Research in NOAA

January 2005

Toward Understanding and Predicting Earth's Environment

A Five-Year Plan: Fiscal Years 2005-2009

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please visit the
NOAA Research Council at:

www.nrc.noaa.gov

Preface

Research underpins the science-based mission of the National Oceanic and Atmospheric Administration's (NOAA's) and research is a cross-cutting priority in the NOAA Strategic Plan. Understanding and predicting changes in Earth's environment involves a continually evolving process of discovery, observation, and analysis to advance our knowledge of the processes that sustain the natural environment.

The NOAA Research Council, a committee of senior scientists from NOAA's line offices, developed this plan to integrate NOAA's research activities across the agency. This plan reflects the Research Council's recognition that an interdisciplinary, coordinated, cross-program approach is fundamental to planning and carrying out the research needed to support NOAA's mission. It also recognizes the need to leverage the assets and capabilities of NOAA's many scientific partners to take full advantage of the expertise available throughout the research community.

Given its focus on the next five years, this plan deals primarily with shorter-term outcomes and the analysis and testing needed to transition research to operations and information products. Because research is an on-going process, this five-year plan is only one step in NOAA's long-range research planning, and as such, it is one of the tools used by NOAA to identify priorities for longer-term research, both within and across programs.

The research described in this plan supports and is organized according to the four NOAA mission goal areas identified in the NOAA Strategic Plan: Protect, Restore, and Manage the Use of Coastal and Ocean Resources through an Ecosystem Approach to Management (**Ecosystems** mission goal); Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond (**Climate** mission goal); Serve Society's Needs for Weather and Water Information (**Weather and Water** mission goal); Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation (**Commerce and Transportation** mission goal). Mission goal teams provide a linkage across NOAA line office research programs. The teams have identified outcomes for each goal and developed relevant performance objectives and research milestones.

As new requirements for research come to the attention of the Council, they will be included in subsequent plans. Further, because this plan is an evolving document, the Council plans to revisit the research activities and milestones yearly to ensure that these remain relevant and that areas of emerging science are considered and incorporated into the plan as appropriate. With regular feedback from the research community, operational users, and stakeholders, we will ensure that NOAA services are based on sound science; evaluate and improve the peer-review process; and develop best practices for NOAA research

Many of the research areas identified in this plan have been part of NOAA's ongoing research program, while others are fairly new to the NOAA research portfolio. Among the latter, for example, are approaches to integrate social science into weather, climate, and ecosystem research.

NOAA serves a large and diverse community of users and stakeholders both in the United States and abroad. NOAA research is carried out in partnership with many other research entities that have provided and will continue to provide valuable input to NOAA's research planning process. NOAA looks forward to working with our partners in implementing this plan and keeping it current.

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1. Introduction

The mission of the National Oceanic and Atmospheric Administration (NOAA) demands a forward-thinking, inter-disciplinary perspective. Whether we are trying to improve weather forecasts, developing innovative tools to assess the health of marine ecosystems, or exploring and describing ocean habitats and processes, discovering more about how our environment functions and applying that knowledge are crucial to our success. NOAA scientists and our external partners work together to bring research results to bear on improving the quality of people's lives and those of future generations.

NOAA's Mission

To understand and predict changes in Earth's environment and conserve and manage coastal and marine resources to meet our nation's economic, social, and environmental needs.

NOAA's science mission is challenging because of the complexity of the natural system with which we must deal. Variability in Earth's environment is governed by many interacting processes. Sunlight shining on Earth is the external source of energy. Variability in the atmosphere's transparency to visible and infrared radiation—caused by clouds, dust, water vapor, or gases—influences how much sunlight reaches Earth's surface and how much infrared radiation escapes back to space. Processes in the ocean and atmosphere then modulate how and where heat is stored, transported, and exchanged within and between the atmosphere and the ocean. Patterns of variability can have large time scales and remote influences; variations in tropical Pacific sea surface temperatures, for example, influence U.S. climate. The local weather prediction and warnings needed for land-based and seaborne commerce rely on global data and models run on global, regional, and local scales. Ecosystems respond to weather and climate, as well as biological and chemical processes. Human impacts such as changes in land use can influence the storage and transport of heat and thus alter weather and climate.

Earth system variability is, therefore, dynamic and occurs at local, regional, and global levels, as well as multiple time scales from minutes (in the case of severe weather) to decades and longer (in the case of climate and sea-level change). The goal of NOAA's research is to identify and improve the measurement of these many variables; to advance understanding of the physical, chemical, and biological processes in the atmosphere, oceans, and land-surface; and to enable predictions of future events and changes. The expertise needed to do this research encompasses many disciplines; therefore, the research approach must be interdisciplinary and must integrate the study of the natural environment with human activities and societal needs.

Research is the cornerstone on which to build and improve environmental forecasts that can enable ecosystem-based management and provide critical weather and climate information for decisions makers and the public. This five-year plan lays the path for how NOAA's research enterprise will deliver, in the near term, improvements to existing forecasting tools. For the longer term, NOAA is developing new observation systems, models, and other assessment tools that will advance environmental forecasting and management. This plan identifies outcomes for the near term and the research milestones we will use to measure progress towards achieving those outcomes, framed within a vision of a future NOAA. We also describe how we prioritize research, who our partners are, and the mechanisms by which we conduct research.

This is an exciting time for the oceanic and atmospheric sciences. NOAA is leading the way in delivering the information and services that the nation will need now and in the future to make intelligent decisions about our environmental resources. These pages reflect NOAA's response to some of our nation's most challenging environmental needs.

2. Framing NOAA's Future Vision

NOAA's Vision

An informed society that uses a comprehensive understanding of the role of the oceans, coasts, and atmosphere in the global ecosystem to make the best social and economic decisions

Robust environmental observation, assessment, and prediction capabilities are at the heart of NOAA's mission. Over the next five years and beyond, NOAA and its regional, national, and international partners will exploit new technologies to better understand, monitor, and predict the behavior of Earth's complex natural systems. We will achieve this capability by working with our federal and state agency partners to establish regional observing systems and with the international community to build an integrated Global Earth Observing System of Systems and linking it with a comprehensive Earth system model. This model will be used to analyze and predict the state of the atmosphere, the oceans, and the land surface, taking into account the hydrological and biogeochemical cycles that couple these components of the Earth system. The integrated observing and modeling system will, in large part, be defined by and be responsive to local needs; at the same time it will provide an international framework that will allow us to predict the local impact of global phenomena and the global consequences of local activities.

In addition to the capabilities described above, NOAA must continue to develop a robust social science capability to link societal benefits to the services and research we provide. This capability will assist in research planning, advance our understanding of linkages between economics and social processes relevant to NOAA activities, and improve decision-making based on enhanced products and services. To meet these needs, NOAA is implementing an agency-wide social science research program. Dimensions of this effort include integrating contributions from multiple social sciences; taking into account the interdependencies of physical, biological, and social sciences; and integrating social science research into NOAA planning and budgeting processes to facilitate use of social science in decision-making.

2.1 A Key Direction for Research in NOAA over the Next Five Years

A priority for NOAA's research is to create an Earth system model based on improved understanding of the components of that system and their interactions. To provide the data needed to study the Earth system and to enable advanced forecast and assessment models, NOAA will also lead the development of an integrated Earth observing system. In addition, NOAA will establish regional observational and research networks to address specific concerns, such as hurricanes, drought, tornadoes, and ecosystem degradation. The efforts of the NOAA research community will be coordinated to support NOAA's research focus.

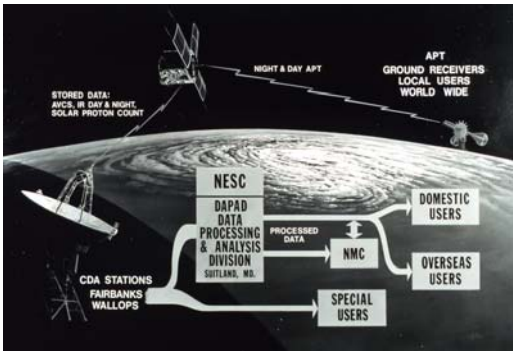
2.1.1 Earth System Modeling

Models will be constructed to assimilate new observational data, providing forecasts and diagnostic assessments of weather, climate, and conditions in the oceans well beyond those currently produced. These models will encapsulate our understanding of the complex physical and biological processes that constitute the Earth system. To understand, model, and predict the evolution of these processes will require new inter-disciplinary approaches that link climate, weather, water, land, ocean, and biochemical processes. Modeling research will focus on linking Earth system model simulations with regional coupled

ecosystem models. The Weather Research and Forecasting Model[1] is one example of a collaborative modeling research effort that will provide a state-of-the-art, inter-disciplinary modeling system for regional weather and air quality prediction and will accelerate the transition of new NOAA weather program technology from research into operations.

2.1.2 Observing Systems and Networks to Support Earth System Modeling

In the years ahead, NOAA will work with domestic and international partners to develop a Global Earth Observing System of Systems. GEOSS will be used to "take the pulse of the planet," providing a level of information about Earth not previously achieved. The observing system strategy must be directed at both local and global scales and must effectively observe and monitor a comprehensive span of environmental phenomena. Critical to this system will be a data management and assimilation strategy that is coordinated with both domestic and international partners.



NOAA's current observing systems measure more than 500 environmental parameters from platforms that include satellites, ground-based monitoring systems, ocean buoys, ships, and aircraft. These observing systems are linked through such international collaborations as the Global Climate Observing System (GCOS), the World Weather Watch (WWW), and the Integrated Ocean Observing System (IOOS) and Global Ocean Observing System (GOOS). To move toward an even more integrated ecological observing and data system for the planet, NOAA research is advancing the application of our current observing systems and data products and participating in the development of new systems, all of which need to be cross-linked to maximize their information content and utility.

The GEOSS and Earth system model will be combined with regional assessment and process studies to develop "place-based" environmental information of value to the public. Regional weather and climate affect regional ecosystems and the human communities within them. All transportation modes—air, land, and marine—are affected by weather and climate. Regional water and air-sheds affect air and water quality, which in turn affect habitats essential for all living organisms, as well as human health. Building all of these local linkages into the observing and modeling systems will be critical to our success. Examples of the near-term actions we plan to take are (1) establish regional research coordination and planning teams in two or three regions relevant to Large Marine Ecosystems and coastal regional observing systems, and (2) establish or enhance national research teams to address issues surrounding aquaculture, urbanization/coastal communities, coral reefs, invasive species, protection and restoration of habitats, protected species and fisheries. NOAA will work with federal, state, and regional science partners in developing the regional research strategies required to develop and implement these systems.

2.1.3 NOAA Observing Systems Research

NOAA's observing systems are a critical part of its infrastructure under the Mission Support goal that supports the outcomes in all four of the Mission Goals previously mentioned. These observing systems measure more than 500 environmental parameters via platforms that include geostationary operational environmental satellites (GOES), polar-orbiting operational

[1] A multi-partner project that includes the NOAA National Centers for Environmental Prediction, the Air Force Weather Agency, and research laboratories such as the National Center for Atmospheric Research (NCAR) and the NOAA Forecast Systems Laboratory.

environmental satellites (POES), ground-based weather and climate monitoring systems, ocean buoys, submersibles, ships, and aircraft. Continuous research is required to improve the information products obtained with these systems, to design new products, and to develop the technology for observing systems of the future. Mission Support research links the design, acquisition, and application of observing platforms to evolving user needs and applications. In addition, this research explores integration opportunities across observing systems and data sets to provide better products for the operational community (for example, new forecast models using both satellite and ground-based GPS data) and for researchers (for example, long-time series data sets for climate change research).

NOAA's satellite observing systems, provide a significant portion of the Earth observation data used by NOAA as well as users around the globe, including NOAA's international partners, commercial users, defense agencies, and the academic research community. Working with the operational community, NOAA conducts ongoing research to increase the accuracy and utility of satellite products and provides on-orbit calibration and validation for operational and experimental satellites used in generating operational products, validating new scientific applied solutions, and to ensure that the accuracy of satellite derived algorithms/products meet user or system specified requirements. These ongoing research and development and operational calibration/validation efforts contribute directly to improved forecasts through improved model initialization and the visual comparison of analyzed satellite data with other information in National Weather Service Forecast Offices. Improvements in satellite data extraction algorithms allow NOAA to observe and monitor various environmental parameters that contribute directly to economic and environmental decisions affecting the nation and its natural resources. Each year numerous algorithms are transferred to operations that improve the ability to make informed decisions about our environment.

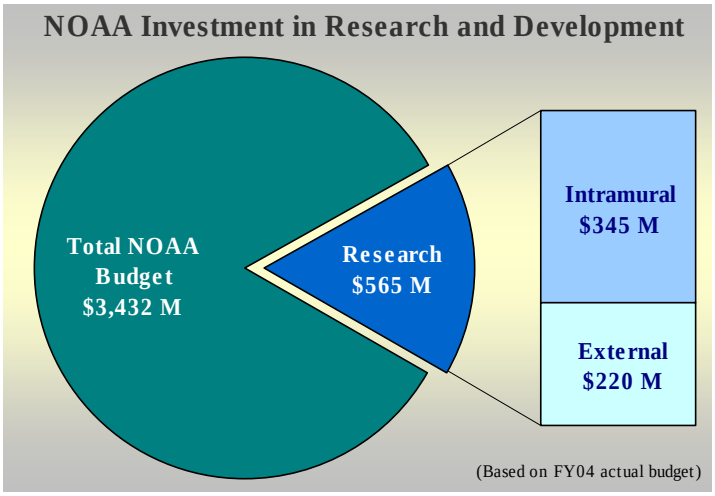
To meet expanding demand for new types of Earth measurements, and for greater data accuracy and coverage (both spatial and temporal), NOAA is planning to deploy major new observing systems such as NPOESS, GOES-R, and an enhanced Climate Reference Network. Acquisition of these systems requires research to develop the sensors and products needed to meet system and user requirements.

2.2 The Role of Our Research Partners

NOAA supports an internal research enterprise to respond to immediate research needs (including those required by regulatory and judicial mandates); to sustain long-term monitoring and modeling capabilities; and to assure that research is forward-looking and responsive to programmatic needs. NOAA also relies on research partners to complement and augment NOAA's internal research capabilities; to provide critical expertise in areas not fully represented inside the agency; and to share new ideas and technologies. Our research partnerships engage other federal agencies; academia; the private sector; state, local, and tribal governments; and the international community.

Extramural research needs are identified and funding is requested and allocated, and progress is reported through NOAA's planning, programming, and budgeting and execution process. This process starts more than two years prior to the execution year. Priorities for research and other activities are identified in the planning phase primarily by considering progress in achieving strategic mission goals. The planning cycle for FY08, which will commence in March 2005, will include an opportunity for NOAA's research partners to identify priorities and comment on candidate priorities in Summer 2005.

Once funds are appropriated, NOAA uses a variety of mechanisms to implement extramural research. These include grants to individual scientists; Cooperative Institutes; the university-based National Sea Grant College Program; and NOAA's Undersea Research Program. Prior to the start



of each fiscal year, a notice of the availability of grant funds for the upcoming fiscal year is announced via a Federal Register notice. This Notice provides a single source for program and application information related to NOAA's competitive grant offerings, Additional program initiatives unanticipated at the time of the publication of the Notice may be announced through both subsequent Federal Register notices and at *http://www.ofa.noaa.gov/~amd/SOLINDEX.HTML.* NOAA's Cooperative Institutes – academic institutions that collaborate in a large portion of NOAA's research – play a vital role in enhancing our capabilities and in broadening NOAA's ability to provide the expanding array of environmental assessment and predictions required to address societal needs. The National Sea Grant College Program and NOAA's Undersea Research Program play essential roles in increasing our understanding of ecosystems by funding research targeted to the needs of resource managers and to enhance ecosystem approaches to management.

