constituents, and Congress -- of how the agency's R&D creates value. As such, it is a framework with which NOAA, and the public at large, can monitor and evaluate the agency's progress in order to learn from experience.

This plan rests upon the strategic foundation laid by other documents. The first of these is NOAA's Next Generation Strategic Plan, which focuses all agency work (including R&D) around four long-term goals for Climate, Weather, Oceans, and Coasts. Second is the NOAA 20 Year Research Vision, which accounts for the social and environmental trends impacting upon NOAA and its mission, and supposes how particular innovations enable us to mitigate or adapt to these changes. Additionally, this plan has been informed by strategic implementation plans developed across the agency, and will inform annual revisions to these plans. Furthermore, this document has benefited immensely from the results of NOAA's recent science challenge workshops, as well as the input from NOAA scientists, engineers, and partners.[1] [2] [3]

Section 1 of this plan introduces R&D as a critical part of NOAA's mission, particularly in light of the agency's vision for the Nation: resilience in the face of change. Section 2 is the body of the document -- NOAA's R&D strategy, itself. NOAA's strategic goals and enterprise objectives frame a number of key questions that can only be answered through research or development. Underneath each question are specific objectives and discrete, five-year targets for R&D that lay the path forward for NOAA.

---

[1] http://www.nrc.noaa.gov/plans.html

[2] *Toward Understanding and Predicting Regional Climate Variations and Change, Findings from the NOAA Science Challenge Workshop, September 20-22, 2011, Final Report dated February 24, 201.2*

[3] *Understanding the Water Cycle, Findings from the NOAA Science Challenge Workshop August 28 – September 1, 2011, Final Report Dated September 28, 2012.*

The R&D objectives and targets in this plan provide the link to NOAA's corporate process for Strategy Execution and Evaluation and, as such, represent the desired outcomes underlying regular decisions in agency-wide planning and budgeting. They make plain ***what the agency will strive to do*** -- in coordination with our partners in the academy, in industry, in the non-profit sector, and in government institutions at the federal, international, state, tribal, and municipal levels. Some key questions in this plan will be difficult to answer. Some objectives are less certain than others. Some targets may not be met. Still, we must act knowing that success will only be partial; this is the nature of R&D. The prospect of failure does not deter the agency from setting bold targets, nor from codifying such ambitions in public documents such as this. NOAA and its stakeholders understand that R&D is an inherently risky endeavor, and there is as much to learn from the results we do not expect as from those we do. Learning from either, however, requires that we make our aims clear before attempting to make them real. That is strategy.

The remaining sections of the plan describe how NOAA will execute the strategy outlined in Section 2. Section 3 describes the assets -- people, places, and things -- that NOAA will bring to bear on the research and development needs of NOAA and the Nation. Section 4 describes the values of a healthy R&D enterprise and the unique capabilities needed to manage it effectively. The appendices offer additional details on the legislation driving NOAA R&D, the organizational units that fund and conduct it, and other supporting information.

Scope of the Plan

The scope of this plan includes those activities through which NOAA improves the conduct of its mission, i.e., through which NOAA innovates. Research is the "systematic study directed toward a more complete scientific knowledge or understanding of the subject studied." Development is the "systematic use of the knowledge or understanding gained from research, directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes."[4]

NOAA adopted these definitions from the National Science Foundation to conform to government-wide practices, but discourages the distinction between basic and applied research, which derives from the oversimplified, linear model of innovation of the post-war era. Instead, NOAA encourages use of Stokes's more contemporary model of innovation, in which research can be directed toward fundamental understanding without concern for ultimate use, toward ultimate use without concern for

[4] NSF, 2009

fundamental understanding, or toward both fundamental understanding and ultimate use (so called "use-inspired" research).[5]

The plan is scoped by "research and development," and not "science" per se. As such, It does not deal with scientific activities that are part of regular NOAA operations (e.g., producing weather forecasts, collecting tide measurements). R&D excludes routine product testing, quality control, mapping and surveys, collection of general-purpose statistics, experimental production, and the training of scientific personnel. However, this plan does account for infrastructure and regular activities in direct and primary support of R&D. It also includes the transfer of knowledge and technology to intended and unexpected applications.

NOAA's extended "R&D enterprise" includes, but is not limited to internal laboratories, science centers, Cooperative Institutes, grant recipients, Sea Grant Programs, and contractors. The R&D planned for in this document may include the research, development, and demonstration activities, and associated infrastructure of Federal agencies (intramural) or of private individuals and organizations under grant, contract, or cooperative agreement (extramural).

---

[5] Stokes, D. (1997). Pasteur's quadrant : Basic science and technological innovation. In Washington D.C.: Brookings Institution Press.

Executive Summary

NOAA R&D is inspired by both immediate and long-term applications. It is focused on the agency's strategic goals and, as such, reflects many contemorary scientific and technological challenges. R&D at NOAA is supported by a network of individuals, institutions, and infrastructure that include but are not limited to those of the agency itself. Finally, it is executed responsibly - resting on a core set of values and rigorous system of strategic management.

Why R&D? NOAA is a mission agency, and NOAA R&D is an integral part of the agency's mission of science, service, and stewardship.[6] 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 ecological forecasts that support national safety and commerce. R&D at the agency is driven toward a vision of *understanding global ecosystems to support informed decision-making*. Innovation at NOAA means improved understanding of the Earth system from global to local scales, improved ability to forecast weather, climate, and water resources, increased understanding of ecosystem health, and how all of these factors affect people and communities. What makes NOAA so unique is the utility of the agency's science and technology, with respect to the Nation's economic, legal, security, and cultural concerns. At NOAA, R&D is "use-inspired" - it is does not only increase our understanding of the world, it also produces applications that are useful and used.[7]

R&D Strategy. NOAA R&D is directed toward the agency's outcome-oriented goals for Climate, Weather, Oceans, and Coasts, as well as its capability-oriented "enterprise" objectives. As such, NOAA's corporate goals and objectives frame the body of this document. The requirements for new knowledge and technology are defined by a series of questions that respond to each goal or objective, as illustrated in the outline of NOAA's R&D strategy presented below. The reader will immediately notice the breadth of social and environmental outcomes NOAA strives to achieve, as well as the disciplinary breadth needed to address the questions that follow. In the body of the plan, particular R&D objectives and targets detail discrete, scientifically-specific steps toward answering each question.

> NOAA's Goal for **Climate Adaptation and Mitigation** is *an informed society anticipating and responding to climate and its impacts.* To achieve this goal, research and development will be directed toward answering the following questions: What is the state of the climate system and how is it evolving? What causes climate variability and change on global to regional scales? What improvements in global and regional climate predictions are possible? How can NOAA best inform and support the Nation's efforts to adapt to the impacts of climate variability and change?

---

[6] NOAA's Mission: To understand and predict changes in climate, weather, oceans, and coasts; to share that knowledge and information with others; and to conserve and manage coastal and marine ecosystems and resources.

[7] Stokes, D. (1997). *Pasteur's quadrant : Basic science and technological innovation.* Washington D.C.: Brookings Institution Press.

NOAA's Goal for **A Weather-Ready Nation** is that *society is prepared for and responds to weather related events.* To achieve this goal, research and development will be directed toward answering the following questions: How can we improve forecasts, warnings, and decision support for high-impact weather events? How does climate affect seasonal weather and extreme weather events? How can we improve space weather warnings? How can we improve forecasts for freshwater resource management?

NOAA's Goal for **Healthy Oceans** is that *marine fisheries, habitat, and biodiversity are sustained within healthy and productive ecosystems.* To achieve this goal, research and development will be directed toward answering the following questions: How do environmental changes affect marine ecosystems? What exists in the unexplored areas of our oceans? How can emerging technologies improve ecosystem-based management? How can we ensure aquaculture is sustainable? How is the chemistry of our ocean changing and what are the effects?

NOAA's Goal for **Resilient Coastal Communities and Economies** is that *coastal and Great Lakes communities are environmentally and economically sustainable.* To achieve this goal, research and development will be directed toward answering the following questions: What is the value of coastal ecosystems? How do coastal species respond to habitat loss, degradation and change? How do we ensure that growing maritime commerce stays safe and sustainable? How do we reduce the economic and ecological impacts of degraded water quality? How is the Arctic affected by expanding industry and commerce?

NOAA's Enterprise Objective for **Stakeholder Engagement** is *an engaged and educated public with an improved capacity to make scientifically informed environmental decisions.* To achieve this objective, research and development will be directed toward answering the following questions: How can we improve the way scientific information and its uncertainty are communicated? How can we improve the capacity of the public to respond effectively to changing environmental conditions?

NOAA's Enterprise Objective for **Environmental Data** is *accurate and reliable data from sustained and integrated Earth observing systems.* To achieve this objective, research and development will be directed toward answering the following questions: What is the best observing system to meet NOAA's mission? How can we best use current and emerging environmental data? How can we improve the way we manage data?

NOAA's Enterprise Objective for **Environmental Modeling** is *an integrated environmental modeling system.* To achieve this objective, research and development will be directed toward answering the following questions: How can modeling be best integrated and improved with respect to skill, efficiency, and adaptability? What is the uncertainty in NOAA's data, analyses, and predictions?

NOAA's Enterprise Objective for **Information Technology** is *a modern IT infrastructure for a scientific enterprise.* To achieve this objective, research and development will be directed toward answering the following question: What technological developments can help NOAA improve its science enterprise?

NOAA's strategic goals, and the key questions guiding R&D toward these goals, are the foci for integrating the work "on the ground" at the many organizations, from NOAA line offices (and their respective programs, laboratories, and science centers) to cooperative institutes, grantees, contractors and other partners. Within this framework of strategic goals and questions, the R&D objectives and targets are actively managed within the agency's corporate system for Strategy Execution and Evaluation (SEE) through regular planning, budgeting, monitoring, and evaluation activities.

Themes of Innovation. A few recurring themes that reflect this particular moment in the history of NOAA, and the agency's present potential for innovation. There are at least five challenges common to R&D activities performed in the interest of all of NOAA's goals. The first of these challenges is the research and development required to optimize the agency's core services: creating better ways to do what NOAA is best known for. Four other challenges define areas in which NOAA can create value for the Nation in qualitatively new ways, and in response to emerging challenges. These include handling big data, modeling and predicting ecosystem behavior, uniting the natural and social sciences, and, perhaps most challenging, preparing for the unpredictable.

Optimizing Core Services. Much of NOAA R&D is intended to improve its core mission responsibilities of predicting weather and climate and managing coastal and marine resources. NOAA will advance predictive services for weather and climate extremes. It will develop integrated real-time analyses of weather conditions, numerical-model-based information at regional & local scales for decision makers, and extend weather predictions from weeks to seasons to a year. The agency will develop Earth System Models for seasonal to centennial climate predictions and projections at regional to global scales, and it will improve understanding of atmospheric composition to provide policy relevant information. NOAA will optimize coastal mapping and charting technology, as well as develop new technologies to collect multi-disciplinary data to support living marine resource assessments.

Handling Big Data. Like so many other data-driven organizations today, NOAA must meet the challenge of managing large and complex data sets. It also has the opportunity to create innovative searching, sharing, analysis, and visualization capabilities. Making massive amounts of integrated environmental data available, and useful to the public could yield unprecedented benefits. NOAA aims to develop regional information and services to address particular societal impacts of climate change and variability. It will create advanced methods to quickly transform data streams into scientific advice for evaluating and adjusting coastal and marine resource management measures. The agency will integrate weather data and delivery systems, and enhancing decision support services through improved communications of weather risks.

Modeling Complex Systems. In many cases, what limits our ability to sustainably manage natural resources or response to natural hazards is the complex and dynamic interconnectedness of large-scale ecological systems. Ecosystems, given their individual components and processes are difficult to understand and even more difficult to simulate, but the potential value of making ecosystem predictions is enormous. NOAA will conduct research on ecosystem structure, productivity, behavior, resilience, and population connectivity, as well as effects of climate variability and anthropogenic pressures on managed resources. The agency will develop numerical ecosystem models within an Earth-system modeling framework to provide reliable forecasts for decision makers. It will expand research focusing on integrating climate change and ocean acidification impacts on ecosystems.

Uniting Natural and Social Sciences. NOAA's expertise has traditionally been in the natural sciences of the ocean and the atmosphere, but more and more, mission success depends on a holistic understanding of natural phenomena that are intertwined with human behavior and institutions. To this end, NOAA will expand integration of social science into NOAA's science, services, and stewardship. It will study the economic and behavioral elements of coastal resilience. It will work to integrate knowledge of multiple stressor risks into customer decision-making, the agency will incorporate socio-economic research models into ecosystems-based management practices, to provide resource managers information on impacts, trade-offs, and distributional effects of management actions.

Preparing For the Unpredictable. Much of the research that NOAA conducts is unexpected, and in response to immediate needs for public safety and security. NOAA's unique research and development capabilities were deployed in the disasters in the Gulf of Mexico, in Fukushima, and along the East Coast during Superstorm Sandy. Events such as these are what Nassim Nicolas Taleb has called "black swans" - high-impact events that only seem predictable in retrospect. We cannot know for sure when disaster or, for that matter, opportunity may strike. But we do know that maintaining - and expanding - the diversity of NOAA's expertise and experience makes the Nation and the world more resilient to the high-impact events that have yet to occur.

People, Places and Things. 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. 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. 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.

In addition to these “soft” assets (i.e., people, institutions, and partnerships) successful implementation of this plan involves “hard” assets (i.e., data, models, computing, and test-beds). 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.

A Healthy R&D Enterprise. A strong R&D enterprise means that the agency funds and 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. 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. To achieve this, NOAA’s R&D enterprise rests on the following fundamental principles.

Integrity. For science to be useful, it must be credible. NOAA’s research must be conducted with the utmost integrity and transparency. The recently established NOAA Administrative Order on Scientific Integrity establishes a code of conduct for scientists and science managers that allows us to operate as trusted source for environmental science.

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 of the components fit together, interrelate and interact. 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.

Innovation. Innovation is the implementation of a new or significantly improved product, process, business practice, workplace organization, or external relations. 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.

