Understanding Global Ecosystems to Support Informed Decision-Making

A 20-Year Research Vision

Message from the NOAA Administrator

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"*

As NOAA works to realize its Vision, it must confront a set of growing challenges in an ever-changing world. As science and technology progress, so too will the effects of globalization and a growing world population on local economies, human welfare, and the environment. NOAA must be able to adapt its posture and develop the necessary tools to support society's changing needs for information and services over the coming decades. Research is at the heart of turning NOAA's vision into reality. Through research, we discover and improve our knowledge of Earth's oceans, coasts, and atmosphere. This knowledge is the foundation for the products and services NOAA provides and allows NOAA and the nation to make sound environmental and ecological management decisions.

The natural systems governing our planet are more complex and interconnected than we can presently describe, and shifting political, economic, and social factors limit our ability to pinpoint the state of the planet 20 years hence. In this challenging context, NOAA must maintain a commitment to pioneering research that will satisfy the evolving needs of resource managers, decision makers, and the American public in the years to come. Indeed, NOAA's ability to conduct research that targets critical national needs is at the core of the present and future success of the agency.

For more than 30 years, NOAA has conducted and sponsored research to support a suite of products and services that span multiple temporal and spatial scales. These deliverables and the discoveries that generated them have been at the forefront of our scientific understanding and technological capabilities. This Vision document lays out a path to enhance NOAA products and services to meet the urgent demands of this new century by continuing to take advantage of discoveries in science and technology and recognizing the connection between our environment, our economic well being, and human health. Integration of research across existing disciplines is a central theme of NOAA's future; the links among the ocean, atmosphere, and biosphere must be further explored, bolstering our nascent understanding of the complex interrelationships that comprise the global ecosystem.

The NOAA 2005-2010 Strategic Plan sets the stage for the short- and medium-term vision of NOAA's research enterprise. NOAA's Strategic Plan highlights focal areas for research in ecosystems, climate, weather and water, and commerce and transportation. The requirements for research in each of these areas determine the near term activities and milestones described in the NOAA 5-Year Research Plan and point the way ahead for the agency's research agenda for the next two decades. The 20-year Research Vision provides the foundation for NOAA's longer-term approach to research. It will position NOAA to support society's changing needs for information and services over the next 20 years and beyond and enable society to make the best social and economic decisions.

Our World in 2025—A Vision of NOAA at the Forefront of Informing Decision-makers

By 2025, the ubiquitous influence of NOAA's environmental forecasts on personal decision- making will span time scales from hours to months. Personal injuries from tornadoes and other extreme events will be almost unheard of thanks to dramatic advances in forecast skill and the likelihood that virtually everyone will have a personal electronic assistant (PEA) that will include ample warnings of every kind of environmental hazard. Through their PEAs, boat captains will have easy access to the latest nautical, weather, and sea conditions and forecasts. Coupled with daily analyses of subsurface oceanfronts and eddies to identify the best fishing locations, captains will be able to limit the exposure of their crews to potentially dangerous conditions.

Forecasts will go beyond the simple weather predictions available at the turn of the century to incorporate air quality and risks of disease, which public health agencies will use to lessen adverse impacts. Emergency managers will have mitigation plans in place that will be selected and initiated based on forecasts. More confident outlooks of the weather seasons ahead will allow people to choose between letting the price of their beach vacation change with the weather forecast or locking in a price six months ahead.

Policy and decision makers at local to national levels will also increasingly factor environmental and ecological predictions and projections into their planning. Imagine, if you will, that on this date in 2025 local government leaders in Charleston, SC are meeting in special session. A new water desalination plant is about to come on line. The timing is critical. Population along the coast has doubled in the last twenty years. A three-year drought in the Southeast has depleted reservoirs. Damage to the local ecosystem is significant, but mitigation activities have lessened the adverse impacts. Fortunately, Charleston political leaders heeded long-range environmental predictions and built the desalination plant to mitigate future water supply challenges. This is a success story that major metropolitan areas around the globe are rushing to emulate as they face their own water shortages.

On an international level, imagine that in 2025 the United States and Canada sign a landmark treaty covering use of fresh water stored in the Great Lakes. The focus of the treaty is to maintain ecosystem and environmental balance while tapping into the largest source of fresh water on the planet. The two-year climate projection indicates a likely decrease in precipitation over the middle of North America, making the treaty all the more timely.

By the end of the first quarter of the 21st century, the world will depend on NOAA's detailed and reliable environmental information and predictions to make the best social and economic decisions. These decisions will improve economies, enhance recreational opportunities, protect public health, reduce dramatically the likelihood of injuries from severe storms, and mitigate the harm from droughts and long-term climate changes.

Societal Needs and NOAA in the 21st Century

Societal demand for information and integrated management solutions provided by NOAA on the state of the atmosphere and oceans, the condition of living marine resources, water rights, ocean navigation and weather prediction will increase dramatically in extent and urgency during this century. The fundamental, overarching reality of growth in worldwide population will create many of these new demands as economies, human welfare, and the environment are affected. Impacts from globalization and associated trends will likewise result in increasing demands on society.