Table 1 lists NOAA's laboratories and cooperative institutes. A more detailed description of these critical elements of NOAA's research infrastructure is included in Section 9.

Table 1. NOAA Laboratories, Centers, and Cooperative Institutes

Laboratories	Cooperative Institutes
National Environmental Satellite Data and Information Service	
Center for Satellite Applications and Research	Cooperative Institute for Climate Studies Cooperative Institute for Oceanographic Satellite Studies Cooperative Institute for Meteorological Satellite Studies
National Marine Fisheries Service	
Alaska Fisheries Science Center Northeast Fisheries Science Center Northwest Fisheries Science Center Pacific Islands Fisheries Science Center Southeast Fisheries Science Center Southwest Fisheries Science Center	Cooperative Institute for Marine Resources Studies Cooperative Marine Education and Research Program
National Ocean Service	
Center for Coastal Fisheries and Habitat Research Center for Coastal Monitoring and Assessment Center for Environmental Health and Biomolecular Research Ocean Systems Test and Evaluation Program Center for Sponsored Coastal Ocean Research Coast Survey Development Laboratory Hollings Marine Laboratory National Geodetic Survey Geosciences Research Division National Geodetic Survey Remote Sensing Research Group	Cooperative Institute for Coastal and Estuarine Environmental Technology Joint Hydrographic Center

National Weather Service	
Environmental Modeling Center Meteorological Development Laboratory Office of Hydrological Development Laboratory Space Environment Center	Cooperative Institute for Applied Meteorological Studies Cooperative Institute at the Pennsylvania State University Cooperative Institute for the Prediction of Hydrometeorological Hazards in the Northeastern United States Cooperative Institute for Regional Prediction Cooperative Institute for Tropical Meteorology
Office of Oceanic and Atmospheric Research	
Aeronomy Laboratory Air Resources Laboratory Atlantic Oceanographic and Meteorological Laboratory Climate Diagnostics Center Climate Monitoring and Diagnostics Laboratory Environmental Technology Laboratory Forecast Systems Laboratory Geophysical Fluid Dynamics Laboratory Great Lakes Environmental Research Laboratory National Severe Storms Laboratory Pacific Marine Environmental Laboratory	Atmospheric Investigation, Regional Modeling, Analysis and Prediction Consortium Cooperative Institute for Arctic Research Cooperative Institute for Atmospheric Sciences and Terrestrial Applications Cooperative Institute for Climate and Ocean Research Cooperative Institute for Climate Applications and Research Cooperative Institute for Climate Science Cooperative Institute for Limnology and Ecosystems Research Cooperative Institute for Marine and Atmospheric Studies Cooperative Institute for Mesoscale Meteorological Studies Cooperative Institute for New England Mariculture Cooperative Institute for Research in the Atmosphere Cooperative Institute for Research in Environmental Science Joint Institute for Marine and Atmospheric Research Joint Institute for Marine Observations Joint Institute for the Study of the Atmosphere and Ocean

3. Research Planning in NOAA

NOAA strives to balance our near-term responsibility to address immediate information needs with a long-term commitment to visionary research that will create the next generation of environmental services. A balanced portfolio of near- and long-term research will yield the greatest benefits to our nation, enable credible science to inform policy debates around today's most pressing issues, and provide tomorrow's solutions.

NOAA's Strategic Plan (available at http://www.spo.noaa.gov) identifies research as a major cross-cutting priority in the agency and expresses NOAA's commitment to support high-quality research to underpin its environmental assessment, prediction, and ecosystem management missions. Derived from its mission statement, NOAA has identified four major mission goals, all supported by a wide array of observing system platforms which constitute the infrastructure of the mission support goal as described in Section 2.3.1.

- ***Ecosystems-****—Protect, Restore, and Manage Use of Coastal and Ocean Resources through Ecosystem-Based Management*
- ***Climate****—Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond*
- ***Weather and Water****—Serve Society's Needs for Weather and Water Information*
- ***Commerce and Transportation****—Support the Nation's Commerce with Information for Safe, Efficient and Environmentally Sound Transportation*

Achieving these goals will require answering complex scientific and socioeconomic questions that can only be addressed by the concerted effort of the global research community. Research and development activities within NOAA populate each of these goals, while ongoing interactions among the goals help NOAA work toward a seamless suite of products based on sound, state-of-the-art science.

NOAA's research activities are planned at the mission-goal level. Scientists from all of NOAA's line offices work together to coordinate common requirements, leverage assets, and establish research and development management practices to maximize success. A close working relationship between our research and operational elements enables research to be responsive to operational needs and keeps operational units informed about the latest scientific developments and possible service enhancements.

3.1 Planning, Programming, Budgeting, and Execution

This Research Plan unifies NOAA's research enterprise by using a Planning, Programming, Budgeting, and Execution System (PPBES) to guide all research activities and to facilitate integration of all research assets. NOAA's research activities need to support the mission goals described in the NOAA Strategic Plan, and this cross-cutting approach to managing NOAA's research enterprise ensures the greatest value for the American public.

NOAA's research activities fit within the larger goal of accomplishing NOAA's mission. PPBES is a formal, systematic structure for making decisions on policies, strategies, capability development, and resource allocation. PPBES provides the framework to develop a strategic vision for NOAA (Planning), a five-year investment strategy that determines the best way to move NOAA toward that strategic vision (Programming), a budget to accomplish its mission (Budgeting), and an assessment of progress in meeting goals and objectives (Execution). PPBES allows management

to look across NOAA and prioritize activities and resources in areas where there is the greatest global and national benefit.

PPBES incorporates and builds on other governmental management processes. Evaluation of progress towards a goal is good management practice and is required under the Government Performance and Results Act (GPRA). PPBES uses a number of management tools to support informed decision making, including:

- Requirements based management - all activities must support a known requirement such as a legal mandate, a policy, constituent requests, or the scientific advances needed to support progress toward achieving a requirement.
- Performance based management - measuring performance allows managers to evaluate progress and make decisions on the reallocation of existing resources and requests for additional resources, or pursuing other research avenues to achieve desired results. Performance measurement within NOAA is consistent with both the Office of Management and Budget Program Assessment Rating Tool (PART) and the GPRA.
- Alternative Analysis - there are often multiple possible ways to achieve a desired result. Careful examination of the ways a goal can be achieved helps to ensure NOAA optimizes its investments.

Active participation by the research community in PPBES ensures a robust research program that contributes to achieving NOAA's goals. There are a number of groups that participate in PPBES that can benefit from input by the research community. These groups include:

- Program Management Teams. Each NOAA program has an officially designated Program Manager. Each Program Manager uses a team of experts on different aspects of the program to assist in assessing program requirements, objectives, and performance. Participation by the research community at the program level is important to ensure research efforts are consistent with and support program requirements and objectives.
- Goal Teams. Each Goal Team has an officially designated Goal Team Lead. Goal Team Leads are responsible for the development of plans that integrate program capabilities to best achieve NOAA's mission goals. Participation by the research community at the Goal level is important to ensure research efforts support NOAA's strategic goals.
- Councils. The NOAA Research Council (described in section 3.3) has the opportunity to assess program plans developed by the Goal Teams. The Council provides its recommendations to NOAA leadership on these plans and can propose alternative courses of action that, while meeting the needs of a Goal Team, also strengthen the overall NOAA research effort.
- Line Offices. Line Offices are responsible for executing NOAA's budget. The research community's participation in Line Office processes is critical to ensure that effective research is accomplished and that research results are appropriately transitioned into operational systems and processes.

3.2 Transfer of Science and Technology Advances to Operations and Information Services

NOAA is committed to maximizing the value of our research to the American people. Our researchers work closely with our operational units to improve performance in all of our existing activities, develop innovative products and services, and strengthen the scientific basis of our regulatory decisions. End to end planning outlines the path for the transfer of new technologies,

research results, and observational advances into improved operational capabilities. This transition is achieved through close collaboration between researchers and service delivery professionals at all phases of the research and development process.

One tool for enabling the transition of research to operational use is the testbed. Testbeds provide the research community a setting to work directly with NOAA's operational elements through established testing and evaluation protocols with clearly defined goals and decision points for cost-effective and rapid transition of new research and technologies into routine operations. With the goal of accelerating infusion of technology and research results into operations, testbeds provide the opportunity to address the following:

- System design studies for the global observing system network
- Assessing scientific breakthroughs and new techniques to identify advanced analysis techniques, numerical forecast models and methods, observational systems, and climate-water-weather linkages having potential for significantly improving forecasts
- Using advanced statistical and numerical weather prediction model output (especially model ensemble information) and stimulating further model enhancements
- Refining computer-based models, products, and observations in a quasi-operational information technology environment subject to metrics that mandate good scientific performance while meeting ease-of-use, reliability, and operational criteria
- Developing enhanced verification capabilities
- Exploring societal impacts resulting from improved products and services

Some examples of testbeds currently being used to facilitate this transfer are:

- **Advanced weather and climate models**. NOAA's laboratories and operational modeling centers are world leaders in the development and use of weather and climate models. NOAA has been a sponsor of community modeling approaches—such as the Earth System Modeling Framework and the Weather Research and Forecasting model—that will accelerate the transfer of the new models into operations. Developmental test centers and companion operational test centers are organized to facilitate the transition from research to operational implementation.
- **Advanced satellite data utilization**. NOAA has contributed to the development of the Joint Center for Satellite Data Assimilation and in the research effort to accelerate the use of existing and planned research and operational satellite data in NOAA's operational models.
- **Air quality prediction**. NOAA research laboratories, NOAA's National Weather Service, and external partners have worked for several years in a New England testbed to improve air quality prediction. The first operational results of this collaboration are beginning to emerge.
- **Tropical prediction**. The Joint Hurricane Testbed, sponsored by the U. S. Weather Research Program, accelerates the infusion of new technology to improve hurricane landfall predictions. Hurricane model and observational advances developed by NOAA research laboratories and the extramural community are used by NWS operations, with new versions continually being evaluated.

To facilitate the smooth transfer of research to operations and information services, research and operations activities must share planning, management, and fiscal responsibilities throughout the transition process.

3.3 Oversight of Research

NOAA is committed to maintaining the excellence that has made us a world leader in environmental research and management. NOAA's research activities are subject to peer review for scientific merit and to thorough management oversight to ensure mission relevance.

NOAA employs a senior management official and three oversight boards to integrate and review the agency's research and development activities. These bodies ensure that our research enterprise maximizes its relevance to NOAA's mission goals.

The Deputy Administrator is the senior management official with the responsibility for overseeing NOAA's research programs. The Deputy Administrator adjudicates issues across NOAA's research program elements, and recommends to the NOAA Administrator the creation and implementation of policies and plans for transferring research to operations and information services.

The NOAA Executive Council is the highest level executive management body within NOAA. The purpose of the NOAA Executive Council is to advise the NOAA Administrator before final decisions on NOAA wide policies, including research policies, are made. It is the forum through which NOAA senior management provides advice and counsel on high level operation and management issues. The NOAA Executive Council also provides active oversight of NOAA's research.

The NOAA Research Council is an internal body composed of senior scientific personnel from the Office for Oceanic and Atmospheric Research (OAR), the National Environmental Satellite Data and Information Service (NESDIS), the National Marine Fisheries Service (NMFS), the National Ocean Service (NOS), the National Weather Service (NWS), NOAA Marine and Aviation Operations (NMAO), and the Office of Program Planning and Integration (PPI). The Council provides corporate oversight to ensure that NOAA's research activities are of the highest quality, meet long-range societal needs, take advantage of emerging scientific and technological opportunities, and shape a forward-looking research agenda. The Council is chaired by the Assistant Administrator for OAR and provides support to the NOAA Executive Council and the Deputy Administrator.

The NOAA Science Advisory Board is an external 15-member Federal Advisory Committee composed of eminent scientists, engineers, resource managers, and educators who advise NOAA on long- and short-range strategies for research, education, and the application of science to resource management and environmental assessment and prediction. The advisory board assists NOAA in maintaining a current understanding of scientific issues critical to the agency's mission. Members are appointed by the NOAA Administrator to serve a three-year term, with the possibility of renewing once.

NOAA ensures the quality, objectivity, utility, and integrity of research information according to guidelines issued as a result of Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554). NOAA acknowledges that the quality of the information we produce is an important management objective critical to fulfilling our mission. NOAA's research information and products comply with the guidelines issued by the Office of Management and Budget, the Department of Commerce, and NOAA (http://www.noaanews.noaa.gov/stories/iq.htm).

3.4 Evaluating Success

The ultimate test of our success is whether we are making a difference to the American people and to the global environment we all share. We will continue to seek input from both the scientific community and the American public to ensure that our research priorities evolve to meet society's needs and that our products and services provide value to our customers. We expect to revise this plan annually to reflect input from the research community and the public.

NOAA will hold general and more focused research community workshops to address research breakthroughs, leverage opportunities for collaborating with our research partners, and identify and fill research gaps. Dissemination of research results at national and international meetings and contribution to international science assessments are other venues for exposure of NOAA research.

Our success will depend upon the active participation of public and private stakeholders and by continuing collaboration with researchers in academia, private industry, the federal sector, and the international research community.

4. Overview of NOAA's Mission Goals

NOAA is a mission agency dedicated to providing a wide array of products and services to the nation. The desired *outcomes* of all of our activities are expressed in the NOAA Strategic Plan and organized by Mission Goal in Table 2 below. All four Mission Goals are also supported by the Mission Support Goal activities described in Section 2.3.1. All of NOAA's research and development activities are directed towards achieving these mission outcomes. Sections 5 through 8, devoted to each Mission Goal, identify the role that research plays in helping NOAA achieve each of the outcomes.

Table 2. NOAA's Outcomes by Mission Goal

Mission Goal	Outcomes
Ecosystems	• Healthy and productive coastal and marine ecosystems that benefit society • A well informed public that acts as steward of coastal and marine ecosystems
Climate	• A predictive understanding of the global climate system on time scales of weeks to decades with quantified uncertainties sufficient for making informed and reasoned decisions • Climate-sensitive sectors and a climate-literate public effectively incorporating NOAA's climate products into their plans and decisions
Weather and Water	• Reduced loss of life, injury, and damage to the economy • Better, quicker, and more valuable weather and water information to support improved decisions • Increased customer satisfaction with weather and water information and services
Commerce and Transportation	• Safe, secure, and seamless movement of goods and people in the U.S. transportation system • Environmentally sound development and use of the U.S. transportation system

Performance objectives have been developed to describe the metric that will be used to evaluate the achievement of the outcomes. In the following sections, interim progress made through research activities in advancing the performance objectives is indicated as *research milestones* in timeframes of *0-2 years* and *3-5 years*. These research milestones are derived from the FY 2005 program plans and assume adequate funding for their completion.

Together, the performance objectives and research milestones will be used to evaluate our success in attaining the outcomes. Because strategic plans and research plans are constantly evolving, we recognize the importance of reviewing and revising our performance objectives and research milestones when necessary to address agency changes in direction or focus.

5. Ecosystem Mission Goal: Protect, Restore, and Manage Use of Coastal and Ocean Resources through Ecosystem Approach to Management

5.1 Introduction

There are more than 90 Congressional Acts, treaty obligations, Executive Orders, regional agreements, NOAA-specific policies, memoranda of understanding with other federal agencies, and court orders that drive the requirements of the Ecosystem Mission Goal. To respond to these drivers, the agency performs specific activities and actions through the Ecosystem Mission Goal programs. As new statutes and policy are created in response to the final report and recommendations of the U.S. Commission on Ocean Policy, new activities and actions will need to be identified. Additional drivers for the Ecosystem Mission Goal include the current and emerging needs of ocean, coastal, and Great Lakes communities arising from stakeholder input. The drivers fall into two basic categories:

- Drivers that require NOAA to manage or protect particular species, specific habitats, or particular areas and their uses.
- Drivers that require NOAA to conduct research or provide scientific information for decision makers, the public, or other agencies in support of our general stewardship mission, and/or in support of treaties, laws, or congressional mandates.