Balance. NOAA is committed to the immediate needs to the Nation and the emerging challenges for the future. As such, it must balance its portfolio of activities for long-term outcomes with short-term outcomes, as well as among its strategic goals and enterprise objectives. NOAA also strives for balance between innovations that are “pulled” by stakeholders versus those that are “pushed” by researchers, those that are low-risk versus high risk, and those that will yield incremental versus radical change.

Collaboration. 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. 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.

A healthy R&D Enterprise 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. Greater detail on this can be found in NOAA's Administrative Order on Strengthening the R&D Enterprise.

A well-functioning innovation system 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.

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. Yet this connection is not without its challenges. High impact weather events, availability of freshwater, urbanization of the coasts, use of ocean and coastal resources, and climate change are among the central challenges NOAA addresses in the interest of public welfare. These are the challenges that we can foresee, but there are many that we cannot, especially in a rapidly changing world.

Sudden events often challenge us and how we co-exist with the environment that supports and defines us. Superstorm Sandy demonstrated the significant vulnerability of the nation's coastal areas to coastal storms and inundation especially with rising sea levels, but also our increased ability to forecast extreme weather events, and then prepare to the best of our ability. 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. They also underscored the need to further improve our capability to understand and predict the earth system and to build resilience. NOAA R&D will continue to be central to creating solutions to the known and unknown challenges before us.

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 ecological 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.[8]

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, either actively or passively, a total of 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[9]

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

[9] 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.

- There are increasing demands on the nation's ocean and coastal resources that provide important products and services. Seafood, tourism, recreation, protection from coastal storms are the source of billions of dollars in economic activity and millions of jobs. For example, in 2009, the U.S. seafood and recreational fishing industry alone supported approximately 1.3 million jobs and generated $166 billion in sales impacts and $32 billion in income impacts (NMFS 2010)[10]
- 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)[11]

"It is through research that society gains the understanding to make informed decisions in this increasingly complex world."[12]

Over the next five years, NOAA research and development activities, conducted by NOAA and our partners, will address those societal challenges and trends that are of increasing importance to decision makers. National and global population growth and migration towards coastal regions, impacts and responses to 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.[13]

II. 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.[14]

---

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

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

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

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

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

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.

III. "Use-Inspired Research"

Innovation at NOAA will create an improved understanding of the Earth system from global to local scales, improve our ability to forecast weather, climate, and water resources, increase our understanding of ecosystem health, and how these factors affect people and communities. It is the utility of the agency's science and technology in light of National concerns that makes NOAA so unique. At NOAA, R&D is "use-inspired," that is, it is intended to simultaneously improve our fundamental understanding of the world and produce particular applications that are useful and used.[15]

A use-inspired philosophy acknowledges the complex ways that value is created in the innovation process. Research results are a valuable input for technology development and ultimate applications, but also that new technologies and applications are valuable inputs for research. Moreover, use-inspired research improves how NOAA conducts its mission, across timescales and spatial domains. While the results of research can result in immediate action, such as improvements to fisheries stock assessment techniques, it can also yield benefits over the longer-term, such as the investigations that showed that CFCs were reaching the stratosphere and that characterized the "structure" of the ozone hole, which ultimately led to mitigation measures. Similarly, exploration of ocean environments underlies future habitat protection, species exploitation, and improved understanding of this yet-largely unknown domain.

IV. 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."[16]

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
- 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

---

[15] Stokes, D. (1997). *Pasteur's quadrant : Basic science and technological innovation.* Washington D.C.: Brookings Institution Press.

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

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.[17]

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 require the focused investment of NOAA's research and development enterprise. Addressing the needs of the individual 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.

V. From Knowledge 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

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

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 understanding and responding to the needs of our stakeholders; 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.

A. 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 is 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; investments in research, monitoring, and modeling now allow us to 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 radiation dispersion around the world. 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, how it impacts people and communities, and the uncertain future that comes with its evolution.

B. Supporting Economic Success

NOAA science and technology impact the daily lives of the nation's citizens, and also impact the national economy. For example, accurate and longer range weather forecasts depend on an ongoing program of research and development. In 2005, one study found that 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. [18]

Incremental benefits are relevant in assessing the merits of investments that will improve forecast accuracy. The same study found that 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

[18] 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).

improvement). It is estimated that a perfect forecast would add $75 million to these savings (all values in 2002 dollars).[19]

Our Nation's ports are critical to a strong national economy, over $1.9 trillion in imports came through U.S. ports in 2010, and U.S. commercial ports directly supported over 13 million jobs. The National Ocean Service's Center for Operational Oceanographic Products and Services has installed Physical Oceanographic Real-Time Systems (PORTS®) at 20 locations around the United States consisting of real-time water levels, currents, and meteorological sensors. Economic benefit studies conducted at four locations (Tampa, Houston/Galveston, New York/New Jersey, and the Lower Columbia River) estimate a combined benefit of $50 million per year by reducing ship groundings by up to 50% and improving the efficiency of commerce from observations provided by PORTS®.[20] [21] [22] [23] The economic benefits of PORTS® result from increased cargo carried per transit, reduced delays, reduced risks of groundings and collisions, and improved environmental planning and analysis.

To ensure that United States benefits from and fully exploits its scientific research and technology, NOAA seeks to protect certain intellectual property through the patent process. NOAA can then transfer its intellectual property through patent licenses and Cooperative Research and Development Agreements (CRADAs). Over the next 5 years, NOAA's Technology Partnerships Office will increase the overall number of CRADAs, patents, and licenses, as well as speed the execution of these agreements. These efforts will allow U.S. companies to make strategic use of public investments in research and development, with the goal of providing them an overall competitive advantage.

Tech Transfer Success Story:
Over the last 20 years, the Physical Science Division of the Earth System Research Lab (ESRL) in Boulder, CO, has teamed with three industrial partners in Cooperative Research and Development Agreements, or CRADAs, to design, develop, and commercialize a wind profiler technology in the United States. The wind profilers measure air turbulence through phased-array radar systems and are very useful in determining the best locations for land-based wind turbines, improved weather forecasting, and air quality forecasts.

[19] 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).

[20] Source: Kite-Powell, Hauke. 2005. Estimating Economic Benefits from NOAA PORTS® Information: A Case Study of Tampa Bay, Tampa Bay Harbor Safety & Security Committee

[21] Source: Kite-Powell, Hauke. 2007. Estimating Economic Benefits from NOAA PORTS® Information: A Case Study of Houston/Galveston. The Port of Houston Authority.

[22] Source: Kite-Powell, Hauke. 2009. Estimating Economic Benefits from NOAA PORTS® Information: A Case Study of the Port of New York/New Jersey. Report prepared for the Center for Operational Oceanographic Products and Services (COOPS), NOS, NOAA.

[23] Source: Kite-Powell, Hauke. 2010. Estimating Economic Benefits from NOAA PORTS® Information: A Case Study of Lower Columbia River, Houston/Galveston and Tampa Bay. Port of Portland.

Throughout the developmental lifetime of this suite of profilers, NOAA technical staff provided critical expertise for the electronic signal processing in data acquisition and interpretation. Industry partners provided real-time customer requirements to NOAA engineers such that design improvements could be incorporated seamlessly in the manufacturing process. The creation of both an engineering and management oversight boards played an important role by allocating new resources at important project moments as technical and market conditions changed.

This successful collaboration and technology transfer from the federal lab to industry has resulted in over $2 million in royalties, as well as an estimated $25 million in global sales of the product.

NOAA also reserves a specific percentage of federal R&D funds for small business, through the Small Business Innovation Research, or SBIR, program. The SBIR provides valuable funds and support for innovative small businesses and enables them to compete on the same level as larger businesses. SBIR funds the critical startup and development stages and it encourages the commercialization of the technology, product, or service, which, in turn, stimulates the U.S. economy.

SBIR Success Story:

Desert Star Systems LLC has been successfully working with the SBIR program since 1995. From 1995 the additional sales revenue generated through Phase 3 commercialization projects has resulted in approximately $6.2 million, or just above half of Desert Star's average sales revenue.

Desert Star recently developed the first stored solar power line of electronic animal tags, used to capture simultaneous migration and oceanographic data, called Sea Tag. SeaTag expands on current tagging technologies by offering a different array of sensors and capabilities. All SeaTag devices are powered through the use of stored solar power with the exception of -CAM and -RC which also use batteries. The tag is equipped with a solar cell and a capacitor which powers the tag for approximately two weeks of total darkness on tens of minutes of sunlight.[24]

According to company representatives, this new product line is expected to double or triple annual revenues within the next 2-4 years.

C. Quantifying and Communicating Uncertainty

The National Research Council (NRC) defines uncertainty[25] as " the condition whereby the state of a system cannot be known unambiguously. Probability is one way of expressing uncertainty." Describing uncertainty in the context of environmental science and prediction, the NRC states that, "The chaotic

[24] http://www.desertstar.com/Products_category.aspx?intProductCategoryID=22

[25] 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.

character of the atmosphere, coupled with inevitable inadequacies in observations and computer models, results in forecasts that always contain uncertainties. These uncertainties generally increase with forecast lead time and vary with weather situation and location. *Uncertainty is thus a fundamental characteristic of weather, seasonal climate, and hydrological prediction, and no forecast is complete without a description of its uncertainty.*"

The NRC discusses the value of communicating uncertainty information, noting that "the inclusion of uncertainty in forecasts has socioeconomic, scientific, and ethical value, and can help ensure user confidence." Particularly relevant to NOAA, the NRC notes that "users – each with their own sensitivity to costs and losses and with varying thresholds for taking preventive action – can better decide for themselves whether to act and the appropriate level of response." The NRC highlights the requirement to improve education about uncertainty and enhance the communication and use of uncertainty information. One of the NRC's formal recommendations to NOAA advises that NOAA's task is to help users, especially members of the public, understand the value of uncertainty information and work with users to help them effectively incorporate this information into their decisions."

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. Consequently, NOAA requires research, development, and implementation of methods and capabilities for quantifying and communicating uncertainty. Research is required to understand, for situations and applications, the amount of uncertainty; contributing factors; how to minimize the uncertainty; and how best to communicate that uncertainty. The reason that understanding uncertainty is so important stems from how significant impacts are, based on the difference in magnitude between what does/can occur versus what is expected/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."[26] Public understanding of the uncertainty for NOAA's products and services will help the public and decision-makers make optimal choices.

D. Integrating the Human Dimension

Sustainable provision of the full suite of coastal and marine ecosystems is widely recognized one of the most important environmental challenges of the 21st century. Given that the principal threat to these ecosystems is derived from anthropogenic sources, it is essential that any strategies for preserving or recovering a coastal or marine ecosystem directly consider human use patterns and values. Incorporating economics, social and, behavioral sciences into emerging integrated ecosystem models and assessments will provide policy makers with an understanding of both the value ecosystem services as well as the trade-offs associated with alternative management scenarios.

[26] 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.

Incorporating the 'human dimension' into NOAA's research mission also allows for improved design and delivery of NOAA's products and services, by increasing our understanding of what information is relevant, and 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, particularly extreme weather events like hurricanes or heat waves. policies. For example, 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.

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 with NOAA's natural sciences to fully understand the services ecosystems provide and how people value them, 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.

E. Using 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 transitioning the knowledge and tools resulting from NOAA's R&D into applications useful to society. Transition 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.

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 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.

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

I. 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, NOAA looked to the future with a 20 year vision for research, developed in 2005. This vision, "Understanding global ecosystems to support informed decision-making,"[27] 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 humans over different scales."[28] 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[29]

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
- 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

---

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

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

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

- Communicate scientific information and its associated uncertainties accurately and effectively to policy makers, the media, and the public at large.

II. Evolution of NOAA R&D

NOAA's R&D enterprise continues to evolve with the needs of NOAA and the Nation. Given the long-time frame of many of the issues with which NOAA deals, much of the research and development is consistent over the years. However, critical events and emergent phenomena serve to further refine NOAA's investment in R&D. The following is high-level account of how NOAA's R&D portfolio has evolved since the last version of this plan, published in 2008.

Climate change and impacts from greenhouse gas emissions

NOAA R&D has been at the forefront in defining the extent and ramifications of global climate change and increased greenhouse gasses. The need for increased understanding of these phenomena has been emphasized throughout the years. Since the last 5 Year R&D plan, we have continued to see the effects of increased greenhouse gases and global climate change, including sea level changes affecting our coastal communities; increased ocean temperatures threatening our coral reefs; and increasing ocean acidity challenging our coastal, marine, and Great Lakes ecosystems.

Of particular note are the recently documented changes in the Arctic. Large changes in multiple indicators are affecting climate and ecosystems, and these changes in combination provide strong evidence of the momentum that has developed in the Arctic environmental system due to the impacts of a persistent warming trend that began over 30 years ago. It is very likely that major changes will continue to occur in the Arctic in years to come, particularly in the face of projections that indicate continued global warming. Additionally, changes in the Arctic marine environment are affecting the foundation of the food web in both the terrestrial and marine ecosystems. While more difficult to discern, there are also observations that confirm the inevitable impacts these changes have on a wide range of higher-trophic Arctic and migratory species. Motivated by these linkages and the record-setting environmental changes in the Arctic region, a number of new programs are underway to more effectively measure, monitor and document changes in the marine and terrestrial ecosystems.[30]

Extreme weather and water events

The Nation has experienced a wave of severe weather events that demand continued improvements in NOAA's ability to forecast those events, effectively deliver those forecasts, and respond effectively to the impacts of those events. 2011 was an unusually active and deadly year for tornadoes across the U.S., with a total of 1,691 tornadoes reported across the country, more than any other year on record except for 2004, which saw 1,817 tornadoes. These include the EF-5 tornado, which hit the city of Joplin, Mo.

[30] http://www.arctic.noaa.gov/reportcard/exec_summary.html

on May 22, 2011, leaving an estimated 157 people dead. The Joplin tornado is the deadliest single tornado since modern record-keeping began in 1950 and is ranked as the 7th deadliest in U.S. history.[31]

Hurricane Irene and Superstorm Sandy are some of the most recent examples of devastating storms that have challenged the Nation. These storms highlighted NOAA's unique ability to generate forecasts critical for decision-makers, but also demonstrated areas where improvements can be made in the observations, models, forecasts and delivery of information. These storms, particularly Superstorm Sandy, demonstrated the significant vulnerability of the nation's coastal areas to coastal storms and inundation especially with rising sea levels. In addition to severe weather, water resources present a challenge for the Nation. According to the U.S. Drought Monitor (USDM), as of early December 2012, more than 60% of the country (geographic area) experienced drought conditions (moderate to exceptional).[32] A partnership of federal agencies, led by NOAA, has begun implementation of the National Integrated Drought Information System (NIDIS) to address this need as it relates to drought, and the demand for increased understanding and prediction will likely only increase.

Integrated ecosystem focus

Since the last NOAA Five Year R&D Plan, the Nation has developed a National Ocean Policy, which "establishes a comprehensive national approach to uphold our stewardship responsibilities; ensures accountability for our actions; and serves as a model of balanced, productive, efficient, sustainable, and informed ocean, coastal, and Great Lakes use, management, and conservation within the global community."[33] Implementing the National Ocean Policy includes advancing our state of understanding of marine ecosystems. As noted in the National Ocean Policy Implementation Plan, current understanding of marine ecosystems has not kept pace with the cumulative impacts of human uses and the environmental changes that are occurring. To implement ecosystem-based management successfully (an integrated approach to resource management that considers the entire ecosystem, including humans), decisions must be informed by the best available ecological, social, and economic science and data.[34] This requires integrating different disciplines, including natural and social sciences, to develop a more holistic understanding of our coastal, marine and Great Lake ecosystems, and inform ecological forecasts, similar to those provided for weather and climate, that can guide decisions in the future.

Responsiveness to sudden events

While research and development often takes years to come to fruition, recent events have demonstrated the need, and the ability, for NOAA science to be responsive on more immediate time frames. In 2010, the Deepwater Horizon oil rig exploded in the Gulf of Mexico, killing 11 people and beginning the largest marine oil spill in US history. This "omnidirectional, almost indeterminate threat"

---

[31] http://www.noaanews.noaa.gov/2011_tornado_information.html

[32] http://droughtmonitor.unl.edu/archive.html

[33] http://www.whitehouse.gov/files/documents/OPTF_FinalRecs.pdf

[34] http://www.whitehouse.gov/sites/default/files/microsites/ceq/national_ocean_policy_draft_implementation_plan_01-12-12.pdf

challenged the resources and capabilities of the federal, state, and local authorities responding to this threat.[35]

In March 2011, an earthquake caused a tsunami that devastated the northern coast of Japan. In addition to the loss of life and property, the tsunami triggered a series of failures at the Fukushima Daiichi Nuclear Power Plant, resulting in the release of radioactive materials. These events reinforced the need for a nimbleness and responsiveness beyond those of NOAA's emergency responders, but also the scientific community to adapt to ever-changing situations, such as incorporating ocean circulation models to track marine debris or oil patterns, and provide critical information needed to inform immediate decisions.

III. NOAA's R&D Strategy - Goals, Questions, Objectives, and Targets

Focusing attention on outcomes rather than activities - ends rather than means - is the basis for making rational investment choices, aligning requirements, and clarifying roles and responsibilities. Goals and Enterprise Objectives are NOAA's highest-level outcomes, as specified in the agency's Next Generation Strategic Plan, the former are outcomes for society and environment and the latter are outcomes for NOAA itself, in the conduct of its mission. On the path to achieving these Goals and Enterprise Objectives, there are gaps in our knowledge and capability. The key questions in this section highlight these gaps, thus framing our strategic needs for R&D. R&D objectives under each question represent major steps that NOAA and its partners must take in meeting those needs. Targets under each R&D objective are the basis for monitoring progress, evaluating approaches, and learning from experience. Not all of NOAA's R&D targets are provided in this plan; the targets described here are those that merit particular attention or are representative of a broader suite of activities.

LEGEND

Goal: Goals (sections A-D below) and Enterprise Objectives (sections E-H below) 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

[35] www.pnas.org/cgi/doi/10.1073/pnas.1204729109

verifying progress toward the objective, to demonstrate value and learn from success or failure.

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

Projected future climate-related changes include increased global air and ocean temperatures, melting sea ice and glaciers, rising sea levels, changes in precipitation, acidification of the oceans, and changes in storm frequency and intensity. These in turn have many impacts such as earlier snowmelt, increased drought, altered river flow volumes, changes in growing seasons, declining air quality, and alterations in species' abundance, distributions, and migration patterns. Many of these impacts have already been observed, and significant additional impacts from these changes are expected to affect nearly every sector of society, including water, energy, transportation, insurance, banking, forestry, tourism, fisheries, agriculture, infrastructure, and human health. A changing climate will alter the distribution and availability of water and other natural resources that the nation depends on. Changes in climate are also expected to exacerbate non-climatic human impacts on fisheries and marine ecosystems, such as overfishing, habitat destruction, pollution, changes in species distributions, and excess nutrients in coastal waters. Increased sea levels lead to amplified storm surge, putting low-lying areas at risk. The direct impact of climate change on commerce, transportation, society and the economy is evidenced by retreating sea ice in the Arctic, which has made coastal communities, including tribes, highly vulnerable to winter storms and inundation, forcing many to begin planning to move inland.

Key Question: *What is the state of the climate system and how is it evolving?* To fully understand how the climate is changing, we must first have the observations that can clearly show us the current state of the full climate system; that is, monitoring our planet's atmosphere, oceans, ice sheets, land surfaces, and so forth through time. Therefore, 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 improving 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 climate extremes. 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 remotely-sensed observations of primary variables describing the ocean, atmosphere, and other components of the climate system. Up-to-date and accurate knowledge of the state of the climate is critical to sustaining the Nation's economy (e.g., transportation, agriculture, fisheries), communities (e.g., health, land use) and ecosystem services (e.g., storm protection, tourism, habitat) in a changing world. NOAA must sustain and build out its longstanding observations, data management, and monitoring of the oceans and atmosphere to enhance the fundamental scientific understanding and knowledge of our climate to help people 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:

- Completed research on technological solutions for climate observations and the data they produce to improve the lifecycle, timeliness, and accuracy of these observations (Research)
- Assessed the climate data that was collected for quality, uncertainty, and the implications for impacts and made that climate data and subsequent products available to users (Transition)
- Developed and tested improved climate observing systems in the deep ocean and Alaska (Development)

Objective for R&D: ***Atmospheric and oceanic observations integrated into Earth System modeling.*** Atmospheric climate models and even coupled atmosphere-ocean models are giving way to Earth System Models (ESMs) that advance our understanding of how the Earth's biogeochemical cycles, including human actions, interact with the climate system. As the models become more complex, the data needed to evaluate and validate the models also becomes more complex and wide ranging. For example, the atmospheric component of the ESMs includes physical features such as aerosols (both natural and anthropogenic), cloud physics, and precipitation. The land component includes precipitation and evaporation, streams, lakes, rivers, and runoff as well as a terrestrial ecology component to simulate dynamic reservoirs of carbon and other tracers. The oceanic component includes features such as free surface to capture wave processes; water fluxes, or flow; currents; sea ice dynamics; iceberg transport of freshwater; and a state-of-the-art representation of ocean mixing as well as marine biogeochemistry and ecology.

Over the next 5 years, NOAA aims to have:

- Model-observation syntheses for reporting on the state of the climate system (Research)
- Integrated short- and long-time scale observations into modeling processes for characterizing the seasonal to multi-decadal scale variation of the climate system and assessing its predictability (Development)

Key Question: ***What causes climate variability and change on global to regional scales?***
Improved understanding of the causes of climate variability and change is vital to achieving NOAA's mission. Such understanding provides a rigorous scientific basis for explaining observed climate trends and variations, as well as a foundation for improving models used in climate predictions and climate change projections.

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

As knowledge of the climate system deepens, an increasing array of processes and their interactions are being recognized and considered as important in understanding the causes of climate variations and change. Major factors include changes in atmospheric composition, the role of the ocean and atmosphere-ocean interactions, atmosphere-land surface interactions including hydrological processes, the role of the cryosphere and interactions with ecosystems and organisms. The processes extend across space and time scales, as do decision-maker needs, from information needed for preparing for extreme events on time scales of a season or less to adaptation and mitigation policy decisions on time scales out to decades. Developing a more comprehensive understanding of climate processes and mechanisms, and their relative importance in explaining observed climate variations and change, will be essential to increasing confidence and credibility in climate predictions and projections. Such knowledge will also provide an improved scientific basis for characterizing associated uncertainties in predictions and climate change projections. The objectives outlined below constitute significant, achievable steps over the next five years necessary to better understand and explain causes of climate variability and change on global to regional scales.

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 (Research)
- Assessed climate-induced changes in tropical and extratropical cyclones and their associated storm surges, as well as droughts and heat waves (Research)
- Assessed the potential for rapid changes in land-based ice sheets and their impact on global and regional sea level (Research)
- Performed model simulations of ocean, atmosphere, and land-surface processes to support climate-scale hydrologic forecasting capabilities (Development)
- Assessed the climate influences of ocean basins for interannual and decadal predictability (Research)

- Assessed the weather and climate features of the tropical oceans to achieve higher confidence in seasonal global and regional predictions (e.g., Madden-Julian Oscillation) (Research)
- Assessed the mechanisms that control climate sensitivity to water vapor and clouds (Research)

Objective for R&D: ***Identify the causes of climate trends and their regional implications***
Because many of the effects of a variable and changing climate will be felt most strongly at regional-to-local scales, it is imperative that understanding and predictions of regional climate variations and trends be improved and placed on a firm scientific foundation. Regional climate trends and extreme events that are unanticipated leave decision-makers and the public poorly prepared for planning and adaptation. A particularly important requirement is to understand the causes of weather and climate extremes, and whether they are changing. Extreme events often have regionally varying manifestations, and corresponding regional differences in decision-maker needs. For example, hurricanes and storm surges are a key concern on the U.S. Gulf and East coasts, while in much of the Midwest droughts and severe convective storms are of especially high interest. Whether recently observed extremes reflect variability that is likely to return to previous conditions or rather are the harbinger of a new long-term climate trend is a question of compelling public interest. Research under this objective will contribute directly to meeting NOAA's science mission "To understand and predict changes in climate, weather, oceans and coasts." Addressing the complex science challenges that occur at regional scales will require multi-disciplinary expertise, necessitating collaborations across NOAA and with external partners.

Over the next 5 years, NOAA aims to have:

- Identified causes for the observed regional and seasonal differences in U.S. temperature and precipitation trends and the relationships between trends in climate means and climate variability, especially extreme events, for predictions and projections (Research)
- Clarified the contribution of climate-scale physical processes to extreme events and their variability and frequency (Research)
- Assessed the connections of Arctic climate variability and change with that of other regions, including the effects of declining sea ice on extratropical climate (Research)
- Provided enhanced access to the current state-of-knowledge on the causes of regional climate trends and extreme events provided to the public and decision-makers for planning, adaptation, and other applications (Research)
- Conducted assessments of climate impacts on regional communities and economic sectors (Research)

Objective for R&D: *Improve understanding of the changing atmospheric composition of long-lived greenhouse gases and short-lived climate pollutants.*
NOAA will improve understanding of changes in atmospheric composition to assess the climate forcings, sensitivities, and feedbacks of both long-lived greenhouse gases (e.g., CO_2, N_2O, CFCs) and short-lived climate pollutants (e.g., aerosols and tropospheric ozone) and the associated uncertainties. Improved measurements and analyses of the trends and distributions, sources, transport, chemical transformation, and fate of these climate-forcing agents will lead to more skilled models, which will yield better predictions and projections of future climate and its impacts at local, regional, and global scales. Moreover, due to their multiple roles in the atmosphere, an improved understanding of these climate-forcing agents and the processes that influence their distributions will yield additional benefits for reduced air quality degradation and stratospheric ozone layer recovery.

Over the next 5 years, NOAA aims to have:

- Quantified emissions of methane, nitrous oxide and black carbon, and assessed the effects of black carbon and organic aerosols on clouds (Research)
- Uncertainty on North American CO_2 flux estimates reduced by 1% (Research)
- Evaluated the effects on climate and on the stratospheric ozone layer of four replacement compounds for refrigerants, solvents, and blowing agents (Research)
- Assessed the impact of stratospheric ozone incursions on the tropospheric ozone burden (i.e., climate effects) and on surface air quality in different regions of the U.S. (Research)

Key Question: *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. predictions and projections) on intraseasonal, seasonal, interannual, and multidecadal timescales and on regional, national, and global spatial scales, to understand and predict the impacts of climate variability, extremes and abrupt climate change, and to contribute and participate in 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, building on the synergies between NOAA, its Cooperative Institutes, regional centers, and the external research community. This research requires cutting edge high-performance computing facilities and a robust platform of scientific research to develop computer models for making climate predictions and projections and a data management and publication system to make the relevant data publicly available.

Objective for R&D: ***Earth System Models for intraseasonal to centennial predictions and projections at regional to global scales.*** NOAA will improve the skill of seasonal forecasts and delivery of predictions and projections information products for decadal to centennial time scales with quantified uncertainties. Additionally, NOAA will improve regional outlooks through downscaling approaches, high-resolution global climate model runs, multi-model ensembles, and better representation of key physical processes, including ocean dynamics, with specification and quantification of uncertainties. Failing to fill the various modeling gaps in key physical processes poses the risk of leaving decision makers with insufficient scientific support concerning future climate states. Without improved information, decision makers cannot properly address regional and local planning for the impacts of flooding and drought, siting of critical infrastructure in coastal communities, and managing natural resources with changing conditions of our oceans and other ecosystems.