Figure 1. Selected External Drivers for the Ecosystem Mission Goal

NOAA's mission is supported by application of scientific data and information and new technology development. By conducting state-of-the-art ecosystem research, the agency strives to be an "honest broker" for the public by providing scientifically defensible approaches to support protection, restoration, and management of marine and Great Lakes ecosystems.

5.2 Outcomes and Performance Objectives

There are two outcomes for the Ecosystems Mission Goal:

- **Healthy and productive coastal and marine ecosystems that benefit society**
- **A well-informed public that acts as steward of coastal and marine ecosystems**

To evaluate the achievement of the outcomes, the following performance objectives have been developed:

- Increase number of fish stocks managed at sustainable levels
- Increase number of protected species that reach stable or increasing population levels
- Increase number of regional coastal and marine ecosystems delineated with approved indicators of ecological health and socioeconomic benefits that are monitored and understood
- Increase number of invasive species populations eradicated, contained, or mitigated
- Increase number of habitat acres conserved or restored
- Increase portion of population that is knowledgeable of and acting as stewards for coastal and marine ecosystem issues
- Increase number of coastal communities incorporating ecosystem and sustainable development principles into planning and management

5.3 Ecosystem Approach to Management

NOAA defines an ecosystem as a geographically specified system of organisms, the environment, and the processes that control its dynamics. An ecosystem approach to planning and management is adaptive, geographically specified, and takes into account ecosystem knowledge and uncertainties. Ecosystem-based management involves environmental conservation, protection, and management approaches that are used in the decision making process. The principal aim is to have a balanced cycle of harvest and renewal of natural resources by reducing current and potential conflicts between the natural resources and the users of these resources through improved ecosystem understanding. NOAA's ecosystem approach to management aligns with the recently issued report of the U.S. Commission on Ocean Policy, which recommends moving ocean management toward an ecosystem-based model and basing ocean policy decisions on the best available science.

An ecosystem approach to management requires that the formulation and implementation of management measures recognize the existence of significant socio-economic, chemical, biological, geological, and ecological relationships both within and among marine species, habitats, and the physical environment. NOAA's five-year research plan includes a key investment in an enhanced understanding of ecosystems by establishing the necessary knowledge, tools, and capabilities needed to accelerate the nation's transition to ecosystem approaches to planning and management. This investment will allow NOAA to deliver state-of-the-art scientific information for objective analyses supporting sound decision-making by resource managers, the public, and Congress.

5.4 Research to Support Planning and Management

An ecosystem approach to management is a relatively new concept that holds great promise for improving how NOAA fulfills its mandates and responsibilities. With the goal of maintaining living marine resource populations and biodiversity at sustainable levels, research activities will focus on

providing better information and tools to inform management and restoration activities for spawning and nursery habitat, marine aquaculture and fisheries enhancement, and to minimize human impacts. Discovery of new ocean and Great Lakes dynamics/phenomena and increased understanding of existing ecosystems are the first steps in effective management. To better understand biological/chemical/physical interactions in the ocean and Great Lakes, NOAA will continue to develop new tools and technologies such as Autonomous Underwater Vehicles (AUVs), sea floor observatories, underwater laboratories, and chemical, physical, and biological sensors that allow in situ, long-term exploration and research of ocean, coastal, and Great Lakes ecosystems. NOAA's ecological research aims to identify potential indicators of ecosystem health, as well as forecast specific threats to these resources and human health, focusing on harmful algal blooms (HABs), invasive species, water quality, disease, and habitat degradation.

Fisheries, tourism, marine aquaculture, and associated businesses depend on a healthy and functioning coastal ecosystem. Coastal areas and oceans provide services, such as aquaculture sites, and sources of potential new pharmaceuticals. Exploitation of near shore and open ocean resources needs to be done in a controlled and sustainable manner. Ecological and technological research conducted by NOAA and partners will maximize the economic and social contributions of resources while minimizing collateral damage to and improving the health of the ecosystems supporting these valuable natural and maritime heritage resources.

Research into anthropogenic stresses to ocean, coastal, and Great Lakes ecosystems have centered primarily on the effects from over-fishing, habitat degradation, and declining water quality. Less is known about the linkages among climate change, food webs, physical-biological coupling, and ecosystem production dynamics. Such knowledge will allow NOAA to develop a new suite of ecosystem forecasts addressing such conditions as HABs, anoxia, beach closings, and water quality and quantity. In addition, NOAA will develop multipurpose integrated forecasts. For example, forecasts of sea-level rise could be used to forecast shoreline location, which in turn could be used to forecast bathymetry, fish community structure, changes in human angler behavior, and thus changes in coastal economies. NOAA forecasts will provide the needed decision-support tools for adaptive, ecosystem-based management of fisheries and marine resources, to predict human impacts on ecosystems, and to protect human health. Additionally, social and economic studies—a critical component of any ecosystem approach to management—will be enhanced as part of NOAA's ecosystem research strategy. The following are key research foci for the Ecosystems Mission Goal:

- Study ocean phenomena—such as hydrothermal vents, methane and other gas hydrates, seafloor spreading zones, submarine volcanism, and subduction zones—to ascertain the potential for generating coastal earthquakes, tsunamis, greenhouse gases, fisheries habitats (seamounts), new islands; to advance the understanding of ocean chemistry and the water column/seafloor interface; and to discover and subsequently analyze the potential of marine natural products for biomedical and commercial applications.
- Study coral ecosystems to improve the understanding of: shallow coral reef ecosystems, including their social and economic value to society and the impact of both natural and anthropogenic stressors (i.e., land and resource use, pollution, disease and other extreme events, climate change, and invasive species) on them; and deep-sea coral ecosystems, including their potential as habitat for fisheries and as paleoenvironmental indicators.
- Promote research on inter-disciplinary and biophysical integration of observation system networks to advance our understanding of the linkages between ecosystem processes and biodiversity.

- Promote technological development and knowledge used to advance research and observing system capability, solve conservation problems, explore undiscovered habitats and systems, and create new opportunities for economic growth without compromising sustainability.
- Investigate sources, fates, and effects of anthropogenic influences, including contaminants (e.g., inorganic and organic chemicals) and thermal changes.
- Explore submerged landscapes and the effects of physical changes (e.g., sedimentation and hydrologic changes) on coastal and marine ecosystems.
- Map and characterize previously uncharted habitats including geological features, ecosystems and maritime archaeological sites to identify directions for future study, help assess the need for habitat protection, and describe sites with potential resources of economic importance.
- Conduct interdisciplinary research to better understand marine biological, chemical, and physical processes and their implications for human health.
- Develop and demonstrate environmentally compatible culture systems (offshore and recirculating) for commercial, overexploited, threatened, and endangered species.
- Forecast and assess temporal scales of ecosystem variability, including impacts of physical processes that affect biodiversity, trophic, multi-species interactions, distribution, and ecosystem production dynamics.
- Create biophysical coupled models of water mass movements and their effects on biological productivity including fisheries recruitment and population distribution.
- Study aquatic biodiversity and how anthropogenic stresses, extreme environmental events, and climate influence population dynamics of coastal and marine ecosystems.
- Understand the dynamics of social and economic systems and their relation to ecosystem management. Develop methodologies and "tools" for estimating non-monetary ecosystem value that can be translated into decision support tools for stewardship of coastal and marine ecosystems.

5.5 Research Activities and Themes

The research activities that support the Ecosystems Mission Goal outcomes, enhance ecosystem approaches to management, and address the performance objectives are organized below by research themes. Included within each research theme is a description of the associated research activities and milestones.

5.5.1 Integrated Earth Observing System and Data Management System

Comprehensive, integrated Earth observing systems are required to take the "pulse of the planet", observe natural scales of variability, identify perturbations and changes, put current trends into an historical framework, provide comprehensive and scientifically sound data to forecasting models, and provide a context for assessing the impact of management decisions. Ecosystem research over the next five years depends on the design and development of an integrated ecological observing system that will expand NOAA's ability to characterize physical, chemical, and biological properties of aquatic ecosystems, and to better understand ecosystem processes and their relationship to NOAA's management responsibilities. Overall, NOAA's ecological observing system is structured to be an "end-to-end" research to operational observing system for the oceans, coasts, and the Great Lakes. It will consist of integrated ecological and physical data acquisition, assimilation, and management, which serves as the basis for routine forecasting products (e.g.,

fish stock assessments, HAB forecasts, beach closings, water quality) for resource managers and the public.

Improved data collection is also required for such diverse needs as managed fish stocks and protected resources; ocean, coastal, and Great Lakes ecosystems; biological, physical, and chemical parameters; social science indices; and identifiable challenges like invasive species, disease, and ocean exploration.

The observing system is not a static enterprise and requires continued research to improve and optimize the products available and to introduce new systems. To define and assess ecosystems, NOAA has at our disposal coastal marine laboratories; dedicated ships; submersible systems; portable observatories; buoy technology; diving technologies; undersea habitats; autonomous and remotely operated underwater vehicles; advanced acoustic, optic, and chemical sensor technology; telepresence tools; survey systems; satellite sensors; and instruments on aircraft and unmanned airborne vehicles.

Table 3. Research Milestones for Integrated Observing and Data Management System

Research Milestone	0-2 Years	3-5 Years
Define the time and space scales needed to capture the fundamental physical and biological drivers that are required for ecosystem forecasts and natural resource assessments.	X	
Measure the natural scales of variability regarding physical-biological coupling, food web dynamics and ecosystem production in selected ecosystems.		X
Design and develop a comprehensive coral reef ecosystem monitoring program (Coral Reef Early Warning System).		3 new stations in the Caribbean
Define observational needs to assess the impact of management decisions on fisheries and coastal and Great Lakes resources and habitat quality.	X	
Test and compare new (multi-beam, laser) acoustical and optical technologies for assessing organism abundances.	X	
Develop and test new chemical and biological sensors for coastal and Great Lakes observing systems.	X	
Develop parameters and indices of eutrophication, water quality, HABs, and contaminants (including pharmaceuticals and steroids) in coastal and marine ecosystems; provide trends in contaminant concentrations; and identify new anthropogenic contaminants.	X	
Evaluate remote camera monitoring system for monitoring nesting sea turtles	X	

5.5.2 Assessments and Forecasts of Coastal and Marine Ecosystems

NOAA will produce ecosystem assessments and forecasts using data generated from the integrated observation system. Forecasting is a standard tool in meteorology but is comparatively new to the aquatic sciences. Ecosystem forecasting predicts the effects that biological, chemical, physical, and human-induced changes—extreme natural events, climate change, land and resource use, pollution, invasive species, fisheries impacts, coral bleaching, and interactive effects—have on ecosystems and their components. An understanding of physical-biological-chemical coupling and the various space and time scales is needed to predict such factors as fish recruitment and productivity, HABs, beach closings, and water quality.

Forecasts and interpretative tools that use a scientific basis to assess the results of management and science policy actions are also needed. These types of forecasts and assessments act as a feedback loop to monitor the effectiveness of the decision-making process. Forecasting capacity will be extended to include the potential impacts of management intervention on social and economic systems associated with ecosystems, and the potential implications for altering the way

people interact with the ecosystems. NOAA scientists and partners can help coastal managers at all levels of governance, by providing a better understanding of the impacts of potential environmental threats and understanding the implications of the decision making process. The overall objective is to support decision makers in managing resources, maintaining or improving quality of life in people who use those resources, and lowering the risk to human health.

Table 4. Research Milestones for Assessments and Forecasts of Coastal and Marine Ecosystems

Research Milestone	0-2 Years	3-5 Years
Develop forecasts for the ecological effects of varying weather patterns and extreme physical events.	X	
Define the primary forcing factors and time and space scales that cause HABs and anoxia for selected coastal, ocean, and Great Lakes regions.	X	
Define the primary forcing factors and time and space scales that affect water quality and quantity for selected coastal and Great Lakes regions.	X	
Define the primary forcing factors and time and space scales that affect fish recruitment and fisheries production for selected coastal and Great Lakes regions.		X
Evaluate pelagic bycatch reduction technology and innovative TED Technology	X	
Conduct environmental impact studies to establish baseline information for siting of commercial aquaculture activities.		X
Develop methodologies and tools for estimating non-monetary ecosystem value that can be translated into decision support tools for stewardship of coastal and marine ecosystems.	X	
Study aquatic biodiversity and how anthropogenic stresses, extreme environmental events, and climate influence population dynamics of coastal and marine ecosystems.	X	

5.5.3 Scenario Development to Support Specific Management Actions and Decisions

NOAA's ecosystem research portfolio also addresses specific management issues, such as aquaculture, coastal resource management, corals, fisheries management, habitat restoration, invasive species, protected areas, and protected species. Research in these areas focuses on understanding the biology, ecology, and life history of important species and the ecosystem resources that support and affect them. In addition, research is directed at investigating the causal relationships among ecosystem resource productivity, habitat quality and quantity, oceanographic and climate processes, and natural and anthropogenic stressors that affect ecosystem resources. Research that addresses specific management needs is necessary in the development of cost/benefit scenarios of management actions and decisions. For example, research in the development of viable alternatives to ballast water exchange could provide specific benefits to the prevention and introduction of exotic species to U.S. coastal waters.

Specific research in this area includes activities that support ecologically sound coastal and offshore aquaculture and marine natural product development; promote understanding and controlling the introduction and dynamics of invasive species; promote understanding of the factors that affect the protection and restoration of coastal and marine habitats, including coral reef ecosystems; promote understanding of aquatic ecosystems; promote understanding of how individuals and groups behave under regulations and differing ecosystem management and governance arrangements; design and evaluate the effectiveness of Marine Protected Areas (MPAs) for restoring and maintaining ecosystem function; and investigate the dynamics of ocean, coastal, and Great Lakes ecosystem communities, including the effects of utilization (e.g., harvests) on those communities and their habitats. The NOAA research community will also examine how these factors are impacted by natural and human-caused sources of environmental variability.

NOAA will also pursue new directions to develop or implement new technologies such as fishing gear that reduce by-catch (conservation engineering), remotely operating vehicles (ROVs), and autonomous underwater vehicles (AUVs) to assess habitat impacts from fishing and non-fishing activities and address emerging problems. New technologies for ecosystem investigations will also be incorporated into operational programs.

Table 5. Research Milestones for Scenario Development to Support Specific Management Actions and Decisions

Research Milestone	0-2 Years	3-5 Years
Develop management tools that are proven effective at preventing invasive species on "no-ballast-on-board" ships.		X
Provide integrated assessments that evaluate the causes of over-fishing and the risk/value of alternative ecosystem-based management strategies.		X
Research to improve our understanding of the factors affecting threatened species and the potential success of alternative remediation/management strategies.	X	
Map habitat types (existing and restorable) and identify key habitat functions; evaluate the function / health of habitat.		X
Define and evaluate the value and economic/ecological costs/benefits of aquaculture for specific species in specific regions.	X	
Create models coupling physical oceanography variability and biological effects on productivity, fish recruitment, and distribution.	X	
Develop the next generation of multi-species fisheries and food web production models.		X
Develop environmentally sound production technologies for marine species.		X
Develop a NOAA-wide research plan for shallow coral ecosystems.	X	
Develop a NOAA-wide research plan for deep-sea coral ecosystems.	X	
Expand an integrated plan to discover and/or research marine archaeological sites	X	

5.5.4 Ocean Exploration

NOAA's mission includes investigation of the oceans for the purpose of discovery and the advancement of knowledge. The creation of NOAA's Ocean Exploration program signaled a turning point for the nation's ocean exploration efforts, and the recent acquisition of a former Navy ship for conversion to a state-of-the-art ocean exploration vessel now positions NOAA to sail on the leading edge of exploring Earth's largely unknown oceans. NOAA will support multidisciplinary teams of Scientist-Explorers on voyages of discovery to map and characterize ocean areas, develop a more thorough understanding of ocean dynamics and interactions, develop new sensors and systems, and communicate to stakeholders how and why unlocking the secrets of the ocean will benefit current and future generations.