Over the next 5 years, NOAA aims to have:

- Transition to the higher-resolution CM2.5 coupled-climate model (Development)
- A prototype decadal climate prediction system (Development)
- A prototype impact scenario models for climate change effects to coastal ecosystems (Development)
- Sound modeling downscaling techniques for climate applications for multiple regional spatial and temporal scales, including an embedded and nested regional Earth system projection capability (Development)
- Models of greenhouse gases, atmospheric aerosols (including black carbon), and aerosol interactions that yield uncertainty in climate sink quantification and effects on climate forcing
- Prototype modeling of climate-stratospheric chemistry interconnections (Research)
- Models simulating regional climate variability and change over the U.S. at scales of approximately 10-20 Km and quantified associated uncertainties, accounting for the known natural and human-influenced forcings and the relevant climate feedback processes (Research)
- Models simulating the ocean biogeochemical systems and ocean climatic impacts at resolutions of 3-5 Km (Development)
- Conducted climate reanalysis of hindcasts and projections employing coupled models and examined differences for enhanced understanding of climate processes and relationships (Transition)
- Assessed predictability and predictive skill for global experimental decadal-scale predictions that account for natural variability and the climate-forcing agents (Research)

- An intraseasonal to interannual prediction system that builds on the currently experimental real-time National Multi-Model Ensemble system and incorporates advances in statistical methodologies and forecast initialization (Development)
- Quantified uncertainties in predictions and projections of Arctic sea-ice extent and thickness, decadal-scale variability (Research)
- Seasonal outlooks and decadal to multidecadal projections of climate-related changes in US ocean regions (Development)

Key Question: ***How can NOAA best inform and support the Nation's efforts to adapt to the impacts of climate variability and change?*** Adaptation efforts help to manage climate-related risks and minimize impacts to communities, ecosystems, and economies. The actions of putting into place the plans, policies, and regulations for adapting to climate variability and change are largely the responsibility of local and municipal governments, with guidance from state and federal agencies and the support of academic institutions, non-governmental organizations, private industry, and academic institutions. NOAA provides information, tools, and services to support decision makers at all levels to prepare for and respond to climate variability and change through adaptation.

Objective for R&D: ***Key impacts and vulnerabilities are identified across regions and sectors.*** NOAA will advance understanding of impacts and vulnerabilities of human and natural systems to climate variability and change. This requires integrating NOAA's capabilities in science (physical, natural, and social), services, and stakeholder engagement. NOAA is experiencing a rapidly growing demand for climate information at scales (e.g. local-to-regional) useful for decision and policy makers.

Over the next 5 years, NOAA aims to have:

- Advanced projects/activities related to the impacts of climate variability and change on four societal challenge areas (weather extremes, water resources, coastal inundation, and sustaining marine ecosystems) (Research)
- Strengthened and tested climate-related vulnerability assessments of ecosystems and social/economic systems and tools and training for conducting vulnerability assessments with NOAA partners (Research)
- Mechanisms and networks (regional and sectoral) to advance effective stakeholder engagement, communication, and collaboration between scientists and decision makers (Development)

Objective for R&D: ***Improved and sustained assessments of risks and impacts.*** NOAA will organize and strengthen capabilities in the sustained assessment of climate risks and impacts on physical, natural, and human systems. This work will leverage and inform existing assessment efforts (e.g., U.S. National Climate Assessment, Intergovernmental

Panel on Climate Change). Assessments will be conducted in partnership with decision makers to ensure that their information needs are addressed.

Over the next 5 years, NOAA aims to have:

- Sustained assessments of the impacts and risks of climate variability and change on U.S. and international regions and sectors, particularly those with high relevance to NOAA's mission (e.g., water resources, coastal zone and marine resource management) (Development)
- A system of indicators of climate impacts on ocean and coastal resources and other sectors (Development)

Objective for R&D: *Climate information, tools, and services are developed and shared broadly to inform society's preparedness and response efforts.* The demand for NOAA's climate information, tools, and services is increasing, as decision makers work to prepare for the impacts of climate variability and climate change. Meeting this demand will require regular interaction between stakeholders and scientists.

Over the next 5 years, NOAA aims to have:

- Visualization and decision-support tools for changes in ocean temperature, coastal inundation, and sea-level at decision-relevant scales (NOP 3.5) (Transition)
- County-level coastal and ocean job trends data integrated and communicated via NOAA's Digital Coast to enable decision-makers and planners to better assess the economic impacts of climate change (NOP 3.6) (Transition)
- Methods (including economic analyses) for evaluating the effectiveness of adaptation strategies and actions, particularly for coasts, oceans, and water resources (Development)
- Improved communication and application of NOAA's climate information to decision makers and the public through outreach, education, training, user-friendly online resources (e.g. climate.gov), social media, tools, and other pathways (Transition)

B. 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, dislocations, and injuries; and that operates a more efficient economy.

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

Objective for R&D: ***Improved Observations.*** The building blocks of the Weather Ready Nation are observations of the current state of the atmosphere. These form the basis of the future state of the atmosphere when assimilated into high resolution computer models which produce so-called 'guidance' upon which public forecasts and warnings are based. They are the underpinning of both tactical and strategic decision support. In particular, an incomplete picture of the atmospheric boundary layer, where most human activity occurs, represents a major gap in our ability to diagnose and predict high-impact weather events. Filling this gap will take more than the next 5 years, but significant milestones are in sight during this time frame.

Over the next 5 years, NOAA aims to have:

- Established rapid radar sampling technologies needed to produce robust warnings of severe weather with extended lead-times, up to one hour or longer (Development)
- An integrated National Mesonet with complete coverage of surface meteorological stations over the continental US, including soil moisture and solar radiation (Development)
- The foundational infrastructure for a "Network of Networks" that provides boundary layer profiles of winds, temperature, and moisture (Development)
- Evaluated Collaborative Adaptive Sensing of Atmosphere (CASA)/Urban Demonstration Network and other partner technology of short-wavelength networked radars, adaptive sampling, and associated numerical weather prediction (Research)
- Operationalized the geostationary lightning mapper (GOES-R) (Transition)
- Developed Global Hawk Unmanned Aerial Systems configurations supporting doppler radar, with at least a 24-hour mission duration, and dropsondes (Development)
- Conduct feasibility studies to fill major gaps in observations of water cycle parameters (water vapor transport, precipitation, snow, surface energy budget terms including evapotranspiration, aerosols) (Research)

Objective for R&D: ***Integrated real-time analyses of weather conditions.*** NOAA will develop tools and algorithms needed to integrate NWS and partners' data 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:

- Prototyped coupled fire weather and fire behavior modeling system for local firefighting applications (Research)
- Implemented prototype of a rapidly updating 3-dimensional state-of-the-atmosphere analysis system (Development)
- Transitioned the Meteorological Assimilation Data Ingest System to NWS operations (Transition)
- Transitioned the Multi-Radar-Multi-Sensor real-time analysis system to operations (Transition)

Objective for R&D: Improved Predictive Guidance. One of the scientific success stories of the 20th century is the development of numerical weather prediction models, and today NOAA produces weather forecasts of proven utility out to a week based on these models. On the other hand, tornado warnings are not issued on the basis of forecasts, but rather upon observed evidence. Today’s science and technology do not allow scientists to describe the genesis of a tornado, model it, and predict its path, a capability that could save many additional lives. Similarly, while we have dramatically improved the prediction of the track of hurricanes in recent years, progress in improving forecasts of hurricane intensity, and associated storm surge and rainfall has been slower. In addition, significant research and development is needed to present NOAA weather forecasts in a probabilistic framework that allows for the proper communication of forecast uncertainty and to enable a wide range of risk-based decision-making.

Over the next 5 years, NOAA aims to have:

- Evaluated the benefits of extending the current Hybrid Ensemble Kalman Filter (EnKF)-3 Dimensional Variational data assimilation system to a Hybrid EnKF-4 Dimensional Variational one (Research)
- Developed a global deterministic forecasting system at a resolution of 10KM and the associated ensemble forecast system at a resolution of 20 KM (Development)
- Determined the impacts of stratospheric resolution on simulations of slowly varying tropospheric weather patterns such as the Arctic Oscillation (AO) and the Pacific North Atlantic teleconnection pattern (Research)
- Evaluated the impact of ocean-atmosphere coupling on short-range weather forecasts (Research)

- Quantified the skill of convective-allowing regional models such as the High Resolution Rapid Refresh and the Nonhydrostatic Multi-scale Meteorological Model on the B grid (NMMB) separately and as a multi-model ensemble (Research)
- Implemented a moveable inner nest for hurricanes within the operational global forecast system (Transition)
- Determined the relative merits of different approaches to ensemble generation including multi-model, stochastic physics, and multi-physics. (Research)
- Identified the most effective way to represent initial condition uncertainty for our forecast models, i.e. EnKF ensemble members versus the breeding method (Research)
- Implemented a dynamically-updating, multi-model consensus, statistical post-processing system (Transition)
- Prototyped a unified (tide-waves-estuarine-surge) probabilistic inundation model for both tropical and extratropical storms (Research)

Objective for R&D: ***Improved Decision Support Tools.*** NOAA is embarking on a major enhancement and expansion of its decision support services to better realize the benefits of its weather forecasts and warnings. For decision makers, the agency will improve the communication of weather, water and climate impacts and risks, as well as develop impact-based communication capabilities. In addition, NOAA will incorporate quantified uncertainty and risk information into its forecasts to facilitate analyses for strategic and tactical preparation and effective response. Limiting weather-related loss of life and property requires eliciting the most effective response to accurate, reliable warnings and forecasts. The target operational system for all these tools is the Advanced Weather Interactive Processing System (AWIPS).

Over the next 5 years, NOAA aims to have:

- A prototype of the a comprehensive operational IT forecaster decision support environment for WRN operations (Development)
- Deployed a unified public warning tool into operations (Transition)
- Implemented initial capability to allow external users to be notified when thresholds for their weather-based decisions have been exceeded in either current or future weather conditions (Transition)
- Evaluated experimental products from which tornado warnings with lead times greater than 1 hour can be generated (Research)
- Developed risk communication tools for core partners and the general public based upon social science research (Development)

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.

Objective for R&D: ***Apply understanding of weather and climate extremes and the weather-climate linkage to improve preparedness and response.*** 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.

Over the next 5 years, NOAA aims to have:

- Applied knowledge of the physical processes of Madden-Julian Oscillation events, atmospheric rivers, predictability of AO/North Atlantic Oscillation, and tropical convection, into the preparation of operational forecast products (Transition)
- Incorporated local and regional climate impacts into extreme meteorological and hydrological event forecasts (Transition)
- Expand the Local Climate Analysis Tool to include multiple time and space scales for delivery of information in support of regional and local decision making (Transition)

Key Question: ***How can we improve space weather warnings?*** When storms in outer space occur near Earth or in the Earth's upper atmosphere, we call it space weather. Rather than the more commonly known weather within our atmosphere (rain, snow, heat, wind, etc.), space weather comes in the form of radio blackouts, solar radiation storms, and geomagnetic storms caused by solar disturbances from the Sun. Earth's magnetic field helps to protect us from the effects of some solar storms, but strong solar storms can cause fluctuations of electrical currents in space and energize electrons and protons trapped in Earth's varying magnetic field. These disturbances can cause problems with radio communications, Global Positioning Systems (GPS), power grids, and satellites. As we become more dependent on technology, the need for space weather monitoring and forecasting becomes more important.

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, wireless communication network, and transportation infrastructure. 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 (Transition)
- Methods of estimating the magnetic field configuration within a CME (Transition)

Objective for R&D: ***Localized specification and forecasts of the impacts of geomagnetic storms at ground level.*** Critical customers, such as 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 and ground data processing system to insure continuity of solar wind observations that drive Geospace models (Development)
- Developed regional and local specification of the geomagnetic conditions relevant to the National electric power grid (Research)
- Identified the best Geospace model for forecasting local geomagnetic storm conditions and begun the transition of this model into operations (Research)

Objective for R&D: ***Predictions of ionospheric conditions relevant to Global Navigation Satellite System users.*** The observation and modeling of ionospheric structures that modify or block the signals from radio navigation systems such as Global Positioning System is critical to providing customers with the services 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:

- Developed assimilative models for COSMIC II data (Development)
- Coupled NOAA's operational WAM (e.g. the extended Global Forecast System) to the Ionosphere Plasmasphere Electrodynamics model (IPE) (Research)
- Assessed the impact of data assimilation in ionosphere-thermosphere forecast modeling (Research)

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 (Transition)

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 agencies 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 match skill afforded by weather and climate predictions.*** The foundation of improved fresh water resources management is improved hydrologic forecasting. Significant advances in hydrologic prediction demand a more complete understanding of the physical processes key to storms and floods. This knowledge must in turn be incorporated into improved numerical hydrologic prediction models.

Over the next 5 years NOAA aims to have:

- Diagnosed the variability of water vapor transport in atmospheric rivers (Research)
- Identified extreme precipitation and precursor land-surface conditions that amplify or reduce drought and flood severity (Research)
- A unified large-scale hydrological modeling system allowing integrated and multiscale predictions, projections and analyses (Development).
- High-resolution hydrologic products that directly link atmospheric and land-surface processes and depict the full water cycle over the U.S. (Development)
- A national water cycle reanalysis (Transition)

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

Coastal communities are dependent upon ecosystem services provided by healthy and productive marine ecosystems. They provide food, recreational opportunities, and support for 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. Humans are an integral part of the ecosystem, so 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, energy, recreational use of aquatic environments, and other pressures on habitats and over--exploited species will increase alongside 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 subsequently affects recreational, economic, and conservation activities.

Key Question: ***How do environmental changes affect marine ecosystems?*** The living marine resources under NOAA's purview, their habitats, and the coastal communities and economies that depend on them exist within ecosystems constantly changing due to environmental variability, climate change, and human activities such as: resource exploitation, development, and pollution. These changes affect species' distributions, migration, reproduction, growth rates, levels of primary and secondary production, and overall habitat suitability. If living marine resources are routinely managed without regard for changing environmental conditions, there is a risk of managing for conditions that do not exist at the time of the management action. A better understanding of how ecological interactions are affected by environmental change and human interactions will enable more certain assessments and forecasts, leading to improved management that ensures sustainable, healthy and productive marine ecosystems.

Objective for R&D: ***Increase our knowledge of the physical and chemical changes in the oceans resulting from atmospheric, ocean, and, and land-based forcing.*** The goal of R&D for this topic is to understand how physical and chemical variables across ocean and watershed conditions change, assess these conditions, and develop the ability to provide regional forecasts and projections across several temporal scales. These forecasts and projections are critical toward incorporating environmental information into marine resource management. Species inhabit certain regions because they are adapted to the environmental conditions typically present there.