Table 6. Milestones for Exploring Unknown and Little Known Areas of Earth's Oceans

Milestone	0-2 Years	3-5 Years
Expand an integrated plan to discover and/or research marine archaeological sites	X	
Develop a telepresence capability to make scientists, advocates, teachers, and students ashore, virtual members of scientist-explorer teams at sea on NOAA's ship for ocean exploration	X	

5.5.5 Capacity Building and Effective Knowledge Transfer

Research findings must be translated into decision support tools for NOAA to successfully conduct its stewardship responsibilities. Research activities include methods for conducting social impact analyses, working with end users through extension activities, evaluating alternative management options, and developing information technology to support management decisions such as data visualization and geographic information systems.

Table 7. Research Milestones for Capacity Building and Effective Knowledge Transfer

Research Milestone	0-2 Years	3-5 Years
Develop fish husbandry and shellfish methods.	X	
Expand extension and education approaches to provide scientific information in advance of actions and regulations and to assist NOAA in fostering increased understanding and partnerships among fishers, conservation and environmental groups, coastal use community, and scientists.	X	
Provide cost-benefit forecasts and risk analyses of management decisions and human use of coastal and Great Lakes ecosystems.		X
Develop a telepresence capability to make scientists, advocates, teachers, and students ashore, virtual members of scientist-explorer teams at sea on NOAA's ship for ocean exploration	X	

6. Climate Mission Goal: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

6.1 Introduction

> ***The nation faces major climate policy challenges in the coming decade; Sound decision-making by others depends on NOAA's ability to deliver the information needed for objective analysis of alternatives.***
>
> ***NOAA Annual Guidance Memorandum FY06***

The Administration's Climate Change Research Initiative (CCRI) was implemented to focus on priority areas for reducing the uncertainties identified in the 2001 National Research Council (NRC) report *Climate Change Science: An Analysis of Some Key Questions*. The community-vetted Climate Change Science Program (CCSP), which encompasses the CCRI and the U.S. Global Change Research Program, reaffirms the high priority for these research areas. NOAA as the lead agency for producing operational climate services has refocused its program on CCRI and CCSP deliverables. In addition to needed improvements in observing and modeling systems, over the next five years, the primary NOAA focus is on three of the high priority topics identified in the NRC report. These are reducing uncertainties in (1) the fraction of the future fossil fuel carbon that will remain in the atmosphere and provide enhanced radiative forcing; (2) the nature and causes of natural variability and its interactions with forced changes; and (3) the direct and indirect effects of the changing distributions of aerosols. Ongoing observing, modeling, and research studies are laying the framework for studying these and other priorities; there is an increasing focus on feedback processes, such as the role of snow and ice in high latitudes and the role of the ocean, natural decadal to millennial variability, and details of regional and local responses. Key to more sustained climate observations will be NOAA's role in the development and enhancement of global integrated observing systems as part of the international GEOSS. The results of these activities will enhance and directly support both national and international assessments of the climate system (e.g., CCSP synthesis products, Intergovernmental Panel on Climate Change [IPCC] Assessment Reports, U.N. Montreal Protocol on the Ozone Layer), as well as contribute to an end-to-end climate program developing and delivering critical climate services to the Nation.

> ***There…is a pressing need for a global observing system designed for monitoring climate.***
>
> **National Research Council, 2001**

Enhancing NOAA's climate services will require NOAA-funded research directed towards improvements and extensions of operational forecasts and data products on intraseasonal to interannual timescales associated with resource management and long-term health and environmental impacts. The new product suites will ultimately include ecosystem and enhanced air and water quality forecasts.

The ultimate success of climate research within NOAA depends on close collaboration with academia, state and other federal agencies, non-governmental organizations, private industry, and international partners. These partnerships are maintained through memoranda of understanding (MOUs), GEO, CCRI, CCSP, international agreements, and grants through the NOAA cooperative institutes and Office of Global Programs.

Stakeholders and customers for climate research range from decision makers, resource managers, and policy makers dealing with global, regional, and local issues in most sectors: energy, transportation, industry, land use, water, agriculture, commerce, environmental organizations, the general public, other federal agencies, and other researchers both internal and external to the federal government.

NOAA climate research is coordinated nationally through the CCSP and internationally through a variety of bilateral and multilateral arrangements. The program is managed through routine development, modification, and assessment of goal and program performance objectives and research milestones.

Figure 2. Selected External Drivers for the Climate Mission Goal

6.2 Outcomes and Performance Objectives

The Climate mission goal supports the following two outcomes:

- **A predictive understanding of the global climate system on time scales of weeks to decades with quantified uncertainties sufficient for making informed and reasoned decisions**
- **Climate-sensitive sectors and a climate-literate public effectively incorporating NOAA's climate products into their plans and decisions**

To evaluate the achievement of these outcomes, the following performance objectives have been developed:

- Describe and understand the state of the climate system through integrated observations, analysis, and data stewardship
- Improve climate predictive capability from weeks to decades, with an increased range of applicability for management and policy decisions
- Reduce uncertainty in climate projections through timely information on the forcing and feedbacks contributing to changes in the Earth's climate.
- Understand and predict the consequences of climate variability and change on marine ecosystems
- Increase number and use of climate products and services to enhance public and private sector decision making

6.3 Research Activities and Themes

Research activities and associated research milestones are described below in each of five research themes. These research themes parallel the structure of the NOAA climate program.

6.3.1 Develop an integrated global observation and data system for routine delivery and attribution of past and current state of the climate and climate forcing

NOAA's integrated global observing system and analyses provide the basic documentation and characterization of the climate system needed to monitor, describe, and explain past and present climate variability and climate change, including variations in extreme weather phenomena. Reliable and timely access to climate data and information is essential to improved understanding of key physical processes of the climate system, improving climate prediction and projection models, and regularly producing integrated analyses of the climate system and reporting on the causes and consequences of observed climate variability and extreme events.

NOAA envisions scientific data stewardship as an end-to-end system that includes: systematic collection of atmospheric and ocean observations; data processing and reprocessing to produce climate-quality data; observing system performance monitoring; long-term archiving; and reliable and timely access to data. These are the key elements needed to respond to the scientific information needs of climate researchers.

Activities in the next five years will focus on five major areas:

- Develop a scientific data stewardship and observing system integration and optimization process that will enable NOAA to identify and implement the most cost-effective observations and improved observing systems.
- Collect and deliver regular, systematic, and reliable climate data and information—with rigorous scientific standards and easy data access by customers—that document and describe the current and evolving state of the climate system through the development of integrated observing systems.
- Conduct research in data assimilation—using data from both current and future advanced satellite systems and in situ observations—to provide new products and measurements that will expand understanding of the climate system.
- Produce reference data sets that provide improved climate information; use these data sets to develop integrated historical analyses of the global climate system through integration of all reference data sets into state-of-the-science global climate models, and use the integrated analysis to carry out detection and attribution studies that link observed climate changes (including changes in extreme events) and climate extremes to specific climate forcing and feedbacks. Fulfill an international mandate to provide online access to data and information about past climate and environmental change derived from paleoclimate proxies through science-driven data management.
- Conduct observational, diagnostic, and modeling research to improve understanding of physical mechanisms and processes of climate variability and predictability that will lead to improved climate models and climate predictions.

Table 8. Research Milestones for Integrated Global Observation and Data System

Research Milestone	0-2 Years	3-5 Years
Produce Climate Data Records	3	21
Report on climate model improvements resulting from Climate Process Teams and recent major field studies		X
Report on state of knowledge of decadal variability, the monitoring ability for this, and potential decadal predictability	X	
Routine reports on detection/attribution studies linking observing capabilities with model projections		X
Implement next generation reanalysis capability		X
Develop observational indices for tracking the Meridional Overturning Circulation [an important indicator of long-term (greater than decadal) climate change]	X	X
Deploy prototype Arctic observing system for monitoring sea ice, heat content, freshwater, and ecosystem indicators with partners	X	
Routine assessments of sea level rise and required observing capabilities		X
Establish Indian Ocean climate observing system		X

The above research activities support a broad spectrum of customers, both nationally and internationally. Users of climate data and information include operational weather and climate centers, resource managers and policy makers at all levels of government, end users (private sector and general public), and the worldwide scientific research community.

Major research objectives described in this theme are long-term goals. While significant achievements are expected within five years, most of the objectives—for example the integrated global climate observing system (which is linked to the international GEOSS and to the interagency 10-year Global Earth Observations Plan) will take longer to complete. Longer-term research efforts will focus on the development of integrated global climate models and analyses at greater resolution, as well as on an improved understanding of decadal variability and the role of atmospheric chemistry in global climate.

6.3.2 Document and understand changes in climate forcings and feedbacks, thereby reducing uncertainty in climate projections

NOAA's climate forcing research is focused on providing improved decision-support information regarding key agents of change within the climate system: greenhouse gases, aerosols, and the stratospheric ozone layer. Three decision-relevant aspects of the radiative forcing of climate change are addressed:

- **Carbon dioxide** – The future atmospheric abundance of this human-produced greenhouse gas will influence the century-long, slow-to-reverse changes in the radiative forcing of the climate system. Key information for carbon management will spring from expanded observational networks in the oceans and atmosphere and improved model simulations of how global oceanic and terrestrial uptake processes control atmospheric abundance of carbon dioxide. Natural uptake processes currently sequester over half of the anthropogenic CO_2 emitted as a result of human activities; it is uncertain how the extent of natural sequestration will change over time.
- **Radiatively important trace species** – These short-lived atmospheric constituents (including aerosols, tropospheric ozone, and methane) represent the largest uncertainties in the radiative forcing of climate change. Better simulation of the linkage between emissions of these short-lived constituents and resulting radiative forcing of climate change will broaden the suite of non-carbon options available for decision makers seeking to reduce radiative forcing of the atmosphere over the next few decades.

- **Stratospheric ozone layer recovery** – The U.N. Montreal Protocol on the stratospheric ozone layer is the roadmap for recovery of stratospheric ozone. Needed decision-support information includes trends of the ozone layer and ozone-depleting substances, as well as information on how climate change could influence ozone-layer recovery.

This research is characterized by a four-element, integrated approach:

- Monitoring the global abundances and trends of the greenhouse gases and aerosols, including the atmospheric and oceanic profiling of carbon dioxide, providing insight into the highly variable terrestrial carbon sink and systematic changes in ocean sequestration.
- Conducting laboratory and field studies of the oceanic and terrestrial processes that control (1) the natural emissions and uptake processes in the global carbon cycle, and (2) the climate properties of aerosols, tropospheric ozone, and ozone-layer depletion.
- Contributing toward the incorporation of this understanding into predictive models and evaluating the capabilities by comparing "hindcasts" to observed trends and by testing the ability to represent the observed changes of atmospheric constituents.
- Delivering peer-reviewed information products, co-identified with stakeholders that assess the state of understanding of climate-change forcing.

NOAA's climate forcing research supports both national and international assessments of the climate system, e.g., the 2-4 year synthesis and assessment products of the CCSP, the 2007 assessment report of the IPCC, and the 2007 report to the U.N. Montreal Protocol on the ozone layer. Such science-based assessments and scenarios will provide (1) tools for better management of carbon- and non-carbon-based climate-forcing emissions, (2) a suite of choices for both air quality and the alteration of climate forcing in the near term, and (3) longer-term assessments of strategies for managing climate-forcing emissions over the longer term.

Table 9. Research Milestones for Documenting and Understanding Changes in Climate Forcings and Feedbacks

Research Milestone	0-2 Years	3-5 Years
Produce regional oceanic and terrestrial carbon uptake maps	X	
Produce first "State of the Carbon Cycle Report" with CCSP partners	X	
Field studies of (a) aerosols–radiation and (b) aerosols–clouds	X (a)	X (b)
Review of aerosol properties and their impacts on climate change, with CCSP partners	Input to IPCC (2006)	Relevance of findings to aerosol-related industrial sectors (e.g., energy)
Assessment of the 2000-2009 change in radiative forcing by pollution over the Pacific Basin		X
Begin annual reporting of the "State of the Ozone Layer", with 5-yr CCSP-sponsored perspectives for N. America	Input to Montreal Protocol report (2006)	CCSP product

Research capabilities developing beyond 2009 include efforts to better constrain the uncertainties of the feedbacks of water vapor in radiative forcing, better linkages of the effects of increasing atmospheric carbon dioxide on marine ecosystems, and an emphasis on integrating radiative-forcing process research into the next generation of climate models.

6.3.3 Improve skill of climate predictions and projections and increase range of applicability for management and policy decisions

Research within this theme focuses on improving and extending the product line for operational intraseasonal and seasonal to interannual (S/I) predictions, to develop and implement a capability for

decadal climate forecasts, to understand and predict abrupt climate change, and to promote credible national and international assessments of future climate trends and change. Current capabilities on intraseasonal time scales include an incipient "threat" assessment for extreme events two weeks in advance. This will be improved through the creation of improved multi-model ensembles and calibration procedures. The existing S/I forecasting capability is based primarily on empirical tools; improvements will result from increased reliance on ensembles of coupled ocean–atmosphere–land models, advanced post-processing methodologies, and improved understanding and modeling of seasonal climate processes. New product suites will be developed for water resource and ecosystem forecasts. Model runs using observed anthropogenic and sea surface temperature forcings and coupled Earth system models will become a new tool for decadal predictions in the near future. Scenarios from the latest generation of coupled models are currently being run for the 2007 IPCC Fourth Assessment Report; further improved and higher resolution models including interactive carbon, atmospheric chemistry, and biogeochemical cycles will be utilized in the "if-then" scenarios for CCSP and CCTP.

Table 10. Research Milestones for Improving Climate Predictions and Projections

Research Milestone	0-2 Years	3-5 Years
Develop dynamic understanding of decadal variability and predictability studies		X
Improved summertime forecasts with analyses of field-driven monsoon data	X	
Develop multi-model based operational seasonal forecast system		X
Develop probabilistic predictions for week 2 extreme events		X
Report on limits of predictability on S/I and decadal timescales		X

The long-term goals are sets of decision support tools for resource managers and policy makers based on a seamless suite of forecast and simulation products for intraseasonal, interannual, and multi-decadal time scales that enable more reliable estimates of the impacts of climate variability and change on physical variables, ecosystems, and life resources, especially those related to the water cycle. This will require research to produce increasingly capable Earth system models and linking forecast and simulation products from global to regional to local scales.

6.3.4 Understand impacts of climate variability and change on marine ecosystems to improve management of marine ecosystems

The desired goal of NOAA's climate and ecosystems research is to predict the probable consequences of global climate change on ecological systems and their living resources, and to deliver to fisheries and coastal zone managers the knowledge and tools needed to incorporate climate variability into the management of living marine and coastal resources. NOAA has made large investments towards understanding the physical climate system and describing the mechanisms that govern climate variability and climate change. By comparison, little work has been done to understand the impacts of climate variability or future climate change on coastal and marine ecosystems and the response of living marine resources and coastal communities to climate forcing. These are currently major issues in the Arctic and of considerable concern to subsistence economies and cultures in Alaska. This program component aims to build a bridge between "physical forcing" and "ecosystem response" through observations, modeling, and research, leading to a better understanding of the critical factors that link climate variability and ecosystem response.

To accomplish this, the following activities will be implemented:

- Continuously monitor changes in coastal and marine ecosystems through an integrated network of in-situ and remote observing systems, especially in the Arctic and sub-Arctic.

- Develop regional-scale coupled physical-biological models that incorporate climate variability for ecological forecasts, assessments, and "if–then" scenarios.
- Conduct process research focused on gaining a better understanding of linkages between climate forcing and ecosystem responses at seasonal, interannual, and decadal scales, such as El Niño, La Niña, and Pacific Decadal Oscillation events.
- Produce a suite of physical and ecological indicators based on modeling and observations, and make use of climate sensitive "sentinel species and sentinel sites," to help determine the current and future status of the climate and ecological systems for coastal and resource management. Such indicators are analogous to "leading economic indicators" and "stock indices" used extensively by the business community.
- Distribute regular assessments of climate impacts on coastal and marine ecosystem health and productivity, similar to IPCC assessments, for scientific, managerial, and decision support.
- Investigate the effect of elevated CO_2 and associated acidification of the ocean on calcifying organisms such as corals.

The following research milestones are related to four major research foci within the theme: climate regimes and ecosystem productivity, North Pacific climate regimes and ecosystem productivity, climate and coastal marine resources, and sentinel species.

Table 11. Research Milestones for Understanding Impacts of Climate Variability and Change on Marine Ecosystems

Research Milestone	0-2 Years	3-5 Years
Integration of CO_2 parameter measurements on coral reef CREWS station	4 stations	12 stations
Ten-year trends in coastal chlorophyll and assessments of climate influence		X
Track and improve the ability to forecast, the relationships among climate and variations in coral cover, bleaching, and anthropogenic impacts on coral reefs		X
Detailed models of coastal inundation and ecosystem change for specific areas for use by land use managers		X
Assessment of the state of Northeast Pacific ecosystems produced		X

Achieving the research milestones will require collaboration with the academic research community, ongoing ecosystem research programs under the Ecosystem Goal, other federal and state agencies, and appropriate international partners. Customers for climate and ecosystems data products and services include coastal communities, municipal planners, coastal resource managers, tourism councils, fisheries stock assessment scientists, Fisheries Management Councils, offshore aquaculture, and individual fishers.

Research over the next five years will provide a foundation for longer-term research. Climate and ecosystem interactions are highly complex, and developing an understanding of the biophysical processes through which ecosystems are affected by climate, sufficient to develop a predictive capability for all resources of interest, will likely take decades.

6.3.5 Enhance NOAA's operational decision support tools to provide climate services for national socio-economic benefits

Research and related activities associated with regional decision support in the NOAA Climate Program will focus on making the climate information that NOAA provides more useful and responsive to the needs of the public, resource managers, and policymakers, especially at regional scales that are the focus for a broad range of public and private decisions. NOAA faces substantial challenges in providing climate information that is relevant to economic vitality and human welfare. Most decision makers in public and private sectors affected by climate variability—today, next

year, over the next decade—operate in complex settings where climate is just one of many factors that they must consider. Understanding and communicating the effect of climate variability and change in complex, multi-factor settings—and doing so in partnership with those affected—will result in returns to the public sector that far outweigh the investment. Achieving "decision-support" requires an expanded view of research that places deliberate emphasis on drawing in decision agents to the research framing and process, making a priority of communicating and translating information (often with a research setting), and evaluating the extent to which research is able to make a viable contribution to practical problems and capitalize on opportunities. It also requires a commitment to testing the innovations that need to take place in practice (e.g., developing prototype climate-resource management tools and testing them with stakeholders).

Information needs may differ significantly for policy development and operational applications. For example, a decision tool developed in a research context (e.g., a web-based evaluation tool or a GIS-based "vulnerability map") might have an impact in a policy context or on the behavior of individuals responsible for resource management, but may not be used on a daily or monthly basis by an operational agency. Similarly, there is an important role for the development of experimental products within a research framework to ensure continued testing, evaluation, and informed use. NOAA has developed various pathways for integrating understanding about the impacts of climate with development of analytical and decision tools designed to contribute to adaptive management.

Table 12. Research Milestones for Enhancing NOAA's Operational Decision Support Tools

Research Milestone	0-2 Years	3-5 Years
Develop new experimental tools (including methods, models, and educational and outreach resources) that communicate climate information and deliver techniques for incorporating that information/analysis into specific decision scenarios.	1 additional	5 additional
Implement prototype decision support tool for water management linking historical, current, next season, and decadal outlooks		X
Identify key climate-sensitive issues at regional scales	X	
Develop prototype methods for the application of climate information to practical challenges associated with natural resource management and hazard mitigation	X	X
Conduct social science-based studies of the context for and the use of climate information for resource and emergency managers	X	X
Provide NOAA's contribution to CCSP deliverable on the state-of-the-science of socioeconomic and environmental impacts of climate variability	X	
Initiate new inter-regional research activities designed to address issues that transcend regional boundaries (Number of joint Regional Integrated Sciences and Assessments [RISA] program activities)	3	4
Initiate new climate research in underrepresented regions of the United States (Number of RISA Programs)	9	11

Vital to all research is the ability to transfer understanding and knowledge to products and services that are relevant and routinely produced operationally, and available to users—the transition of research to practical operational support. This requires close working relationships between the users, the operational service providers, and the external research community. Education and training programs contribute to ensuring that NOAA personnel are best able to deliver data, information, products, and services based on sound research that meet the needs of the public and decision makers.

Regional decision support research focuses on translating an improved understanding of the nation's principal climate sensitive resource challenges and opportunities (e.g., water supply and quality, coastal zone management, integrated drought monitoring, improved health early warning systems, urban planning, etc.), and developing tools useful to business and government leaders through intensive collaboration with the university and stakeholder communities. This research effort is composed of a suite of activities intended to further research-based integration between

studies of the climate system, including socio-economic components (e.g., energy and water management, public health and safety, and food production) and evolving informational and educational needs of decision makers in climate sensitive sectors.

7. Weather and Water Mission Goal: Serve Society's Needs for Weather and Water Information

7.1 Introduction

Each year thousands of lives and billions of dollars are lost due to severe storms, floods, heat waves, and other natural events. Severe weather continues to have major impacts on the nation with over $11B in damages per year. Drought and fresh-water availability are growing national concerns with $6B–$8B in losses per year. Poor air quality has had a significant effect on our nation's health and economy as pollution causes an estimated 40,000 deaths and up to $150B in costs per year. With the increased population along our nation's coastline, the costs associated with winds, storm surge, inland flooding, and tornadoes from landfalling tropical storms continue to rise.

The nation's ability to anticipate and plan for these impacts has been enhanced through weather, water, and climate forecasts and warnings for the United States, its territories, adjacent waters, and ocean areas. A relatively modest national investment in weather services has provided daily aviation, marine, fire, weather, river, and flood forecasts and warnings. In the last decade, the lead time for tornado warnings increased from 6 to 13 minutes. Four-day weather forecasts have become as accurate as two-day forecasts were two decades ago. The national infrastructure providing weather and water information is composed of both public and private partners. Together they provide a critical service that contributes to the protection of life and property and enhances the nation's economy.

There are many congressional acts, international agreements, agency policies and plans, and memoranda of understanding with other federal agencies that drive the requirements for NOAA Weather and Water products and information. The major law and policy drivers for the Weather and Water Mission Goal and its programs are illustrated below.

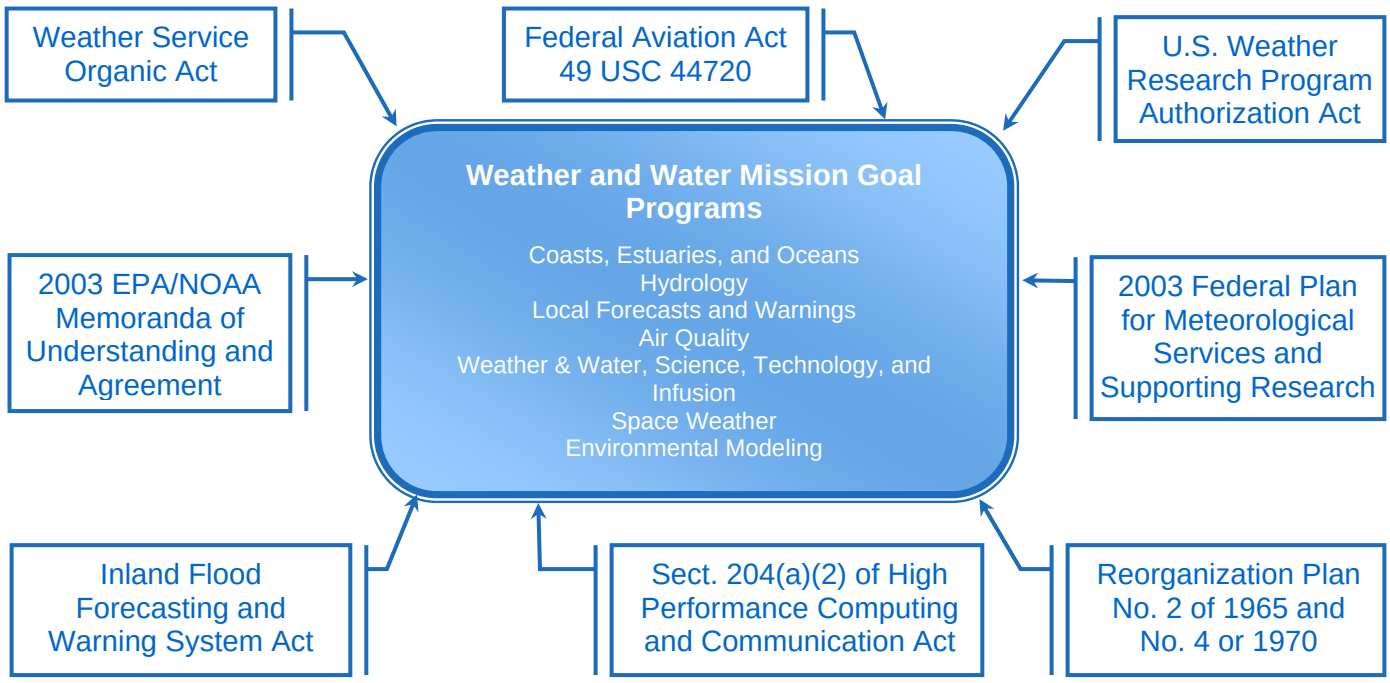


Figure 3. Selected External Drivers for the Weather and Water Mission Goal

While the incorporation of new science and technology into NOAA operations has led to marked improvements in weather, water and climate forecasts and warnings over the last decade, the American public and economic sectors continue to increase their demand for timely and accurate weather and water information. NOAA must position itself to provide additional and more accurate environmental products and services to sophisticated government and public communities (air quality, energy, aviation, surface transportation, space, coastal resource managers, etc.) through an acceleration of new science and technology into improved service delivery that meets society's needs. NOAA strives to improve products and services that will (1) greatly reduce the loss of life and injury due to weather, water, and related environmental factors such as air quality, (2) enable communities threatened by weather and water hazards to take mitigating actions well in advance of events, and (3) alert economic and resource management sectors about weather and water risks with sufficient lead time to take action to avoid or greatly reduce costs and adverse effects.

In support of Homeland Security, research under this mission goal will support and improve NOAA's ability to provide and improve hazardous-material trajectory forecasts, dispersion models, and chemical threat analyses that allow emergency managers and first responders to make timely and effective decisions. NOAA's mission to provide forecasts to protect the public extends to the provision of forecasts of the dispersion of hazardous materials, over distances ranging from local to global. These forecasts are disseminated to a variety of clients, including the Weather Forecast Offices of NOAA and a wide range of emergency response entities, both nationally and internationally. NOAA recognizes the need to provide forecasts of dispersion that are relevant to people where they live and work. A strong involvement of other agencies is needed to ensure that the refined NOAA products will address the operational needs of those agencies directly concerned about the health of the public. The provision of relevant local data and the need for their assimilation are tantamount.

7.2 Outcomes and Performance Objectives

During FY 2005–2009 the Weather and Water Program will focus its research and development activities to achieve three outcomes:

- **Reduced loss of life, injury, and damage to the economy**
- **Better, quicker, and more valuable weather and water information to support improved decisions**
- **Increased customer satisfaction with quality of weather and water information and services**

The following performance objectives have been developed to evaluate the achievement of the outcomes:

- Increase lead time and accuracy for weather and water warnings and forecasts
- Improve predictability of the onset, duration, and impact of hazardous and severe weather and water events
- Increase application and accessibility of weather and water information as the foundation for creating and leveraging public (i.e., Federal, state, local, tribal), private and academic partnerships
- Increase development, application, and transition of advanced science and technology to operations and services
- Increase coordination of weather and water information and services with integration of local regional, and global observation systems
- Quantify and reduce uncertainty associated with weather and water decision tools and assessments

- Enhance environmental literacy and improve understanding, value, and use of weather and water information and services

7.3 Research Activities and Themes

To meet future service delivery goals to the nation, NOAA must address a number of existing scientific and technological deficiencies. NOAA is committed to ***improving the accuracy and capabilities of its monitoring and observing systems both in situ and remotely sensed***, including improving the timeliness, data quality, and long-term continuity of observations necessary to reduce observational, analysis, and model initialization errors and provide a basis for improved verification of all forecasts. NOAA will integrate multi-purpose observing systems, especially those involving radars, satellites, and profilers, and obtain observations of new environmental elements to improve and create new products and services. Commercial weather service providers, in partnership with NOAA, provide a significant fraction of such products and services to industry and to the general public. NOAA also relies heavily on the private sector for research and development efforts in key areas such as the development of improved surface sensors, radiosonde equipment, and radar signal processors.

Advanced data assimilation techniques are needed to improve the quality of analyses and model initialization, and to maximize the value of existing and new observational data sets, with a focus on the newer more voluminous satellite data. Better representation of cloud processes, topographical effects, fluxes, and other processes linking the atmosphere, water, land, and space must be incorporated in models to enhance prediction accuracy.

Environmental predictive models and information delivery systems must be enhanced through a community model approach, including improving and coupling numerical modeling systems to adequately simulate weather, air quality, water, climate, and other geophysical phenomena in common modeling systems. To quantify forecast uncertainty, NOAA will improve probabilistic prediction systems by advancing ensemble modeling techniques and partnering with international modeling centers to determine the optimal combinations of model resolution and number of ensembles to maximize accuracy while providing quantitative measures of forecast certainty (with varying dynamics, physics, and initialization).

NOAA will ***improve its understanding of Earth's environment*** by working in partnership with the larger meteorological research and operational community through programs like the U.S. Weather Research Program (USWRP) and to conduct and participate in international programs such as THe Observing system Research and Predictability EXperiment (THORPEX) with the end goal being more accurate weather and water prediction out to 14 days in advance. NOAA is leading the international Distributed Model Intercomparison Project (DMIP) to help understand complex hydrologic issues related to distributed models, with the ultimate goal of improving hydrologic forecasts.

Research activities that support the above outcomes and performance objectives are organized by research themes and are described below along with their associated research milestones.

7.3.1 Improve weather forecasts and warning accuracy and amount of lead time

Critical weather information falls short of national needs and expectations due to an incomplete understanding of meteorological processes, inadequate frequency and coverage of environmental observations, and inadequate data assimilation and numerical modeling. The basic understanding of why tornadoes form, the process of hurricane formation and intensification, and the ability to forecast precipitation amounts sufficient to forecast floods are among the weather research challenges ahead. Other research issues that must be addressed include linking larger-scale global circulation fluctuations to specific and local severe weather outbreaks, improving data assimilation efforts, establishing a multidisciplinary approach to models that link various fundamental components, and

addressing short-range rapid changes in mesoscale phenomena. NOAA must also increase its knowledge of the space environment and advance the development of prediction models of solar and geomagnetic storms. An understanding of these processes will be critical if forecasts and warnings are to continue to improve.