Over the next 5 years, NOAA aims to have:

- Greater collection and use of high-quality environmental data in describing and understanding the dominant forcings of the oceans and their physical and chemical impacts (Research)
- Greater collection and use of high-resolution, regionally constrained environmental data to support regional forecasts and projections (Research)

Objective for R&D: ***Increase our knowledge and understanding of the mechanisms and impacts of environmental changes on marine species and ecosystems.*** The National Ocean Policy establishes ecosystem-based management (EBM) as a foundational principle for ocean resource management in the United States. Understanding how environmental changes affect marine ecosystems provides the scientific underpinning of EBM and is crucial for sustaining marine fisheries, habitat, and biodiversity within healthy and productive ecosystems. A combination of retrospective, monitoring, process and modeling studies are required to advance our understanding of the impacts of environmental change. NOAA must understand the mechanisms by which environmental change impacts marine species and ecosystems to confidently predict or project the impacts. Without this mechanistic understanding, there is no basis for predictions or projections when conditions change, resulting in uncertain assessments and forecasts. Observations coupled with information from retrospective and process studies generate the necessary foundation for understanding environmental-ecosystem relationships. Combining this information with ecosystem models that include environmental forcing also contributes to understanding the mechanistic linkages between environmental forcing and species' responses.

Over the next 5 years, NOAA aims to have:

- Less uncertainty in the forecasts generated from ecosystem models (Development)
- Developed analytical models and tools to understand and quantify impacts of environmental change in 3 large marine ecosystems (Development)

Objective for R&D: *Incorporate environmental change information into operational marine resource assessments and decision-making.* The objective for R&D on this topic is to provide a stronger scientific basis for improved marine resource management by increased incorporation of environmental change information into operational assessments and decision-making. To transition to EBM, the increased knowledge obtained through the first two objectives must be incorporated into operational assessments and the decision making process. The increased knowledge will advance the development and testing of indicators and models to predict with greater certainty the probable consequences of environmental changes on regional ecosystems. Some of these indicators or derived parameters may be incorporated directly into next generation stock assessments. Moreover, the development of ecosystem assessments and management strategy evaluations that incorporate environmental and climate change information and evaluate different ecosystem management strategies will provide resource managers with information to make more cost-effective and informed decisions in an ecosystem context.

Over the next 5 years, NOAA aims to have:

- Developed regional-scale ecosystem models driven by regional-scale climate models
- Developed next-generation stock assessments that incorporate the effects of environmental change on stock dynamics
- Developed protected species and habitat valuation for regions identified in the Habitat Blueprint (Research)
- Assessed social and economic benefits of fish stocks and the potential trade-offs associated with managing competing ecosystem services or allocating an ecosystem service among competing user groups (Research)

Key Question: *What exists in the unexplored areas of our oceans?* The ocean remains almost entirely unexplored. Because of this, answers to this key question will expand NOAA's and the Nation's knowledge and understanding of marine biodiversity, biogeochemical processes, ecosystems, living and non-living marine resources, and ocean-climate interactions at local to global scales. This new knowledge will inform current and future research and technology initiatives, marine policy and management decision making, private sector interests, and the public at large. NOAA facilitates ocean discoveries as well as the transfer of knowledge and technologies to operational use at the agency as well as partner applications in ocean exploration and management.

Objective for R&D: ***Map and characterize ocean basin boundaries.*** Ocean boundaries include those with the solid earth (e.g., the seafloor, ridges, canyons, faults, and seamounts), the atmosphere (e.g., air-sea interface), ice (e.g., ice types and ages, keels, ridges, shelves, icebergs) and boundaries within the water column itself. Processes occurring at these boundaries have economic, natural hazards, scientific, and cultural importance. OER will characterize ocean basin boundaries using advanced technologies and systems, including autonomous underwater vehicles, multi-beam sonar, side-scan sonar, and other advanced seafloor and water column sensors and mapping technologies.

Over the next 5 years, NOAA expects to have:

- Explored poorly-known or unknown regions in support of the U.S. Extended Continental Shelf Project and in the Expanded EEZ in the Mid-Atlantic, Gulf of Mexico, Caribbean, West Pacific, and Arctic (Research)
- Developed technologies and systems to document ocean basin boundaries in areas defined above and provide ecological baseline characterizations of these areas (Development)

Objective for R&D: ***Discover and characterize new ocean resources***
Discover, observe, and describe new species, communities of organisms, and resources, both living and non-living, including those of economic importance and/or benefit to humanity (e.g., natural products for pharmaceutical or biotechnology applications; new hydrate, seep, or microbial environments; cultural/archaeological resources; fish stocks and baseline biodiversity inventories; valuable mineral resources).

Over the next 5 years, NOAA aims to have:

- Completed the Atlantic Canyons Undersea Mapping Expeditions (ACUMEN) Project in support of the NOAA Habitat Blueprint northeast regional initiative (Research)
- Discovered new species living in the deep ocean (Research)
- Discovered and characterized microbial and hydrothermal vent communities, mesophotic and deep-sea coral habitats, and methane seeps and communities (Research)
- Identified new natural products derived from deep sea biota and marine microbes (Research)
- Identified undiscovered-areas of the ocean with potential high concentrations of economic assets (Research)

- Located new underwater cultural and archaeological heritage sites in US territorial waters for Federal management (Research)

Objective for R&D: *Transition ocean exploration discoveries to the rest of NOAA and other agencies.* Results above will highlight areas, resources, or processes that are new to ocean science or in need of further study. A portion of these, those not directly applicable to NOAA's missions, will benefit other agencies for further research. By intent and design, the majority will have direct NOAA relevance and will be expanded upon through further study and application within OER and other NOAA programs.

Over the next 5 years, NOAA aims to have:

- Provided baseline characterization information for the establishment of marine protected areas for sensitive deep-sea coral ecosystems in the Atlantic, Pacific and Gulf of Mexico (Research)
- Explored Mid-Atlantic Deepwater Hard Bottom Habitats and Shipwrecks with Emphasis on Canyons and Coral Communities joint project with the Bureau of Ocean Energy Management (Research)
- Characterized marine archaeological discoveries of cultural or archaeological significance (Research)

Key Question: *How can emerging technologies improve ecosystem-based management?*
In order for an ecosystem-based approach to be successful in meeting its management objectives, it requires a synthesis of scientific information from relevant physical, chemical, ecological and human processes in relation to specified marine ecosystem management objectives. The intent is to understand and apply the effects of these processes on the sustainability of living marine resources, production of marine ecosystems, and health of the oceans. This information is necessary to establish target levels and thresholds for important ecosystem components, and evaluate the impacts of management options and risks of not attaining these target ecosystem states. Policy decisions for fishery management and protection of endangered species require improved scientific information from various spatial and temporal scales. Current sampling technologies need improvement in their survey capabilities to provide more accurate and precise synoptic information of key marine populations and environmental influences on their production and distribution.

Objective: *Improve survey capabilities to provide more accurate, precise and synoptic information of key marine populations.* Improvements are needed to improve the survey capabilities to provide more accurate, precise, and synoptic information of key marine populations and environmental influences on their production and distributions using innovative technologies, and remote sensing and alternative platforms can improve survey coverage without significant increases in expensive ship time.

Over the next 5 years, NOAA aims to have:

- Less uncertainty in the forecasts generated from ecosystem models (Transition)
- Enhanced UAS camera systems for marine mammal surveys (Development)
- Animal-borne observing systems at the scale of NOAA's regional ecosystems (Development)

Objective: ***Improve biomass and mortality estimates and address measurement uncertainty with technologies aboard existing surveys.*** Improve abundance estimates and address measure uncertainty with the development and implementation of technologies aboard existing surveys, and pertinent environmental and ecological measures.

Over the next 5 years, NOAA aims to have:

- More ecosystem-process studies that employ advanced sampling technology (Transition)
- Less uncertainty in the forecasts generated from ecosystem models (Transition)

Objective: ***Develop integrated models that take advantage of synoptic data at various scales, to inform ecosystem-based management approach.*** Data from emerging sampling technologies will provide synoptic information to develop biological models capable of providing regional-scale assessments and forecasts of biological productive.

Over the next 5 years, NOAA aims to have:

- Less uncertainty in the forecasts generated from ecosystem models (Transition)

Key Question: ***How can we ensure aquaculture is sustainable?*** Encouraging marine aquaculture R&D within the context of NOAA's stewardship mission, as guided by NOAA's Marine Aquaculture Policy, continues to be in the public health, safety, and economic interest. NOAA's responsibility as steward of our nation's living marine resources includes fostering the development of marine aquaculture for a variety of purposes – to supply safe, sustainable seafood for our entire nation; to create employment and business opportunities in coastal communities; to help support domestic wild fisheries, such as salmon, through hatcheries; to preserve and rebuild threatened and endangered species such as abalone; and to restore habitats such as oyster reefs. When it is considered that the U.S. imports 91% of its entire seafood supply, with almost half of that amount being foreign aquaculture products, it is clear NOAA needs to encourage and enhance domestic, safe seafood production. By increasing and enhancing the capabilities of domestic aquaculture production of marine fish, shellfish, and plants and encouraging consumers to buy domestic seafood we can ensure that what is on consumers' plates benefits the U.S. economy and has been properly and sustainably managed and produced.

Objective for R&D: ***Enhance current species culture methods and identify new commercially viable species.*** Increasing the aquaculture capacity of the U.S. to compete with foreign nations and improve culture methods domestically will enhance not only the sustainability of our products but also increase the variety of seafood available and ensure a consistent supply of healthy protein options. Increasing the accuracy and ability to monitor and evaluate culture methods will also ensure that these practices are done in a smart way. In order to do so, NOAA will need to increase capacities encouraging expansion of seafood options.

Over the next 5 years, NOAA aims to have:

- Identified new commercially viable marine aquaculture species (Research)

Objective for R&D: ***Supporting aquaculture as an effective tool for improving coastal community economies and improving habitat quality.*** NOAA is committed to increasing our ability to continue conducting aquaculture practices sustainably. Along with improving coastal economies, aquaculture is a tool that can be used for improving and monitoring habitat quality. Shellfish, such as oysters, clams, and mussels, remove excess nutrients from the water column and can be used as bioremediation tools.

Over the next 5 years, NOAA aims to have:

- Assessed the potential of shellfish as bioextraction tools in polluted waters (Research)
- Identified the social and economic impacts of marine aquaculture upon U.S. coastal communities (Research)

Objective for R&D: Create new technologies for better siting aquaculture facilities. This objective demands that we increase our ability to understand the impacts of commercial aquaculture on the environment and to limit these impacts by placing facilities in areas that do not interfere with other coastal resources. Increased knowledge of proper site selection is critical for sustainability. Water quality impacts are likely to be minimal at offshore fish farm sites that are sited in deep, well flushed water. Technologies such as ecological models and GIS databases of coastal use areas will enable sustainable choices.

Over the next 5 years, NOAA aims to have:

- Developed models to assess environmental impacts and technical feasibility to permit offshore finfish operations (Development)

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

Ocean chemistry is a fundamental defining attribute of any marine environment and can often reflect the quality of a marine habitat. Human influences on nutrient cycling, coastal pollution, and ocean acidification can be important forcing agents of change particularly for coastal and estuarine environments. Human-induced changes to nutrient loading can drive the extent and severity of oxygen depletion (i.e., hypoxia and anoxia). Future changes in nutrient management coupled with a changing climate will likely exacerbate low-oxygen conditions and associated impacts to marine ecosystems. Furthermore, there is mounting evidence that ocean acidification driven by increasing CO2-levels could have significant effects on global marine ecosystems.

Effectively forecasting the long-term and ecosystem-level effects of ocean acidification is an emerging challenge. Short-term and resident factors controlling carbon chemistry (e.g. upwelling, riverine discharge, nutrient loading) can further exacerbate global acidification at local scales. Long-term chemical observations necessary to track ocean acidification are limited especially within dynamic coastal environments. Critical research needs remain in order to confidently incorporate ocean chemistry into ecosystem forecast models.

Objective for R&D: ***Understand causes and effects of nutrient over-enrichment.*** Nutrient over-enrichment is a major coastal ecosystem stress. Excess nutrients can cause eutrophication, which often stimulates excess algal primary production, leading to oxygen depletion as decomposers of the excess production consume oxygen. Extensive oxygen depletion leads to hypoxia (i.e. oxygen < 2mg/l) and drives up CO_2 acidifying local waters. Most aquatic species cannot survive in hypoxic waters and acidification causes further complications to some organisms. Multiple nutrient sources exist in watersheds with complex transport and delivery processes controlled by a range of factors. These factors include the chemistry, ecology, hydrology, and geomorphology of the watershed and receiving system. Furthermore, human activities are an important part of coastal nutrient dynamics.

Over the next 5 years, NOAA aims to have:

- Conducted characterizations of nutrient, microbiological and other contaminant levels in the coastal zone receiving land and atmospheric based sources of pollution (Research)
- Developed sensors for nutrients and chemical contaminants (Development)

Objective for R&D: ***Understand the processes of ocean acidification and its consequences for marine organisms, ecosystems, and human communities.*** As atmospheric CO_2 continues to rise, ocean chemistry is fundamentally altered through the continual uptake of excess carbon. Changes include acidifying surface waters (i.e. reduced pH), enriching them in CO_2, and making the waters less supersaturated with respect to carbonate minerals. Many marine ecosystems may be susceptible to ocean acidification particularly organisms partly composed of calcium carbonate (a chalk-like mineral) such as foraminifera, clams, oysters, mussels and corals. Local processes can exacerbate global-scale ocean acidification such as coastal upwelling along the west-coast of the U.S. Here, acidified waters likely contributed to a recent crisis in larval supplies in the Northwest's shellfish industry. Much research is needed before we can fully understand the broader impacts to marine life and human societies. Understanding acidification and predicting the consequences for marine resources and ecosystem services is critical to carbon mitigation discussions and to aid local communities in better preparing and adapting to ocean acidification.

Over the next 5 years, NOAA aims to have:

- Developed bio-economic models informed by targeted experimental studies to forecast ocean acidification impacts on federally managed Alaska managed crab species (Development)
- Conducted OA vulnerability assessment of California Current food webs and economics (Research)
- Established long-term high quality monitoring capabilities of ocean acidification and ecosystem response (Transition)
- Implemented coupled biogeochemical and ecological coral reef ocean acidification status and trends diagnostic monitoring as a key attribute of the National Coral Reef Monitoring Plan within each U.S. coral reef jurisdictions (Research)
- Provided scientific stewardship of comprehensive ocean acidification data (Transition)

Objective for R&D: ***Monitor and assess the impacts of land-based sources of pollution.*** Land-based stressors include, most notably, toxicants, sediments, and nutrients. The suite of problems facing coastal ecosystems from land-based sources of pollution (LBSP) is broad due to the variety of land-based activities that transport sediments, nutrients, and chemical contaminants via surface waters, runoff, groundwater seepage, and atmospheric deposition into coastal waters. The health of many U.S. coastal ecosystems ultimately depends on effective management of land-based activities in adjacent coastal and upland regions.

Over the next 5 years, NOAA aims to have:

- Supported Gulf of Mexico ecosystem restoration by completing a risk assessment for the Gulf of Mexico as part of the Integrated Ecosystem Assessment NOAA-wide initiative (Research)
- Assessed the impacts of water use practices and atmospheric land-based pollution on marine and Great Lake coastal ecosystems, water quality, and human and animal health (Research)

D. 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, pathogen outbreaks, and severe weather hazards.

Key Question: ***What is the value of coastal ecosystems?*** One particularly compelling way to strengthen our understanding of the interaction between economies and ecosystems is through the economic valuation of services provided to society by the ecosystem (e.g., clean water, nutrient cycling, and natural storm buffers). The contributions of ecosystem services are often difficult to quantify and as such, are often omitted from traditional economic analyses and discounted in policy decisions. However, there are techniques available that can help us to understand the benefits a healthy ecosystem provides, both in terms of market value for industries such as energy and recreation, as well as non-market valuation of services that are not as easily quantified. Advancing and implementing these techniques will result in more accurate information on the comprehensive value that ecosystems provide. Our coasts are where the land meets the sea, and are an appropriate place to describe how NOAA ecosystem service valuation (ESV) efforts will cut across resilient coastal communities and economies, healthy oceans, climate mitigation and adaptation, and a weather-ready nation.

Objective for R&D: ***Improved understanding of the economic and behavioral elements of coastal resilience.*** 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 to help mitigate negative impacts, and assess and understand 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 the natural capital provided by ecosystems. This research will improve understanding of that connection.

Over the next 5 years, NOAA aims to have:

- Identified best practices and incorporated international standards for ecosystem services valuation (Research)
- Conducted ecosystem services valuations in National priority areas using best practices (Research)
- Socio-economic indicators of vulnerability of coastal communities to industrial development and environmental change, and application of the indicators in developing regional ecological characterization reports (Research)
- Built integrated water level models, and evaluated costs and benefits of transitioning coastal storm surge model (surge plus wave prediction) to operations (Transition)

- Characterized climate sensitivity of selected National Estuarine Research Reserve System sites using social vulnerability and biophysical indicators (Research)
- Estimates of monetary and social costs of hypoxic zones, regions experiencing Harmful Algal Blooms, and designated Areas of Concern in Lake Michigan (Research)

Key Question: ***How do coastal species respond to habitat loss, degradation and change?*** Coastal species respond to environmental stress at all levels of biological organization – from biochemical, physiological and histological aberrations, loss of a population or sub-population, and disruption of ecosystem structure and function. Greater scientific insight, improved measurement technologies and modeling now offer a suite of measurement to document stress at the sub-cellular levels, even from low levels of stress and with presumed causality. At this stage, response sensitivity is rapid and generally reversible. On the other hand, changes at the ecosystem level, even though highly relevant for resource management decisions, are difficult to discern and, when documented, they indicate an altered or degraded state. Newly emerging data suggest that combined effects of multiple stressors, synergistic or otherwise, may be a more common occurrence in the field. NOAA will continue to improve and develop new methods to document effects of environmental stressors on coastal species and ecosystems, and develop a cohesive program of research on multiple stressors.

Objective for R&D: ***Determine combined effects of environmental stressors on coral reefs***
Coastal ecosystems are affected by different environmental stressors, including extreme natural events, coastal subsidence and sea-level changes. These stressors, when coupled with land and resource use activities, cause changes in ecosystem structure and function that have proven difficult to assess or mitigate. It has not been possible to determine combined effects of environmental stressors on coastal ecosystems, including those caused by myriads of toxic chemicals. New and developing technologies, including those based on genomics, DNA probes, immunological biomarkers, etc. are beginning to offer a common denominator or a suite of methods that could infer or quantify such impacts.

Over the next 5 years, NOAA aims to have:

- Identified sub-lethal effects, including metabolic dysfunction and transcriptomic and proteomic changes, in species under environmental stress (Research)
- Documented the combined effects of multiple stressors on at least one coastal ecosystem and the valued species therein (Research)
- Characterized sources, transport, transformation and fate of mercury pollution in Mobile Bay (Research)
- Models that simulate contaminant transport from the watershed to coastal bays and estuaries (Development)

Key Question: ***How do we ensure that growing maritime commerce stays safe and sustainable?*** More than 350 commercial ports in the United States move some $3.8 billion worth of goods each day, and contribute significantly to the national economy in the form of personal income, infrastructure support, and ancillary jobs. A majority of that contribution is from 13 major ports. According to the U.S. Chamber of Commerce, 15,000 jobs are created for every $1 billion in manufactured exports shipped through seaports (American Association of Port Authorities, 2011). In addition, the economic impact of the North American cruise industry is approaching $40 billion per year. U.S. ports are located in different coastal environments, ranging from shallow estuaries on the East Coast (having a mean depth much lower than the dredged shipping lanes), and constructed waterways leading to the Great Lakes and the Gulf of Mexico, and deep fjords in the Pacific Northwest. As such, they require a variety of navigation devices and services to assure protection of life and property and increased efficiency in maritime traffic. Typically, such aids include maps and navigation charts, positioning and control systems, hydrographic and environmental data, and buoys. NOAA continues to explore, develop and implement a suite of tools to support and improve safe and efficient marine transportation in major U.S. ports and harbors. Particular attention is placed on delivering information on water levels, tides and currents from in situ sensors and outputs from nowcast and forecast models, and on geo-referenced Electronic Navigation Charts.

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:

- Corrected meter-level errors in Arctic positioning and provided a new vertical reference frame to support Arctic navigation, per the National Ocean Policy and NOAA Arctic Plan (Development)
- Documented mathematical proof that 1-cm accuracy geoid is achievable, and a description of U.S. areas where it cannot be achieved (Research)
- Evaluated and transitioned new technologies and tools that provide real-time observations and forecasts of water levels, tides and currents to mariners and offshore industries (Transition)
- A comprehensive, integrated inventory of ocean and coastal mapping data, linked to Ocean.data.gov (Transition)

Key Question: *How do we reduce the economic and ecological impacts of degraded water quality?* Water quality-related water quality-related coastal problems are readily seen as harmful algal blooms, widespread and increasing hypoxic (or dead) coastal areas, putrid shorelines, presence of nuisance algae and debris, proliferation of waterborne pathogens on recreational beaches and in seafood harvest areas, and human illnesses from exposure to polluted waters and consumption of contaminated seafood. They are cause business losses, lowered consumer confidence, and medical bills whose total impact is difficult to surmise at a national scale. Societal costs associated with specific water quality issues, for example, mercury pollution, approach billions of dollars each year. NOAA has embarked on an agency-wide effort to develop and transition ecological forecasts that integrate information from wide-ranging research and observations programs, and document anticipated changes in water quality conditions over different temporal and geographical scales. They cover a range of issues, such as harmful algal blooms, impact of changes in freshwater flows on key species, and the extent and severity of seasonal hypoxia. In areas where this capability has matured, ecological forecasts have improved decisions to protect ecosystems, economies and human health from adverse environmental phenomena and events, and they continue to offer a unique platform for inter-disciplinary linkages and feedbacks from stakeholders on land-use scenarios and economic activity. In areas for which it has management responsibility, e.g., National Marine Sanctuaries, NOAA works with other Federal agencies and state jurisdictions in improving water quality, and fosters non-regulatory programs with farmers, ranchers and rural land-owners to assess and mitigate water quality-related issues.

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.* Environmental characterizations provide comprehensive and integrated information about the coastal environment and are prepared in anticipation of a specific resource development or an emerging environmental issue. Often they include analysis of management options and may include modeling of specific environmental processes and scenarios, for example, habitat suitability modeling, simulations to identify impacts of coastal wind energy development on birds, and projections to determine biological concentrations and habitat use in areas of data paucity or gaps. The scope and nature of ecological characterization are determined by working collaboratively across federal agencies and with state, regional, local and Tribal partners, as well as non-governmental organizations. Characterization reports are made broadly available for use by industry, federal and state mangers, industries, and other stakeholders to make informed decisions moving forward

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 (Research)

- 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 (Research)
- 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 monitoring data from the reserve (Development)
- Established linkages between land-use and coastal habitat degradation within priority geographic areas (NOAA Habitat Blueprint), including models that predict their future state (Development)

Objective for R&D: ***Region-specific, nationwide, operational capability for ecological forecasting.*** NOAA will develop a regionally focused, nationwide capability to forecast event-specific harmful environmental conditions, transition the capability into operations and facilitate its management applications. Emphasis will be on improving the modeling architecture and reducing forecast uncertainties. 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 exists (Research)
- A concept paper on positive feedback models of toxic algal blooms: influence of increased toxicity under nutrient limitation on bloom formation, persistence, and toxicity (Research)
- 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 (Research)
- Assessed the impacts of land-based sources of contaminants (nutrients, toxic chemicals, and pathogens) for hypoxia in northern Gulf of Mexico (Research)

Objective for R&D: ***Improved water quality testing and monitoring technologies***
NOAA actively promotes research for developing tools and technologies to improve field detection of toxins, contaminants, pathogens, and toxigenic algae. This work relies on high-end scientific instrumentation, development of micro-fabrication technologies, new data processing methods, and ultra-sensitive analytical capabilities. A related aspect of the objective is development and application of procedures based on genomics, DNA probes,

immunological biomarkers, bioinformatics, and modeling of biological systems that have a potential for offering a common denominator of health or a suite of measures that could better quantify source attribution and effects of stressors. All such technologies and systems have potential for commercial use.

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 (Transition)
- A prototype membrane electrode for detecting algal toxin(s) in the field and routine monitoring applications (Development)
- Developed methods for taxonomic differentiation and classification of pathogens found in coastal environments and protected species, and identified factors for their virulence (Development)

Objective for R&D: ***Improved understanding of emerging water quality issues, including the sources, environmental fate and ecological consequences of nanoparticles and microplastics.*** Nanoparticles, including fullerenes, in coastal waters present major analytical challenges and conceptual shortcomings. Some nanoparticles are now commercially produced for a wide range of applications, for example, as an oxygenation source in catalytic converters of internal combustion engines, antibacterial agents, sunscreens and a variety of coatings. They are found in wastewater effluents and coastal runoff. Data are beginning to emerge on their roles in retarding biological growth, disrupting geochemical cycling, and accelerating biological uptake of certain contaminants (which are otherwise present in concentrations lower than the "level of concern"), though NOAA's own research on the subject is scant. A somewhat related issue is of microplastic debris, on which there is sufficient scientific information to be concerned about their long-term ecological effects, and NOAA is engaged in elucidating pertinent scientific questions and approaches.

Over the next 5 years, NOAA aims to have:

- Identified the environmental significance of nanoparticles, focusing on metal oxides and carbon particles and developed a blueprint for high priority research needs and monitoring protocols (Research)
- Report assessing state of knowledge and on scientific challenges in determining the quantity and ecological impacts of microplastics (Research)
- Established the relationship between microplastics and toxic chemicals in coastal and marine waters, and the resulting impacts on marine organisms via the food chain (Research)

Key Question: ***How is the Arctic affected by expanding industry and commerce?*** The Arctic has a strong and pervasive influence on global climate, transport and transformation of toxic chemicals and greenhouse gases, and functioning of ecosystems. Increasing air and ocean temperatures, thawing permafrost, elevated freshwater flow from Arctic rivers, and declining sea ice cover illustrate profound environmental changes that are impacting ecosystems, regional economies, and health, welfare and ethos of regional populations. Currently anticipated accelerated energy development and increased maritime traffic pose new or heightened environmental issues and navigational challenges in the region. NOAA is participating in inter-agency forums to further inform environmental, economic and societal decision-making regarding Arctic resource utilization, and is poised to apply its extensive portfolio of environmental observations, research and modeling capabilities to detect, better understand, predict and plan for consequences of ongoing environmental change and enhanced industrial activities.

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:

- 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 (Research)
- Developed coastal inundation maps for Chukchi Sea based on anticipated storm-surge occurrences (Development)
- Documented the likely movement, weathering and fate of crude oil trapped under sea ice, and its likely effects of coastal ecosystems (Research)

Objective for R&D: ***Improved characterization of Arctic marine ecosystems.*** Arctic ecosystems have evolved to cope with strong seasonal fluctuations in sunlight, presence of a permanently ice-covered deep ocean basin and seasonally covered marginal seas, episodic freshwater flows, generally low primary productivity, and low biological diversity. No less important are its connections with the Arctic and Pacific Oceans that enhance biological productivity in certain areas and serve as migratory corridors for several species of marine mammals. Long lifespans, strong fecundity, unique adaptations to the presence of sea ice (for example, epontic algae)-, and maximal use of key habitats define key features of Arctic fauna and ecosystem. However, paucity of data precludes knowledge of their organizational structure, energy flows and resilience. Predicting environmental consequences of climate change and industrial activities on Arctic ecosystem is a major scientific challenge; assessing consequences altered ecosystems on fisheries and wildlife resources, subsistence lifestyles, human settlements, regional economies and social fabric, and human health over the next five years even more so.