Research results are now emerging that provide insight into the appropriate amount and type of data needed to address these deficiencies. NOAA's challenge is to determine the most cost-effective means for observing the sun, space, the atmosphere, land, water cycle, and ocean to support these requirements. Once the data are collected into a coherent format, assimilating them into numerical models to describe the current state of the environment for use by forecasters, researchers, and modelers will continue to be a topic of NOAA-funded research.

NOAA will conduct, direct, and leverage research and development in cooperation with other federal agencies and the academic community to better understand key processes governing the environment from the sun to the sea. Research will be conducted in NOAA laboratories, academia, and elsewhere to improve predictions of severe weather, fire weather, hurricanes, winter storms, associated heavy precipitation, and flood events. This research will add critical information and understanding about severe storms to forecast which mesocyclones will produce a tornado or damaging winds, and the size of hail associated with individual storms. The duration and speed of storm movement are frequently critical unknowns to the forecaster and affects the impacts of the storms. Hurricane intensity, track, rainfall amounts, and tornadoes greatly affect the impacts on the communities at risk along the coast and well inland along the track of landfalling hurricanes. A greater understanding is needed to improve and extend forecasts especially for hurricane intensity changes. Winter storm formation, tracking, precipitation amount, precipitation type, wind speeds, and wind direction need to be better quantified to provide effective forecasts and warnings. Fire weather research is required to improve upon fire weather guidance and analysis graphics containing weather parameters deemed important for fire weather conditions and forecasting. Ice storms are major hazards that need to be better understood to better predict the areas that will be impacted by them. Convective (springtime) precipitation needs to be monitored and modeled as a component of the seasonal water balance. Precipitation amount and the uncertainty associated with weather events are critical to improve forecasts and information for water management and flood warnings.

NOAA will participate in targeted field experiments and observing system studies, and will conduct diagnostic modeling studies to better understand specific forecast challenges. NOAA will advance data assimilation and the transfer of new research and technology into operations through operational and developmental testbeds. Fixed, mobile, and airborne radar systems continue to be used and improved for the detection of storms, including polarized radar which has shown potential to improve quantitative precipitation estimation (QPE) and phased array radar technology which shows promise in providing higher resolution data both spatially and temporally to help improve lead time in forecasting severe storms. The process of incorporating these and other new technologies will be a challenge for NOAA. The use of testbeds will continue to expand and put new technology, researchers, and operational forecasters together to jointly evaluate new ideas and techniques to smooth the transition from research to operations.

Table 13. Research Milestones for Improving Weather Forecasts and Warnings

Research Milestone	0-2 Years	3-5 Years
Improve radar observations and characteristics of precipitation		X
Develop dual polarization knowledge and expertise	X	X
Continue investigation the utility of phased array radar technologies.	X	X
Advance forecasts through related testbeds	X	X
Complete 15 Joint Hurricane Testbed Projects per year	X	X
Advance data assimilation techniques; satellite, radar, ocean, hydrologic, and land surface assimilation	X	X
Develop and evaluate space environment forecast model		X
Accurate measurements of geomagnetic activities and solar energetic particles	X	
Winter Weather Experiment - includes expanding and assessing the application of short-range ensemble forecasts and their use in winter storm watch and warnings	X	
Advance ensembling and statistical post-processing techniques	X	X
Improve the utility of advanced prediction information	X	X
Improve numerical techniques and physical parameterizations, advance to earth system modeling framework	X	X
Advance networking and information technology research and development	X	X

7.3.2 Improve water resources forecasting capabilities

NOAA will enhance its hydrology program to meet broader national water resources information needs. While NOAA has produced streamflow and flood forecasts for several decades, there is economic value of an expanded suite of water resource predictions to support flood mitigation and manage water availability and quality for agriculture, potable water, hydropower, thermal power cooling, sustainable ecosystems, navigation, and contaminant loading. NOAA will integrate its research and operational assets to deliver water resource predictions and information. Although the accuracy of flow forecasts has improved, there is a need to conduct research and development to address challenging problems, such as increasing the lead time for flood warnings and flow predictions, and quantifying and reducing the uncertainty in these estimates.

There are several research challenges that will be addressed by activities in the FY 2005-2009 timeframe. Flow forecasts will include all ranges from droughts to floods, which will require the explicit modeling of entire watersheds. River forecasting models will have to account for the potential releases and evaporation losses from reservoirs in a watershed, the influence of surface water diversions and return flows for irrigation and domestic water supply, and the effect of groundwater pumping on river flows. Research will be conducted to improve our understanding and predictions of the sub-seasonal variability in rainfall and the onset and cessation of heavy rainfall events. NOAA will improve its ability to monitor and predict the runoff from snow-melt, forecast snow levels, and monitor soil moisture which can precondition runoff rates. Because of the substantial economic impacts of reservoir operations on power generation, flood control, and potable water and agricultural water use, these research efforts will include social scientists. Research and development of radar systems (e.g., polarized radar) and technologies (e.g., multi-sensor QPE algorithms) are needed to improve the accuracy of radar measurements of precipitation, both in quantity and type of precipitation. Research and development of microwave remote sensing of snow and ice are needed to improve estimates of regional water supplies and snowmelt flood forecasting. Leveraging satellite instrumentation to observe precipitation, snow water content, and soil moisture and incorporating satellite information to fill in gaps in the ground-based radar coverage is necessary to improve hydrologic models. A new generation of high-resolution distributed rainfall-runoff models will be developed. These new models will be coupled with mesoscale weather models to make better use of data to increase the accuracy and specificity of river and streamflow predictions. Research is needed to advance understanding of

uncertainty and assimilation of observations into this new generation of distributed models. Research is needed to advance the understanding of the effect of climate phenomena to develop a new generation of long-range hydrologic prediction products for prudent allocation of water resources. This research will require the coupling of ocean, atmospheric, and hydrologic models.

Table 14. Research Milestones for Water Resources Forecasting

Research Milestone	0-2 Years	3-5 Years
Describe water resource allocations and socio-economic impact	X	X
Improve radar estimates of precipitation; combine with satellite data	X	
Development of improved rainfall - runoff models		X
Incorporated Satellite information – Quantitative Precipitation Estimation	X	X
Coupled weather/climate and rainfall-runoff models		X
Describe the effect of climate phenomena on the hydrologic cycle		X

7.3.3 Provide information to air quality decision makers and establish and improve a national air quality forecast capability

NOAA has begun providing air quality forecast guidance for the Northeast U.S. The initial operational capability, dealing with surface ozone concentration, is a first step in producing timely and accurate air quality forecast guidance to help society mitigate impacts of unhealthy pollution levels. NOAA will provide air quality decision makers with better information and tools for making decisions that have large public health and economic consequences. Research is required in three key areas: model development, regional assessments, and improved measurement tools to monitor long-term trends. NOAA is a leader in the development of air quality model assessments of tropospheric ozone and particulate matter levels. Future modeling research will include expanding the scope of the models to create a particulate matter model that can be used for operational forecasting, to extend the forecast interval to several days and beyond, and to enhance the quality and accuracy of information they provide. NOAA, along with partners from academia and other agencies,, will also perform regional assessments that identify and characterize the key atmospheric processes that control air pollution transport and transformation in areas that have serious air quality problems. A central element of each assessment is a comprehensive regional field study that deploys state-of-the-art instruments to measure myriad weather and air quality parameters from the ground, air, and the water. These assessments provide information that allows regional and urban decision makers to better protect public health while maintaining economic vitality and also provide scientific advancements that can be used to improve models. In addition, NOAA will develop improved measurement tools in support of national operational networks that monitor long-term trends of deposition of atmospheric pollutants to the surface. These trends are used to evaluate models, the effect of air pollution policies, and atmospheric influences on land and water bodies.

Table 15. Research Milestones for Providing Information to Air Quality Decision Makers and Establishing and Improving a National Air Quality Forecast Capability

Research Milestone	0-2 Years	3-5 Years
Provide prototype model suitable for implementing new particulates forecasts		X
Understand key air quality processes	X	X
Assess deposition trends	X	X
Develop advanced air quality models for regulatory assessments	X	X

7.3.4 Improve NOAA's Understanding and Forecast Capability in Coasts, Estuaries, and Oceans

The NOAA research community will integrate and improve weather and water information, warnings, and forecasts in our coastal zones to provide services as accurate, comprehensive, and

responsive as over our nation's interior areas. There are four distinct research challenges to move to knowledge-based decision-making tools—lack of an integrated observation system; lack of an integrated assessment and forecast system; lack of integrated dissemination and outreach; and the required mechanisms to support accelerated transition of research to integrated operations. Scientific research and technology development will expand process models and work toward coupled models for coastal, estuary, and ocean and improve the linkages between fresh and saltwater models and those between biological and physical-chemical models. Research will improve forecast capabilities by enabling integration of wind, wave, water level, storm surge, current, and related data. Seamless descriptions and understanding of coastal, estuarine, ocean, and inland areas will be enhanced by research integrating erosion, flood, riverine, hydrodynamic, wind, ocean circulation, storm surge, and related processes. This will also require data assimilation and improvement in observational capabilities in coastal zones. Research activities will support the network of coastal and ocean observing systems to improve the accuracy, resolution and coverage in the nation's ports, bays, estuaries and open oceans. New techniques of observing and monitoring coastal regions from existing and new satellite sensors will be developed. Enhanced observational sensors and monitoring techniques will enable expansion and enhancement of a more complete and cost-effective system of national coverage.

A primary outcome will be an expanded and consolidated coastal-estuary-ocean water condition report. The research and development will make weather and water information, forecasts and warnings in coastal zones as comprehensive and responsive as over our nation's interior. NOAA will integrate and improve its environmental information products and services for the nation's coastal zones. A focused research and development program in coastal, estuarine, and ocean science will contribute to the development of an expanded and integrated suite of coastal water prediction products. Research is required to identify and characterize the key transition zone processes in this coastal and ocean environment to predict true coastal flooding and its impacts. In addition, evolving coastal and ocean observations will be incorporated into new ocean system prediction algorithms and models to achieve a new ocean forecast.

Table 16. Research Milestones for Improving Understanding and Forecast Capability in Coasts, Estuaries, and Oceans

Research Milestone	0-2 Years	3-5 Years
Development of a transition zone modeling system to integrate river, estuarine, and coastal models		X
Develop and evaluate advanced ocean forecasting system for currents and ocean status		X

8. Commerce and Transportation Mission Goal: Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation

8.1 Introduction

NOAA provides critical information, products, and services essential to the safe and efficient transport of goods and people at sea, in the air, and on land. Today, more than 95 percent of non-North American Free Trade Agreement (NAFTA) United States foreign trade moves by sea. Two-thirds of everything purchased by American consumers arrives by ship, and this trade is conservatively expected to double by 2020. In addition, the U.S. coastal recreation and tourism industry with over 17 million recreational boats has an annual economic value of about $24 billion to the country. While traveling on our nation's roadways, adverse weather conditions are associated with over 1.5 million vehicular crashes, which result in 800,000 injuries and 7,000 deaths annually. In addition to the tragic loss of life, there are also significant delays in arrivals of people and goods (trucking, rail, transit, pipeline, ferry, and airport ground transportation factors), resulting in more than $42 billion per year in economic cost.

There are a large number of congressional mandates, international agreements, agency requirements and policies, and memoranda of understanding with other federal agencies that drive the mission of NOAA's Commerce and Transportation Mission Goal and the activities of its programs.

To fulfill this mission, it is necessary to acquire a wide array of data, ranging from periodic to continuous, ocean to land to atmosphere, and utilizing both fixed and mobile platforms, both in situ and satellite. Real-time observations, analyses, and forecasts of temperature, wind, pressure, precipitation, and visibility are provided to support the nation's diverse land-based economy. Real-time and forecast navigational data are acquired, and products (such as nautical charts) are distributed to mariners navigating our waters and key players active in port and harbor development, from the ice-covered waters in Alaska to the small estuaries along our coasts.

Figure 4. Selected External Drivers for the Commerce and Transportation Mission Goal

Appropriate research and development are needed to maximize the quality and efficiency with which NOAA acquires, manages, and distributes our data and associated products and services to ensure they are accurate, reliable, secure, understandable, timely, and readily accessible to meet the stringent demands of the transportation sector.

In support of Homeland Security, research under this mission goal will support and improve NOAA's ability to accurately and rapidly disseminate up-to-date nautical charts, critical chart corrections, and specialized mapping products. These research and development efforts are instrumental to the security of our nation by enhancing NOAA's ability to provide accurate, real-time data and timely forecast guidance supporting safe passage and disaster response on both land and water. Research will also lead to an increase in the number of coastal communities with the capacity to respond to spills and other hazards that result from manmade or natural disasters by offering forecasts of oceanic and atmospheric dispersion of hazardous materials, and giving emergency responders reliable tools to take action and geographically position resources.

8.2 Outcomes and Performance Objectives

The research activities for the Commerce and Transportation Goal support two outcomes:

- **Safe, secure, efficient, and seamless movement of goods and people in the U.S. transportation system**
- **Environmentally sound development and use of the U.S. transportation system**

The following performance objectives have been developed to evaluate the achievement of the outcomes:

- Enhance navigational safety and efficiency by improving information products and services
- Realize national economic, safety, and environmental benefits of improved, accurate positioning capabilities
- Reduce weather-related transportation crashes and delays
- Reduce human risk, environmental, and economic consequences as a result of natural or human-induced emergencies
- Increase total government procurements from NOAA-licensed commercial firms operating remote sensing systems

8.3 Research Activities and Themes

The research activities that support the outcomes above are organized by themes and are described below along with their associated research milestones.

8.3.1 Reduced Risks to Life, Health, and Property within Our Nation's Transportation System

There are two areas that particularly address this theme. Accurate, timely, and appropriate information is critical to protect lives, cargo, and the environment. To ensure that this important information will be available, advances are required in sensing technology, the acquisition and processing of data from these sensors, and the ability to integrate and blend data from all sources.

Remote Sensing – Sensor, Data Acquisition, and Processing Advances

Continued research, development, and systems integration are required for remote sensing technologies—such as multibeam, side scan sonar, topographic and bathymetric Light Detection

and Ranging (LIDAR), imaging spectroscopy, and Synthetic Aperture Radar (SAR)—that are used to collect, process, and manage survey data; we are gaining efficiencies from these versatile instruments and continuing to extract new products from them. The data are used for many purposes in support of safe navigation such as updating NOAA's nautical charts and defining our nation's shoreline and maritime boundaries. These data are also used to support many non-navigational needs such as characterizing sensitive marine habitat, building storm surge and tsunami models, monitoring subsidence, surveying hurricane evacuation routes, supporting homeland security initiatives, and determining the effects of hazardous storms. Continued development is required to investigate new products and services that incorporate benefits of new technology including delivery mechanisms such as GIS and web-based interactive programs. Among the GIS techniques to be developed are algorithms that take advantage of newly acquired, complete coverage bathymetric data to optimize potential claims for an extended continental shelf under UNCLOS Article 76. Also, continued effort is needed in the technology of data visualization, particularly in the development of new and unconstrained paradigms in electronic navigational charting. Successfully developed technology and software whose use would result in increased efficiency, cost savings, and/or accuracy are transitioned to operational use. Close cooperation with the private sector is essential throughout the entire process to facilitate the incorporation of standard-compliant techniques into industry products.

National VDatum

Geospatial data collected by NOAA and elsewhere, particularly data collected in coastal regions, suffer from being tied to many different vertical reference datums. NOAA is developing a revolutionary vertical datum (VDatum) transformation tool to address this problem. VDatum translates geospatial data between vertical reference systems and removes the most serious impediments to data sharing allowing for the easy and accurate transformation of elevation data from one vertical datum to another to seamlessly integrate geospatial data for the benefit of the American public. VDatum will also allow NOAA to make full use of recent technological advancements (such as kinematic-GPS and LIDAR) that will greatly improve the efficiency with which it acquires new and more accurate data for its nautical, navigational, and geospatial products and services.