Over the next 5 years, NOAA aims to have:

- Completed the pilot phase analysis and reporting on distributed biological observatory (DBO) activities and results (Research)
- 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 (Research)
- Identified areas of special value and vulnerability to offshore petroleum development and coastal infrastructure by applying NOAA's Biogeography Assessment Framework (Research)

Objective for R&D: *Improved impact assessments of changing sea ice.* The report entitled "NOAA's Arctic Vision and Strategy " (2011) articulates wide-ranging impacts of rapidly changing environmental conditions in the Arctic, including effects of declining sea ice cover and longer duration of sea ice melting, and how such changes affect regional weather, biological productivity, and human communities reliant on coastal ecosystems. The report and a following Ice Forecasting Workshop report (September 2011) underscore the need for improving NOAA's sea ice forecasting capability. The current state of sea ice cover has fallen below the previously established trend line for the period 1979 through 2006. Reduced sea ice and snow cover also reduce the overall surface reflectivity of the region in summer – positive feedback – further moving the Arctic environmental systems toward a new state. As the ice-edge retreats, so do the phytoplankton blooms; relatively huge phytoplankton blooms are now observed beneath sea ice in Chukchi Sea, resulting in estimates of primary productivity that are 10 times greater than before. The ecological implications of such increased primary productivity, coupled with its northward extent, are not well known but they point to a shift in the pelagic-benthic coupling of food webs. In many parts of the Arctic this coupling is instrumental in delineating critical biological habitats, for example, the Chirikov Basin. The longer duration of open water also affects characteristics of sediment-laden ice, i.e., ice with coarse sediment, gravel and kelp uprooted of the seabed, and ice with fine-grained sediment (clay, silt, organic matter) that first appears near the top of the ice cover. In either case, sediment-laden ice drastically reduces light penetration below the sea ice cover and could have potentially strong consequences on coastal ecosystems. The US Arctic is also becoming increasingly more favorable to routine maritime traffic, identified as an area for expanded oil and gas development in the near future, and would require changes in current oil spill response plans.

Over the next 5 years, NOAA aims to have:

- Assessed the causes of the rapid decline in Arctic sea ice (Research)
- A sea ice forecasting test bed in the Chukchi-Beaufort Seas that tests and evaluates models from different agencies and Canada (Transition)
- Evaluated current and emerging technologies that could support navigation needs for trans-Arctic traffic, including ship-to-shore communications (Transition)
- A sediment scavenging model that uses multiple sediment entrainment scenarios and factors that govern the entrainment, particularly frazil ice crystals, turbulence, storm events (Development)
- Documented changes in size and persistence of sea ice habitats, particularly recurring polynyi, landfast ice, and ice floes (Research)

E. 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 support informed public response to changing environmental conditions?*** An essential component of NOAA's efforts, as an operational agency, is ascertaining what stakeholders need and want, particularly in light of evolving science, technology, and data. Information only has economic value to the extent that it changes behavior. Independent of how information is transmitted and received is what people do with the information that they have. The service aspect of NOAA's mission will not be accomplished through the mere provision of information; it also requires the use of information in a way that best suits peoples' particular needs. To this end, NOAA must improve its knowledge of how the public responds to knowledge of environmental changes, both natural and manmade, slow and sudden. Further, NOAA's broad mission requires differing communication approaches for its large variety of 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 and situations.

Objective for R&D: ***Improved understanding of what kinds of information the public needs to make actionable decisions***

NOAA's broad mission results in the need for quite different decision support 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 these sorts of applications, where there are commonalities and where there are differences. This involves studying perceptions of risk of individuals, businesses, and communities, as well as their capacity to alter their actions once they have decided to do so.

Over the next 5 years, NOAA aims to have:

- Assessed how the public perceives risk and uses probabilistic information to make decisions (Research)
- Developed decision-support tools to inform stakeholders and the public on the impacts of critical issues, situations, and subsequent actions (Development)
- Determined which stakeholder engagement methodologies are most effective for eliciting requirements for each of the Mission Goals (Research)
- Determined how to efficiently keep stakeholder and public requirements current (Research)

Objective for R&D: ***Identify and measure NOAA's policy and programmatic outcomes through social science research.*** The most appropriate way to describe policy and programmatic outcomes is with reference to NOAA's mission and to the societal value generated by NOAA's products and services. When social science capabilities are fully and appropriately integrated into NOAA activities, NOAA will be able to valuate the contribution of its products and services with respect to the nation's stock of coastal and marine resources, commercial and non-market economic activities, and changes in the health and safety of the nation's citizens.

Over the next 5 years, NOAA aims to have:

- Conducted valuation assessments on priority NOAA programs, products and services (Research)
- Developed a satellite account, with the Bureau of Economic Analysis, that links NOAA's products and services to elements of the coastal and ocean economy (Development)

Key Question: ***How can we improve the way scientific information and its uncertainty are communicated?*** Scientific information can be quite complex and require substantial background to fully understand its content and associated context. Therefore, effectively communicating scientific information requires a clear understanding of the recipient, how the information will be used, and how best to present the information for effective and efficient understanding. An underlying consideration for making a decision is how accurate the information is or what the confidence is in a forecast, *i.e.*, the likelihood of that forecast being correct. Consequently, understanding associated uncertainty is critical for making a decision, imposing the responsibility upon NOAA to determine and convey that uncertainty to users in an effective manner along with NOAA's data and products.

Objective for R&D: *Improved understanding of how NOAA's stakeholders consume information.* NOAA's success in performing its mission depends on successful communication of its objectives and scientific and economic information and guidance with stakeholders and the public. Consequently, NOAA needs social science research on how best to communicate the scientific content of its data, products, and guidance to achieve 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 (Research)
- Optimized NOAA web presence with respect to communicating NOAA objectives, activities, products, services, and public issues (Development)

F. 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, including objective simulation-based approaches, 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:

- Established an initial corporate capability to perform rigorous quantitative, simulation-based analysis to optimize NOAA's global observing system, extensible to the breadth of NOAA's mission objectives (atmosphere, ocean, land, cryosphere, regional and global forecast) (Development)
- Data denial experiments (observing system experiments (OSE)) and observing system simulation experiments (OSSE) performed for the significant components of NOAA's observing system (Research)
- An observation system prioritization tool based on quantitative impact assessments employed to optimize model predictions and projections of the Earth system (Development)
- 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 (Development)

Objective for R&D: ***Maximize the amount of information from NOAA observing systems, partnerships, and leveraged non-NOAA observing capabilities.*** 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 available non-NOAA data to fill gaps is critical. This objective includes assessing the optimal location and density (spatial and temporal) of collected observations, informing the reconfiguration of existing NOAA observing systems.

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) (Development)
- Evaluated technical options for or modifications to NOAA's current observing system that enhance understanding, accurate assessments, characterizations, and monitoring, including ecosystem state and processes, or reduce costs (Research)
- Established a methodology to assess the optimal location(s) and density (spatial and temporal) of collected observations to inform optimization of existing NOAA observing systems (Development)
- 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, and cost 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. This objective entails creating prototype sensors and methodologies that provide new ways of sensing NOAA's required observation parameters, increased measurement accuracy, and increased effectiveness/efficiency in measuring observations (e.g., enhanced coverage, resolution, and collection time. This objective also includes evaluating the utility, effectiveness, efficiency, and economy of new sensors and methodologies, as well as their transition to applications and operations.

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 (Research)
- Marine sensors and biosensors capable of withstanding the stresses of an aquatic environment while providing accurate and reliable data (Development)
- Instrumentation for highly-accurate measurements of ocean acidification in both surface and subsurface locations (Development)
- Prototype instrumentation and methodologies for exploiting lidar and acoustics technologies to measure ocean parameters (Research)
- Next-generation geostationary, GOES-R series, and polar-orbiting, JPSS series, operational environmental satellites (Development)
- JPSS User Services free-flyer satellites (Development)

- Jason Continuity of Service satellites for altimetry observations of the oceans (Development)

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 or 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 (Development)
- Established the measurement uncertainty for non-satellite instruments and observation systems for data analysis and model assimilation (Development)

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: ***Exploit emerging data types and observing capabilities to satisfy NOAA's observing requirements and to support new and improved applications, products, and services.*** NOAA seeks better ways to address its observing requirements, as well as technologies and methodologies that permit the measurement of previously unmeasured or unmeasurable requirements. This objective comprises demonstrating new satellite remote-sensing and new non-satellite observation capabilities that address NOAA mission-related concerns, as well as designing and developing new operational satellite remote-sensing observation system capabilities. NOAA needs full exploitation of its observations for mission-oriented applications to maximize the return on its observing system investments, extracting value by applying the observation data to the Nation's benefit. This objective aims to more fully leverage regional observing system data from the U.S. Integrated Ocean Observing System (U.S. IOOS) and the broader international Global Earth Observing System of Systems (GEOSS), e.g., the Global Ocean Observing System (GOOS), the Global Climate Observing System (GCOS), the Global Terrestrial Observing System (GTOS), and the Global Atmosphere Watch (GAW). The R&D to achieve this exploitation comprises prototyping and demonstrating new/improved observational data products and applications, including fusing satellite, other remotely-sensed observations, *in situ* observations, and model-based analyses to generate the best possible depictions of the state of the oceans, atmosphere, climate, and marine ecosystems.

Over the next 5 years, NOAA aims to have:

- Demonstrated and transitioned to applications/operations NOAA's next-generation operational satellite data streams (Transition)
- Operationalized NOAA's first satellite ocean color capability (JPSS-1) (Transition)
- Operationalized the new polar-orbiting day-night band (JPSS-1) (Transition)
- Exploited international components of the Global Earth Observing System of Systems (GEOSS) for operational use, notably focusing on unique and complementary observations, such as satellite observations of sea-surface height, sea-surface salinity, sea ice extent and thickness, and sea-surface swell waves
- Automated sea-ice and snow cover data (Research)
- Completed a conceptual design of an extended range version of the FSV-40 Oscar Dyson class ship ships (Development)
- Transitioned unmanned airborne systems (UAS) and autonomous underwater vehicles (AUV) transitioned into NOAA's operational observing system (Transition)

Key Question: ***How can we improve the way we manage 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 has an obligation to the Nation to maximize the utility and value associated with its investment in observations and data management, in order to enable customer-focused outcomes that benefit society, the economy, and the environment. NOAA must ensure environmental data and products reach the users in a timely manner and in a usable format. 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 process and disseminate ever increasing volumes and types of environmental information. It will also require sound and standardized data management practices to organize and optimize data so that it can be effectively retrieved, preserved, analyzed, integrated into new data sets, and shared across communities and with the public. 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. Unfortunately, many of these observing systems were designed independently using different data systems, formats, quality assurance / validation, storage, and access/delivery methods. Data from NOAA observing systems must be accessible, high quality, documented, and archived for research and posterity. The reanalysis of historical data, cross-disciplinary searching, and collaborative editing capabilities must also be available.

Objective for R&D: ***Leverage advanced technologies to improve data access.*** NOAA needs to ensure that data customers have easy and convenient access to timely, well-documented and accurate environmental data and information products. This objective comprises evaluating emerging communication technologies and delivery mechanisms to reduce information distribution costs. The goal is to demonstrate enhanced access and use of environmental data through data storage and access solutions and the integration of systems.

Over the next 5 years, NOAA aims to have:

- Prototypes and tested internet services for real-time customization and localization, as well as on-demand visualization (Development)
- Evaluated commercial cloud resource solutions for providing reliable, scalable access to NOAA data and information at a reduced cost (Research)
- Demonstrated enhanced access and use of environmental data through data storage and access solutions and the integration of systems (Development)
- Advanced data assimilation through increased access to high-quality U.S. IOOS regional observing system data (Development)
- Demonstrated significantly improved Direct Broadcast capabilities on JPSS-1, with a much wider swath (Development)
- Demonstrated tools to help optimize use of growing volumes of observations and guidance (Development)

Objective for R&D: ***Leverage advanced technologies to improve data archiving technology.*** Massively increasing volumes of data requires that NOAA leverages the latest technological solutions for integrating and archiving its data, along with all necessary metadata, in order to provide the capability for readily accessing the data later with full understanding of the dataset. This objective includes developing a capability for an enterprise computer and information system that delivers environmental products ranging from local to global predictions of short-range, high-impact events to longer-term intra-seasonal climate forecasts.

Over the next 5 years, NOAA aims to have:

- Established an initial NOAA enterprise system for long-term safe storage and access for all critical NOAA data (Transition)
- Established initial distributed catalog services that enable comprehensive cataloging of NOAA data (Transition)

- Demonstrated an enhanced onboard data management capability, including developing a vessel/aircraft data management framework and a Rolling Deck to Repository (R2R) ship catalog (Development)
- Initiated a capability for an Operational Integrated National Information Management System supporting Marine Planning (Transition)
- Initiated prototyping, testing, and assessment of Cloud-computing techniques for data management applications and services (Development)

Objective for R&D: ***Enhance data stewardship.*** NOAA must develop and protect its investment in observations for future use while ensuring that the data reflect the highest quality, accomplished through the incorporation of the latest information, compilation techniques, scientific understanding, and calibrations. This task comprises producing authoritative quality-controlled environmental data records, such as Climate Data Records (CDRs) for designated parameters describing key physical and chemical processes that influence climate, weather, oceans, water quality, and ecosystems.

Over the next 5 years, NOAA aims to have:

- Reanalyzed designated observation data records, employing the most current knowledge, information, techniques, and calibrations (Transition)
- Demonstrated improved quality-control techniques for radar data (Transition)
- Demonstrated improved metadata regarding quality and lineage (Transition)

G. 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. An integrated system 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. Enhanced service capabilities and integration will lead to 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. This task encompasses 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, coupling, and nesting models.*** 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.; establish an Earth System Prediction Capability (ESPC), extending predictive capability from days to decades based on that enhanced understanding; and identify and quantify uncertainty and risk. This objective aims to improve model nesting capabilities that optimize modeling, data assimilation, and prediction between different spatial/temporal scales and coverage, as well as enabling a robust operations-to-research (O2R) environment that facilitates research and subsequent transitions to applications and operations.