With the completion of VDatum in our nation's waters, advancements in the "awareness" of electronic navigation chart (ENC) electronic charting systems and Electronic Chart Display and Information System (ECDIS) will be possible. A vessel's exact position in the water can be accurately determined using Differential GPS. This information could then be incorporated into the charting system along with real-time display of actual water depths for the entire body of water. This will allow danger areas to be identified, displayed, and adjusted depending on a vessel's draft as it transits through areas of concern.

Table 17. Research Milestones for Reduced Risks to Life, Health, and Property

Research Milestone	0-2 Years	3-5 Years
Enhanced use of emerging airborne technologies, such as LIDAR and Synthetic Aperture Radar (SAR)	X	X
Investigate AUV and UAV R&D technology and integration into survey operations		X
Develop new concepts and technology for processing, analysis, and management of hydrographic and ocean mapping data	X	X
Design and build a VDatum database	X	

8.3.2 Issues that Slow or Stop movement of Goods and People in the U.S. Transportation System

Real-time information to understand the present and predictions for the future are imperative to ensure continued movement of goods and people in our transportation system. Knowing the positions of ships relative to their surroundings over time is critical for the safe and efficient transportation of people and goods on our nation's waterways. Five research and development efforts that advance seamless movement address the need for improved instrumentation, systems, and procedures, as well as for hydrodynamic modeling and dynamic mapping to allow for the acquisition of more relevant, accurate, and timely data.

Real-Time Physical Oceanographic Data Collection

NOAA tests and evaluates oceanographic and marine meteorological sensors and systems to improve the quality, responsiveness, and value of individual sensors or integrated sensor systems to customer requirements, thereby improving the overall performance of the marine transportation system. Performance testing, quality assurance, repeatability, and endurance assessments are provided to a level required by NOAA to accept legal liability required for navigational products and services. Partnering with other government or private organizations that specialize in new sensor testing and development is a key component in this overall effort.

Customers include the navigation community (pilots, captains, recreational boaters), coastal managers, emergency managers, meteorologists, and climatologists, and there is a continuous dialogue with users to determine needs and requirements. New and improved sensors and sensor systems to monitor wind, tide, waves, and currents will improve the safety and efficiency of navigational services provided by NOAA, which translate into cost savings for shipping operations and reduced risks due to groundings, accidents, or collisions.

Real-Time Weather Data Collection – Standards, Methodology, and Integration

To mitigate the adverse impacts of localized weather conditions, travelers need weather advisories based on timely, fine resolution weather observations along the nation's roadways to enable them to make the most informed traveling decisions. Local effects such as fog, blowing and drifting snow, ice, high winds, and other hazardous weather conditions can impact travel conditions with very short notice.

NOAA will engage international, federal, state, and local agencies; academia; and private industry partners to join NOAA, the Federal Aviation Administration, and the Federal Highway Administration in defining and validating the roles and requirements necessary to provide accurate and timely information to meet air and surface transportation needs. Research and development needs apply to all surface transportation modes but will address highways as a priority and for prototype purposes.

Research and development for real-time weather data collection will focus on the following:

- Standardizing methods of data gathering, archiving and exchange;
- Assessing the refinements needed to meet surface transportation needs (performance standards, densification, accuracy, siting criteria, proprietary data);
- Developing an integrated prototype observing methodology at selected transportation choke points or high impact areas; and
- Demonstrating integration of mesonet data, surface transportation data, and the modernization of the NOAA Cooperative Observer Network, based on weather sensor-equipped vehicles positioned with GPS or other advanced technology.

- Providing reports for safety and efficiency of air navigation

Looking to the future, research will concentrate on sensor development to adequately determine surface conditions, technology for data sharing and transmission, and incorporating human factor engineering into products/services including usability, education, and training.

Hydrodynamic Modeling

Continued research and development of oceanographic forecast models are required for transition into an operational environment for more efficient transit scheduling, oil spill response, and other applications. NOAA's oceanographic forecast model systems have reached a level of sophistication such that they can now be used to benefit safe and efficient maritime commerce in the United States. The parameters forecast by these model systems—such as water levels, current fields, salinity, and water temperature—can also be beneficial to protecting the marine environment, which is critical for recreational boating and tourism. As forecast systems are tested and fully evaluated according to established standards, they are then transitioned into a 24x7 operational environment and made available online to the general public. The selection of the locations of models to be developed is based on specific criteria including user input.

These models, which are operating in some U.S. ports today, provide 24-hour or longer forecasts of water levels which allow commercial shippers and port authorities to make economic decisions such as how much cargo to load or when an incoming ship should arrive to maximize safe and efficient transit of waterways. The models also provide salinity and temperature forecasts, which are important for predicting water density impacts on a ship's draft, oil spill transport in the water, and for related ecosystem modeling.

Applied research is also carried out to further improve the skill and applications of the nowcast and forecast models. This includes data assimilation techniques, ensemble averaging, Lagrangian/ trajectory outputs, residence time calculations, and the coupling of estuary models with coastal models. Another important research area is developing methods to produce accurate estimates of uncertainty for each individual model forecast, including the use of ensemble techniques.

High-Resolution Weather Information

Current weather infrastructure and models support useful regional weather forecasts for many public safety purposes; however, to reduce the effects of adverse weather, the nation's network of weather and road condition observations must be modernized and integrated, and these data must be disseminated to the public and to surface transportation system operators.

Research and development will also focus on filling observational gaps, which will be critical given the rapid growth in the use of the transportation system, which is expected to outpace the deployment of new infrastructure. A database containing the data from a dense national network of environmental sensors is needed for the production of relevant NOAA forecast grids. This database will also enable the private sector to produce route and customer-specific road weather observations and predictions.

NOAA will work in concert with our research partners in the transportation community to reach a common goal of reducing the weather-related loss of life and property on the roads, rails, and transit. Our contribution will consist of efforts to increase the usage and utility of surface observations, maximize the value of existing NOAA products, and conduct research and development to identify appropriate actions to improve our services. Activities will be aligned with the Federal Highway Administration's CLARUS initiative to build a National Surface Transportation Weather Observation and Forecasting System.

As research and development regarding roadway transportation matures and transitions into operations, integration of scientific capabilities and activities towards intramodal (e.g., rail and transit) and intermodal (e.g., aviation and marine) transportation forecasting should commence. NOAA will seek out synergies and efficiencies between road weather research and parallel efforts regarding other models of transportation.

National Spatial Reference System

Research activities are performed to support NOAA's mission to provide the nation with the National Spatial Reference System (NSRS), which enables a consistent, accurate, and timely positioning capability nationwide. Research is carried out within NOAA in collaboration with academic and commercial entities. The tools developed reside on site but are made available to the public via the Internet when appropriate.

Table 18. Research Milestones for Issues that Slow or Stop Movement of Goods

Research Milestone	0-2 Years	3-5 Years
Provide performance testing, quality assurance, repeatability, and endurance assessments of marine meteorological sensors and systems as applicable		X
Investigate High Frequency Radar (current mapping) for reliability, accuracy, and application	X	
Develop the standardized Next Generation Operational Forecast System	X	
Develop methods to determine uncertainties for model forecasts		X
Develop methodology to attain 1-cm geoid model accuracy		X
Obtain nationwide real-time positioning within a few centimeters		X
Develop standards and protocols for weather-related electronic data exchange	X	
Validate methodologies for acquisition, processing, and dissemination of weather-related data	X	
Transfer research weather-observation prototypes into full operational use		X
Transfer road weather prototype modeling efforts into operations		X

8.3.3 Reduced Risks and Adverse Environmental Impacts from the U.S. Transportation System

Thousands of incidents occur each year in which oil or chemicals are released into the coastal environment. Spills into our coastal waters, whether accidental or intentional, can harm people and the environment, and cause substantial disruption of waterways with potential widespread economic impacts. The nation's dependence on the marine transportation system creates an ongoing need to efficiently develop preparedness and response actions that reduce the risks of spills and minimize the impact on commerce and the environment when spills do occur.

NOAA is working to develop a comprehensive strategy to identify the information necessary for making reliable decisions in preparedness, response, damage assessment, and restoration. This research will improve our basic understanding of coastal and marine spills and, most importantly, advance our capacity for:

- Responding to spills in a manner that minimizes the impacts to biological, economic, and cultural resources.
- Assessing the impacts of both the spill and the response efforts on those resources.
- Restoring the impacted resources with the highest degree of efficiency and effectiveness.

This information is used not only by NOAA, but also by external customers such as the U.S. Coast Guard; U.S. Army Corps of Engineers; Minerals Management Service; U.S. Navy; Environmental Protection Agency; individual state governments; energy development, production, and

transportation firms; spill response and clean up firms; marine transportation firms; and port authorities.

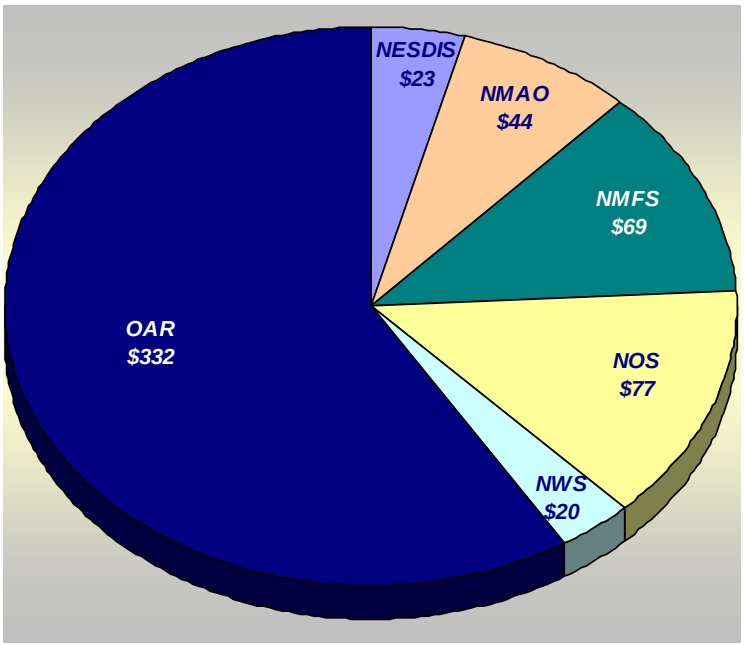
Table 19. Research Milestone for Reduced Risks and Adverse Environmental Impacts

Research Milestone	0-2 Years	3-5 Years
Develop tools that support prevention, preparedness, and response decisions at the community level		X

9. NOAA's Research Infrastructure

The NOAA research infrastructure includes a system of federal laboratories and science centers and ship, aircraft, and other observing systems and platforms. This infrastructure is enhanced though assets provided by our external partners.

Research planning throughout NOAA is based on mission goal relevance; however, because research is implemented and executed at the NOAA Line Office level, NOAA's infrastructure is characterized here according to NOAA Line Office assignment. Figure 5 indicates the research funding allotments to the line offices based on the actual budget for FY 2004.



Based on FY 2004 actual budget – in millions of dollars

Figure 5. Funding for Research and Development in NOAA by Line Office

9.1 NOAA Laboratories and Centers

Accomplishing NOAA's missions requires a solid underpinning in atmospheric sciences, limnology, oceanography, chemistry, biology, mathematics, and space physics. NOAA's ability to meet our mission goals can only be as good as the state of knowledge in these scientific disciplines. Our laboratories and science centers 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.

9.1.1 Oceanic and Atmospheric Research (OAR) Laboratories

Aeronomy Laboratory (AL)

AL conducts research to improve the capability to observe, understand, predict, and protect the quality of the atmosphere, especially the chemical and physical processes of the Earth's atmosphere. This research concentrates on the lower two layers of the atmosphere—the troposphere and the stratosphere.

Air Resources Laboratory (ARL)

ARL conducts research on processes that relate to air quality 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.

Atlantic Oceanographic and Meteorological Laboratory (AOML)

AOML conducts research in oceanography, tropical meteorology, atmospheric and oceanic biogeochemistry and acoustics with a focus on the Atlantic Ocean, Caribbean, and South Florida. AOML also collects and manages data from several components of the Global Ocean Observing System. AOML research seeks: to understand the physical characteristics and processes in the ocean and the atmosphere, both separately and as a coupled system, and their implications upon biogeochemistry, ecosystems and tropical storms; and, to contribute to both seasonal to interannual climate forecasts and decadal to centennial climate predictions.

Climate Diagnostics Center (CDC)

CDC identifies the nature and causes for climate variations on time scales ranging from a month to centuries, including separating natural variability from anthropogenically induced climate changes in order to provide an improved scientific basis for public planning and policy decisions. The CDC also acts as an Applied Research Center of the Office of Global Programs (OGP) (see Section 9.3 for additional discussion).

Climate Monitoring and Diagnostics Laboratory (CMDL)

CMDL conducts sustained observations and research related to source and sink strengths, trends, and global distributions of atmospheric constituents that are capable of forcing change in the climate of Earth through modification of the atmospheric radiative environment, those that may cause depletion of the global ozone layer, and those that affect baseline air quality.

Environmental Technology Laboratory (ETL)

ETL supports the strategic goals of NOAA and OAR through regionally specific research efforts in weather, climate, and air quality that exploit the ETL's unique expertise in remote sensing of the geophysical environment.

Forecast Systems Laboratory (FSL)

FSL conducts applied research to improve/create short-term warning and weather forecast systems, models, and observing technology using supercomputing and other leading-edge technology. FSL then transfers the new scientific and technological advances to its clients, including the NWS, the commercial and general aviation communities, the U.S. Air Force, many foreign weather forecasting offices, and various private interests.

Geophysical Fluid Dynamics Laboratory (GFDL)

GFDL conducts comprehensive long-term research fundamental to NOAA's mission of understanding climate variability and change. The goal of this research is to expand the scientific understanding and modeling of the physical processes that govern the behavior of the atmosphere and the oceans as complex fluid systems.

Great Lakes Environmental Research Laboratory (GLERL)

GLERL carries out research and provides scientific products, expertise, and services required for effective management and protection of Great Lakes and coastal ecosystems.

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.

Pacific Marine Environmental Laboratory (PMEL)

PMEL carries out interdisciplinary investigations in oceanography and atmospheric science. Results from PMEL research activities contribute to seasonal-to-interannual climate forecasts, assessing and predicting decadal to centennial climate change, advancing short-term warning and forecast services, and building sustainable fisheries.

9.1.2 National Marine Fisheries Service (NMFS) Science Centers

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, U.S. representatives participating in international fishery negotiations, and the fishing industry and its constituents.

Northeast Fisheries Science Center (NEFSC)

NEFSC manages a multidisciplinary program of basic and applied research to better understand living marine resources of the Northeast Continental Shelf from the Gulf of Maine to Cape Hatteras. The NEFSC also describes and provides to management authorities, industry, and the public, options for the conservation and utilization of living marine resources.

Northwest Fisheries Science Center (NWFSC)

NWFSC conducts multidisciplinary research to provide fisheries management information and technical advice. Such information supports national NMFS programs, responds to the needs of the Pacific Fishery Management Council, and supports other constituencies along the U.S. West Coast.

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 and endangered species. 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.

Southwest Fisheries Science Center (SWFSC)

SWFSC conducts research in mathematics, oceanography, economics, and computer sciences for the purpose of developing information to support management of Pacific coastal and high-seas fishery resources. SWFSC activities support the needs of both the Western Pacific and the Pacific Fishery Management Councils; the NMFS Southwest Regional Office; and International Commissions for worldwide tuna and Antarctic resources.

Pacific Islands Fisheries Science Center (PIFSC)

PIFSC conducts research on fisheries, coral reefs, and protected species. The PIFSC also conducts biological, ecological, and economic research in support of fishery management 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 green sea turtle.

9.1.3 National Environmental Satellite, Data, and Information Service (NESDIS) Center

Office of Research and Applications (ORA)

ORA develops algorithms and conducts research on the use of satellite data for monitoring meteorological, climatological, and oceanographic environmental characteristics. ORA is made up of three divisions: the Satellite Meteorology and Climatology Division (SMCD), the Satellite Oceanography Division (SOD), and the Cooperative Research Program (CoRP).

9.1.4 National Ocean Service (NOS) Laboratories and Centers

Center for Coastal Fisheries and Habitat Research (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 and 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 Coastal Environmental Health and Biomolecular Research (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.

Ocean Systems Test and Evaluation Program (OSTEP)

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.

Center for Sponsored Coastal Ocean Research (CSCOR)

CSCOR/COP 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 develops/improves cartographic, hydrographic, and oceanographic systems used by the Coast Survey and NOS to provide products and services for the coastal community, especially in support of safe and efficient navigation and the utilization and protection of the coast. The CSDL consists of three organizational parts: Cartographic and Geospatial Technology Programs (CGTP), Hydrographic Systems and Technology Programs (HSTP), and Marine Modeling and Analysis Programs (MMAP).

Hollings Marine Laboratory (HML)

HML is 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.

National Geodetic Survey (NGS) Geosciences Research Division

The NGS Geosciences Research Division performs fundamental research in applications of GPS technology to Earth science and in development of gravity measurement systems.

National Geodetic Survey (NGS) Remote Sensing Research Group

The NGS Remote Sensing Research Group performs research, development, and systems integration of new remote sensing technologies to provide for efficient and accurate shoreline data collection and for the long-term development of standards, specifications, and procedures.

9.1.5 National Weather Service (NWS) Laboratories and Centers

Environmental Modeling Center (EMC),

EMC, part of the National Centers for Environmental Prediction (NCEP), develops and improves numerical weather, climate, hydrological, and ocean prediction through a broad program in partnership with the research community.

Meteorological Development Laboratory (MDL)

MDL develops and implements scientific techniques into NWS Operations. MDL furnishes a full spectrum of forecast guidance, provides interactive tools for decision assistance and forecast preparation, and conducts comprehensive evaluations of NWS Products.

Office of Hydrological Development Laboratory (OHD)

OHD enhances NWS products by infusing new hydrologic science, developing hydrologic techniques for operational use, managing hydrologic development by NWS field offices, and providing advanced hydrologic products to meet needs identified by NWS customers.

Space Environment Center (SEC)

SEC provides space weather alerts and warnings. SEC continually monitors and forecasts Earth's space environment; provides accurate, reliable, and useful solar-terrestrial information; and leads programs to improve services.

9.2 Cooperative Institutes

NOAA's Cooperative Institutes are academic institutions that collaborate in a large portion of NOAA's research and play a vital role in broadening NOAA's ability to provide the expanding array of environmental assessment and predictions required to address the nation's forecasting needs.

Because many Cooperative Institutes are collocated with NOAA research laboratories, there is a strong, long-term collaboration between scientists in the laboratories and in the university. Cooperative Institutes not collocated with a NOAA laboratory often serve diverse research communities and research programs throughout NOAA.

Cooperative Institutes serve an additional important function: they help educate and train the next generation of NOAA's and the nation's scientific workforce. Many of the cooperative agreements between NOAA and our academic partners provide for formal NOAA sponsorship of students through fellowships.

9.2.1 OAR Cooperative Institutes

Atmospheric Investigation, Regional Modeling, Analysis and Prediction Consortium (AIRMAP)

The AIRMAP consortium at the University of New Hampshire studies climate variability and the source of air pollution in New England in order to identify the causes of climate variability, predict air quality changes, and demonstrate new forecasting technologies.

Cooperative Institute for Arctic Research (CIFAR)

CIFAR is a cooperative institute with the University of Alaska. CIFAR conducts research on a variety of issues critical to the Arctic and focus on fisheries oceanography; hydrographic studies; sea-ice dynamics; atmospheric research; climate dynamics and variability; tsunami research and prediction, assessment, and monitoring; and numerical modeling.

Cooperative Institute for Atmospheric Sciences and Terrestrial Applications (CIASTA)

CIASTA is a cooperative institute with the Desert Research Institute of the University and Community College System of Nevada. CIASTA focuses on weather research, climate, air quality, and terrestrial ecosystem studies related to global change, hydrology, and water supply in the arid regions typical of the intermountain West.

Cooperative Institute for Climate Applications and Research (CICAR)

CICAR is a cooperative institute with Columbia University. Research themes include modeling, prediction, and assessment of climate variability and change; development, collection, analysis, and archiving of instrumental and paleoclimate data; and development of climate variability and change prediction and assessment to provide information for decision makers.

Cooperative Institute for Climate and Ocean Research (CICOR)

CICOR is a cooperative institute with the Woods Hole Oceanographic Institution. The research activities of CICOR are organized around the coastal ocean and near-shore processes, the ocean's participation in climate and climate variability, and marine ecosystem processes analysis.

Cooperative Institute for Climate Sciences (CICS)

CICS is a cooperative institute with Princeton University. Research will support Earth system model development, climate product generation, and development of models to study regional/global climate variability and change, oceanic and terrestrial carbon cycles, and other processes important in projections of future climate variability and change.

Cooperative Institute for Limnology and Ecosystems Research (CILER)

CILER is a cooperative institute with the University of Michigan, with formal links to Michigan State University and other universities. Primary research focuses on climate and large-lake dynamics, coastal and nearshore processes, large-lake ecosystem structure and function, remote sensing of large lake and coastal ocean dynamics, and marine environmental engineering.

Cooperative Institute for Marine and Atmospheric Studies (CIMAS)

CIMAS is a cooperative institute with the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences that works closely with AOML. Research is conducted within five themes—Climate Variability, Fisheries Dynamics, Ocean Observing Systems, Air-sea Interaction, and Coastal Ocean Ecosystem Processes—all in collaboration with NMFS. The latter theme is also in collaboration with OAR.

Cooperative Institute for Mesoscale Meteorological Studies (CIMMS)

CIMMS is a cooperative institute with the University of Oklahoma. Research includes basic convective and mesoscale forecast improvements, climatic effects of controls on mesoscale processes, socioeconomic effects of mesoscale weather systems, and regional scale climate variations. CIMMS collaborates with the NSSL and supports the NWS modernization efforts.

Cooperative Institute for New England Mariculture (CINEMAR)

CINEMAR is a cooperative institute with the University of New Hampshire that serves as a regional center where representatives from universities, industry, federal and state programs, and the private sector can work together on issues surrounding fisheries management, mariculture and marine policy in New England's waters.

Cooperative Institute for Research in the Atmosphere (CIRA)

CIRA is a cooperative institute with Colorado State University. CIRA conducts research involving global and regional climate, local and mesoscale area weather forecasting and evaluation, applied cloud physics, applications of satellite observations, air quality and visibility, societal and economic impacts, numerical modeling, and education, training, and outreach.

Cooperative Institute for Research in Environmental Sciences (CIRES)

CIRES is a cooperative institute with the University of Colorado. CIRES conducts research in environmental chemistry and biology, atmospheric and climate dynamics, cryospheric and polar processes, and the solar-terrestrial environment.

Joint Institute for Marine and Atmospheric Research (JIMAR)

JIMAR is a cooperative institute with the University of Hawaii. Research includes equatorial oceanography, climate research, tsunamis, fisheries oceanography, tropical meteorology, and coastal research. JIMAR works closely with the Pacific Regions of NMFS and NWS, as well as the Coastal Services Center in Honolulu.

Joint Institute for Marine Observations (JIMO)

JIMO is a cooperative institute with the University of California's Scripps Institution of Oceanography. State-of-the-art observation capabilities—such as platforms (surface, subsea, and air/space), sensors, and systems architecture—are utilized to fill pressing research needs. Of particular interest at JIMO are coupled ocean-atmosphere climate research, oceanography, marine geology and geophysics, and ocean technology.

Joint Institute for the Study of the Atmosphere and Ocean (JISAO)

JISAO is a cooperative institute with the University of Washington. JISAO complements the research at PMEL in climate variability, environmental chemistry, estuarine processes, and interannual variability of fisheries recruitment.

9.2.2 NMFS Cooperative Institutes

Cooperative Institute for Marine Resources Studies (CIMRS)

The CIMRS is a cooperative institute at Oregon State University that brings together scientists from NOAA's NW Fisheries Science Center, the Pacific Marine Environmental Laboratory, and Oregon State University to work on problems of mutual interest relating to the living and non-living components of the marine environment and their interrelationships. CIMRS research staff is currently involved in scientific efforts that parallel NOAA's program objectives in the areas of geological/chemical and fisheries oceanography.

Cooperative Marine Education and Research (CMER) Program

The CMER program is a partnership between NOAA and five academic institutions: the University of Massachusetts, the University of Rhode Island, Rutgers University, the Virginia Institute of Marine Science and Hampton University. This cooperative program addresses mission-related research problems identified by the agency and facilitates the training of marine scientists and strives to help the nation meet the challenges posed by issues of resource management in the marine environment.

9.2.3 NESDIS Cooperative Institutes

Cooperative Institute for Climate Studies (CICS)

CICS is a cooperative institute with the University of Maryland. CICS was established to foster collaborative research in studies of satellite climatology, climate diagnostics, modeling, and prediction.

Cooperative Institute for Meteorological Satellite Studies (CIMSS)

CIMSS is a cooperative institute with the University of Wisconsin-Madison. CIMSS conducts research using passive remote-sensing systems for meteorological and surface-based applications and develops techniques for using geostationary weather satellite thermal radiation observations to improve severe storm forecasts.

Cooperative Institute for Oceanographic Satellite Studies (CIOSS)

CIOSS is a cooperative institute with Oregon State University. CIOSS develops, improves, and evaluates methods of ocean remote sensing and ocean-atmosphere modeling. Specific applications include basic research into ocean and atmosphere dynamics, contributions to ocean observing/modeling systems, and evaluation of plans for future systems and models.

9.2.4 NOS Cooperative Institutes

Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET)

CICEET uses the scientific capabilities of the University of New Hampshire, the private sector, and academic and public research institutions throughout the United States—as well as the National Estuarine Research Reserve System—to develop and apply new environmental technologies and techniques.

Joint Hydrographic Center (JHC)

Established at the University of New Hampshire, JHC is a national center for expertise in ocean mapping and hydrographic science. JHC expands interaction and cooperation with the private sector, other government agencies, and universities. Its research focuses on developing and evaluating a wide range of state-of-the-art hydrographic and ocean mapping technologies and applications.

9.2.5 NWS Cooperative Institutes

Cooperative Institute for Applied Meteorological Studies (CIAMS)

CIAMS is a cooperative institute with Texas A&M University. Research at CIAMS focuses on understanding and predicting synoptic and mesocale weather phenomena and better utilizing radar and lightning data. CIAMS works most closely with the NWS Southern Region.

Cooperative Institute at the Pennsylvania State University (CIPSU)

Research at CIPSU is aimed at applying data and knowledge of the atmosphere, hydrosphere, and biosphere to the solution of specific applied and operational forecast problems, including atmospheric, hydrologic, and climatic prediction. CIPSU works closely with NCEP and the NWS Eastern Region.

Cooperative Institute for the Prediction of Hydrometeorological Hazards in the Northeastern United States (CIUA)

CIUA is a cooperative institute with the University at Albany, State University of New York. Research at CIUA focuses on better understanding and prediction of both warm and cold season precipitation systems. CIUA works closely with the NWS Eastern Region.

Cooperative Institute for Regional Prediction (CIRP)

CIRP is a cooperative institute with the University of Utah. Research at CIRP focuses on numerical weather prediction within complex terrain and mesoscale observing systems. CIRP works closely with the NWS Western Region and NCEP.

Cooperative Institute for Tropical Meteorology (CITM)

CITM is a cooperative institute with Florida State University. Research focuses on tropical meteorology, the understanding and prediction synoptic and mesoscale weather phenomena, and

climatology. CITM works closely with the NWS Southern Region and the National Centers for Environmental Prediction (NCEP).

9.3 Grant Programs

9.3.1 Office of Global Programs

NOAA's OGP sponsors scientific research through several grant programs and its Applied Research Centers. OGP's grant programs are aimed at understanding climate variability and its predictability. Through studies in these areas, researchers coordinate activities that jointly contribute to improved predictions and assessments of climate variability over a continuum of timescales from seasonal to interannual and beyond.

9.3.2 The National Sea Grant College Program

Sea Grant is a nationwide network of 30+ university-based programs that partner with coastal communities. Sea Grant provides a stable national infrastructure of programs located at universities in every coastal and Great Lakes state, and Puerto Rico. These programs serve 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. Sea Grant invests in NOAA priorities such as coastal communities and economies, coastal hazards mitigation, ecosystems and habitats, aquaculture, fisheries and seafood technology, marine biotechnology, the urban coast, ocean technology and education. 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.

9.3.3 Ocean Exploration Grant Program

The Office of Ocean Exploration is NOAA's center for new activities to explore and better understand our oceans. This office supports grants for expeditions, exploration projects, and a number of related field campaigns for the purpose of discovery and documentation of ocean voyages.

9.3.4 NOAA's Undersea Research Program

NOAA's Undersea Research Program (NURP) is a unique national service that provides scientists with the tools and expertise they need to work in the undersea environment. The six regional Research Centers provide the scientific community with access to a wide array of underwater technologies, including submersibles, ROVs and AUVs, underwater laboratories, seafloor observatories, and SCUBA and mixed-gas diving programs. Undersea technology issues such as biotechnology and pharmaceuticals, seafloor observing and sensing, and vehicle development are addressed by NURP's National Institute for Undersea Science and Technology.

9.3.5 Geodetic Science and Applied Research (GSAR) Program

The objective of the GSAR Program is to improve positioning operations and services in support of transportation and commerce on a national basis.

9.4 Other Partners

NOAA participates in numerous interagency partnerships and takes advantage of many mechanisms to coordinate research activities with other government agencies and the larger scientific community.

NOAA works with the **National Science and Technology Council's** Committee on Environment and Natural Resources and the **National Oceanographic Partnership Program** to facilitate interagency coordination on many domestic and international environmental and natural resources issues, including research and development.

NOAA is a sponsor of **University Corporation for Atmospheric Research (UCAR),** a consortium of universities dedicated to education and research that enriches our understanding of the Earth system. UCAR manages the National Center for Atmospheric Research (NCAR) and the UCAR Office of Programs (UOP).

Several NOAA entities are Associate Members of the **Consortium for Oceanographic Research and Education (CORE)**. CORE represents 74 of the nation's academic institutions, aquaria, nonprofit research institutes, and federal research laboratories. CORE's common goal is to promote and enhance ocean research and education. As a member of CORE, NOAA works in concert with the national oceanographic community.

9.5 Observing Systems Supporting Research in NOAA

Research throughout NOAA depends on the vast amount of data collected from observing systems that range from simple measuring devices to extremely sophisticated satellite platforms. The NOAA Observing Systems Council has provided an in-depth evaluation of NOAA's observing systems and future plans through its recent publication, *Strategic Direction for NOAA's Integrated Global Environmental Observation and Data Management System* (June 2004). The evaluation includes a comprehensive review of all of NOAA's observing systems and their interrelationships, as well as a catalog of observing systems arranged alphabetically by NOAA Line Office.

NOAA Marine and Aviation Operations (NMAO) 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 rotary 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.