Over the next 5 years, NOAA aims to have:

- Earth System Modeling Framework (ESMF) connectivity coupling the atmosphere, ocean, land, and ice at global and regional scales for NOAA's operational numerical models, serving as an initial NOAA ESPC capacity (Development)
- Initial modeling techniques and capabilities for coupling physical domains and ecosystem domains (Research)
- Prototyped optimal nesting between NOAA's operational global, regional, and coastal ocean models, as well as relevant operational ecological models (Development)

Objective for R&D: ***Advance Earth system modeling development, addressing underlying processes and relationships, seamless connectivity across spatial and temporal scales, and coupling across domains.*** 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. Processes of interest include 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, and space weather prediction. A key element of this objective is moving toward robust ecosystem modeling.

Over the next 5 years, NOAA aims to have:

- Extended NOAA's radiative transfer modeling capability to additional satellite sensors while demonstrating improved surface emissivity modeling, increased accuracy, and more efficient computation (Development)
- Demonstrated skilled modeling of sea-ice, particularly for the Arctic region, incorporating improved modeling of ice processes, *e.g*. ice melt, and coupling with atmospheric and ocean forcing (Research)
- Demonstrated a data-assimilating common-core surface and subsurface transport, mixing and fate (e.g., dispersion) modeling capability for ocean, coastal, and local scales (Transition)
- Prototyped data-assimilating hydrodynamic modeling capabilities that include nutrients, phytoplankton, zooplankton, and detritus (NPZD), and geochemistry, on relevant temporal and spatial scales for the oceans and coasts (Research)
- Prototyped modeling for understanding the factors affecting ocean and coastal ecosystems structure, function, and dynamics, demonstrating an initial NOAA capacity for projecting significant environmental changes over the next several decades and early warnings about threats to critical coastal and marine ecosystem services (Research)

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:

- Quantification of model uncertainty and skill for all NOAA operational models and forecast products, including quantified understanding of the uncertainties between different climate models in their projections of sea ice, atmosphere-ocean-cryosphere interactions, and ocean heat storage (Research)
- An initial capability to produce objective uncertainty information for models and products from the global to the regional scale (Development)
- Prototyped an ensemble prediction system for evaluating probability at multiple spatial and temporal scales (Development)
- Improved probabilistic predictions, with routine evaluations of the skill and accuracy of operational wind, solar, and moisture forecasts (Development)
- Raw and post-processed probabilistic products easily accessible at full spatial and temporal resolution (Development)

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. NOAA will 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 data assimilation methods for: coupled modeling; two-way nested modeling; and transport and fate modeling (Research)
- Hybrid and ensemble assimilation methods for standard, non-standard, and intermittent observations (Development)
- Assimilation of non-NOAA IOOS, private sector, and international GEOSS data, particularly non-satellite data, in NOAA research and operational models, addressing feasibility, data quality, skill improvement (Development)
- Demonstrated enhanced ocean data integration and assimilation for current and emerging data types, specifically salinity, ocean color parameters, synthetic aperture radar parameters (e.g. high-resolution winds, swell spectra), HF radar, freshwater inputs (riverine), and biogeochemical data (Research)

Objective for R&D: ***Produce best-quality reference data.*** 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:

- 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. (Transition)
- Reanalyzed operational model results, examining differences for enhanced understanding of environmental processes and relationships (Research)

H. 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 enable 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?*** Numerical prediction of the Earth systems is very computationally intensive, requiring large storage and access capacities and very fast speed. Users demand near-real-time predictions, driving operational production requirements and access to output data and products. Consequently, NOAA requires research and development on leveraging evolving commercial technology for innovative solutions to NOAA's high-performance computing and communication needs.

Objective for R&D: ***Identify economical technology 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. An important element of this objective is establishing a robust Operations-to-Research (O2R) high-performance computing environment.

Over the next 5 years, NOAA aims to have:

- Evaluated Graphical Processing Unit (GPU) technology within NOAA's IT architecture as a computing resource for running NOAA models (Research)
- Prototyped, tested, and assessed cloud-computing techniques, demonstrating shipboard cloud-computing (Research)

NOAA's strategic goals, and the key questions guiding R&D toward these goals, are the foci for integrating the work "on the ground" at the many organizations, from NOAA line offices (and their respective programs, laboratories, and science centers) to cooperative institutes, grantees, contractors and other partners. Within this framework of strategic goals and questions, the R&D objectives and targets are actively managed within the agency's corporate system for Strategy Execution and Evaluation (SEE) through regular planning, budgeting, monitoring, and evaluation activities.

IV. Interdependencies Among Objectives

[This section to come. It will provide an overview of how many of the R&D objectives identified above are dependent upon others.]

V. Themes of Innovation Across Objectives

A few recurring themes reflect this particular moment in the history of NOAA, and the agency's present potential for innovation. There are at least five challenges common to R&D activities performed in the interest of all of NOAA's goals. The first of these challenges is the research and development required to optimize the agency's core services: creating better ways to do what NOAA is best known for. Four other challenges define areas in which NOAA can create value for the Nation in qualitatively new ways, and in response to emerging challenges. These include handling big data, modeling and predicting ecosystem behavior, uniting the natural and social sciences, and, perhaps most challenging, preparing for the unpredictable.

Optimizing Core Services. Much of NOAA R&D is intended to improve its core mission responsibilities of predicting weather and climate and managing coastal and marine resources. NOAA will advance predictive services for weather and climate extremes. It will develop integrated real-time analyses of weather conditions, numerical-model-based information at regional & local scales for decision makers, and extend weather predictions from weeks to seasons to a year. The agency will develop Earth System Models for seasonal to centennial climate predictions and projections at regional to global scales, and it will improve understanding of atmospheric composition to provide policy relevant information. NOAA will optimize coastal mapping and charting technology, as well as develop new technologies to collect multi-disciplinary data to support living marine resource assessments.

Handling Big Data. Like so many other data-driven organizations today, NOAA must meet the challenge of managing large and complex data sets. It also has the opportunity to create innovative searching, sharing, analysis, and visualization capabilities. Making massive amounts of integrated environmental data available, and useful to the public could yield unprecedented benefits. NOAA aims to develop regional information and services to address particular societal impacts of climate change and variability. It will create advanced methods to quickly transform data streams into scientific advice for evaluating and adjusting coastal and marine resource management measures. The agency will integrate weather data and delivery systems, and enhancing decision support services through improved communications of weather risks.

Modeling Complex Systems. In many cases, what limits our ability to sustainably manage natural resources or response to natural hazards is the complex and dynamic interconnectedness of large-scale ecological systems. Ecosystems, given their individual components and processes are difficult to understand and even more difficult to simulate, but the potential value of making ecosystem predictions is enormous. NOAA will conduct research on ecosystem structure, productivity, behavior, resilience, and population connectivity, as well as effects of climate variability and anthropogenic pressures on managed resources. The agency will develop numerical ecosystem models within an Earth-system modeling framework to provide reliable forecasts for decision makers. It will expand research focusing on integrating climate change and ocean acidification impacts on ecosystems.

Uniting Natural and Social Science. NOAA's expertise has traditionally been in the natural sciences of the ocean and the atmosphere, but more and more, mission success depends on a holistic understanding of natural phenomena that are intertwined with human behavior and institutions. To this end, NOAA will expand integration of social science into NOAA's science, services, and stewardship. It will study the economic and behavioral elements of coastal resilience. The agency will work to integrate knowledge of multiple stressor risks into customer decision-making, and incorporate socio-economic research models into ecosystem-based management practices to provide resource managers with information on impacts, trade-offs, and distributional effects of management actions.

Preparing For the Unpredictable. Much of the research that NOAA conducts is unexpected, and in response to immediate needs for public safety and security. NOAA's unique research and development capabilities were deployed in the disasters in the Gulf of Mexico, in Fukushima, and along the East Coast during Superstorm Sandy. Events such as these are what Nassim Nicolas Taleb has called "black swans" - high-impact events that only seem predictable in retrospect. We cannot know for sure when disaster or, for that matter, opportunity may strike. But we do know that maintaining - and expanding - the diversity of NOAA's expertise and experience makes the Nation and the world more resilient to the high-impact events that have yet to occur.

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 "soft" assets (i.e., people, institutions, and partnerships) as well as "hard" assets (i.e., data, models, computing, and test-beds).

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. [36]

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.[37]

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, a significant portion of those conducting NOAA R&D are from academic, private, or not-for-profit

---

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

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

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

NOAA's laboratories, science centers, programs, and Cooperative Institutes 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 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, the private sector, non-profit organizations, state, local, and tribal governments, and the international community.[38]

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.

II. "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.[39]

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

---

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

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

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.[40]

Escalating costs to support existing and emerging observations require rigorous analysis and determination of the most effective observing portfolio.

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 collect and effectively manage ever increasing volumes and types of environmental information. 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 modeling 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

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

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.[41]

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 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.[42]

---

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

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

Section 4. A Healthy Research and Development Enterprise

I. Values

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.[43] 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. NOAA's research must be conducted with the utmost integrity and transparency. The recently established NOAA Administrative Order on Scientific Integrity establishes a code of conduct for scientists and science managers that allows us to operate as a trusted source for environmental science. With this Order, NOAA has seized an opportunity to strengthen the confidence -- of scientists, decision-makers who depend on NOAA science, as well as the general public -- in the quality, validity, and reliability of NOAA research and development.[44]

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 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."[45]

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

---

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

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

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

marketing method, or a new organizational method in business practices, workplace organization or external relations.[46]

Ideas and inventions are necessary for innovation, though alone 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 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. As such, it must maintain an appropriately balanced portfolio of activities (see section 4.II.A below for more details on portfolio management). It must balance the need for long-term outcomes with outcomes that are more immediate. It must also balance the R&D needs among its strategic goals and enterprise objectives. Further, NOAA's R&D enterprise must be balanced with respect to demand for service and stewardship improvements (the "pull") with the new ideas that could revolutionize how goals are accomplished (the "push").[47]

NOAA should strive for a balance of incremental, low-risk research investments with high-risk, high-reward initiatives (i.e., transformational research). Indeed, part of NOAA's scientific strength rests on its ability to encourage risk and, in doing so, tolerate failure. The agency should also balance the potential of research directed by discrete, well-defined challenges with research that has objectives that are less well-defined - knowing that often, the highest risk, most potentially transformative research is that which has the most tangible, time-bound objectives. The right balance on any of these dimensions is often a judgment call, but we can have better faith in such judgments when they are informed by the knowledge of how heavily NOAA has invested in R&D of one type or another.

E. Collaboration

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.[48]

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

---

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

[47] 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.

[48] 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.

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. Capabilities

A strong R&D enterprise means that the agency funds and 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 results to subsequent planning, budgeting, and execution. Greater detail on this can be found in NOAA’s Administrative Order on Strengthening the R&D Enterprise.

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 Management

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 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, and the options within each dimension, as stated by the Science Advisory Board.[49] There is no one option that is inherently better or

[49] NOAA Science Advisory Board (2012). *Research and Development Portfolio Review Task Force - Additional Information*, Available at:

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[50]
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 attention and effort 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.

The second dimension in need of rebalance is *type of process*, within which NOAA must invest a larger proportion of its attention and effort 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

---

http://www.sab.noaa.gov/Working_Groups/current/SAB%20R&D%20PRTF%20Additional%20Information%20Final%2005-09-12.pdf

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

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.

[Incorporate PRTF results in this section]

B. Planning R&D

To achieve its mission, NOAA must continually strengthen the quality, relevance, and 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 build 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".[51] 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 partnerships with the external research community, whose valuable contributions are critical to meeting

[51] 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.

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 of hurdles than from multiple opportunities to iterate objectives with leadership and stakeholders as capabilities emerge from the work.[52] 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 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

---

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

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.[53] 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. National Sea Grant follows a rigorous review of all its state Sea Grant programs. Formal policy establishes that peer review panels investigate every OAR lab every five 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.[54]

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 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

[53] 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.

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

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 stakeholders 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 mission agency. NOAA's next breakthrough in research and development may depend upon the unique knowledge or needs of a partner or customer. NOAA's long-term success will be determined by its capacity to effectively engage individuals and other organizations.

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 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 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 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. NOAA will increase outreach to community leaders and decision makers, engage stakeholders and the public through innovative technologies, forge strategic connections with science education communities to advance scientific and technical education opportunities, and attract populations who are currently underrepresented in the science workforce. NOAA will also work with other Agencies, including other Federal scientific and environmental Agencies, to further their education and outreach initiatives.

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

Section 6. Appendices

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 advanced 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 and 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 (FMPs) 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): 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. 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. 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.

<u>Non-Legislative Drivers</u>

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: [TBD]

Montreal Protocol on Substances that Deplete the Ozone Layer: [TBD]

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 (AFSC)
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)
The Northeast Fisheries Science Center is the research arm of NOAA Fisheries in the region. The Center plans, develops, and manages a multidisciplinary program of basic and applied research to: (1) better understand living marine resources of the Northeast Continental Shelf Ecosystem from

the Gulf of Maine to Cape Hatteras, and the habitat quality essential for their existence and continued productivity; and (2) 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 marine environmental quality. The functions are carried out through the coordinated efforts of research facilities located in Massachusetts, Rhode Island, Connecticut, New Jersey, Washington DC, and Maine.

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)

The Northwest Fisheries Science Center conducts research to conserve and manage living marine resources and their marine, estuarine and freshwater habitat. The NWFSC's research supports NOAA Fisheries' Northwest Regional Office, the Pacific Fishery Management Council and other agencies in managing more than 90 commercially important fish species, recovering over 30 threatened and endangered fish and marine mammal species, and identifying and mitigating coastal and ocean health risks. The NWFSC also fills an important role, together with the Southwest Fisheries Science Center, in providing the scientific knowledge to inform management decisions on the stewardship of the California Current Large Marine Ecosystem (CCLME). The California Current encompasses a broad range of coastal ecosystems, diverse habitats and biological communities. The CCLME provides vital habitat for living marine resources, economic development within coastal communities, and aesthetic enjoyment.

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 is 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[55] (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[56]

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

[55] This counts people working at a NOAA facility, whether or not the person is a federal employee, who are encouraged or expected to publish peer-reviewed technical reports, journal articles, or other peer-reviewed materials--even if those people would not be a lead author. Each R&D unit leader had the option to include additional employees whose scientific work is integral to the scientific research of the unit and/or who facilitate and enable peer-reviewed publications but may not necessarily appear as co-authors on the papers.

[56] See footnote above.

Appendix D. References