- Population growth—in the United States and globally— will increase the threat of severe weather impacts on human health, water rights, safety, and economic investments. The U.S. population will increase its expectations and reliance on weather forecasts, and more sophisticated land planning will create a greater need for NOAA data and analyses.

- Fisheries resources will experience increasing stress in most regions until worldwide demand for protein creates financial incentives for society to insist on better management. This will result in a need for substantially improved description, understanding, and prediction of fisheries productivity. Increased marine aquaculture will be necessary to keep up with global demands for food protein, impacting economies and marine ecosystems.

- Threats to the oceans and human health will include infectious diseases. Increased monitoring of medical waste disposal and means of infectious agent transmission will be required. There will also be additional stresses on the oceans as their natural resources are explored in search of marine biomedicines and cures for noninfectious diseases such as cancer, multiple sclerosis, and Alzheimer's disease.

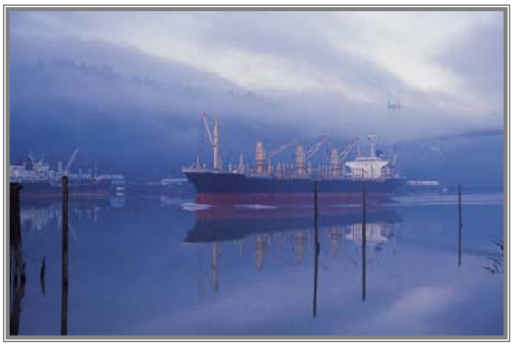
- Pollution will continue to increase as a result of normal human pursuits such as work, transportation, and recreation. Nitrogen and other by-products of human endeavor will continue to flow from the land into the oceans. Phenomena like harmful algal blooms, such as red and brown tides, will inhibit our use of ocean resources and will increase demand to monitor and moderate nutrient runoff from land. Increased introduction of invasive species due to ballast water exchange and recreational fishing will increase biological pollution. Atmospheric pollutants, originating both in the United States and off shore, will require enhanced monitoring, modeling, and tracking.

- Carbon and other greenhouse gas releases into the atmosphere will continue to increase on a worldwide basis even as industrialized countries, including the United States and Western Europe, reduce their releases. As carbon and other greenhouse gas releases continue to promote global warming, the United States and other

developed nations will put increased emphasis on atmospheric monitoring as a basis for providing economic incentives to reduce greenhouse gas releases.

- The potential for accidental or purposeful releases of biological, chemical, or radiation toxins into the environment has increased. This increase will create a need for enhanced observations and analyses incorporated into a quick response systems that coordinate with federal, state, and local emergency managers.

- Increasing international commerce will create a demand for more and larger ocean transport vessels and infrastructure improvements, such as larger and deeper channels. The larger vessels will operate more efficiently and safely by optimizing their routes using weather, wind, and current information. However, the larger and more numerous vessels will create congestion in ports with negative consequences on the economy and the environment as well as increased concerns for public safety. These increased risks will require location information that will allow vessel arrival times to be properly scheduled, including an increased demand for real-time information on vessel location, sea state, weather, and ocean mapping.



- The economic significance of longer-term climate predictions for activities such as agriculture, manufacturing plant site location, and recreation industry decisions will grow substantially.

- Improved knowledge about ecosystems will demonstrate the need for society and government to adapt and respond to changes and demands in a more efficient manner than is possible today. This will demand understanding and improving the structure and functioning of NOAA with its fellow agencies and academic, private sector, and international partners to support sustainable development of marine and other natural ecosystems.

Technology and NOAA in the 21st Century

Accompanying society's increasing dependence on integrated ecological analyses and predictions will be the continuing introduction of new technologies in the marketplace that will enable NOAA to address these societal needs. There are four key technology sectors that NOAA depends on to describe, understand, and predict the environment—*sensors*, *platforms*, *information technology*, and *telecommunications*.

- *Sensors* that are capable of gathering most of the desired information about the biological, chemical, and physical components of the environment already exist. Many of these sensors are not deployed in the environment because of expense and fragility. Substantial improvements in both cost and ruggedness of sensors will occur in the next 20 years. This will allow the deployment of large numbers of biodegradable sensors in target environments that are cheap enough to simply be

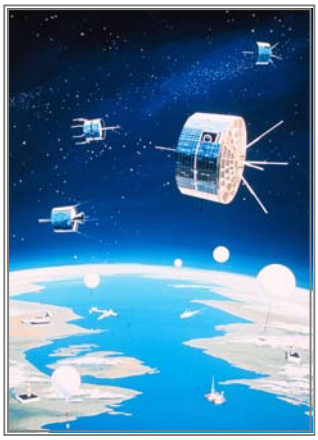
replaced rather than maintained. Adaptive technologies that can react dynamically to rapidly changing situations will be critical to NOAA in the next 20 years.

- *Platforms:* In addition to deployment of autonomous sensors on fixed platforms, NOAA will also exploit *mobile sensor platforms* (e.g., unmanned aerial vehicles and autonomous undersea vehicles) to monitor and observe the land, the atmosphere, and the ocean surface, depths, and floor. This approach will be particularly advantageous for deep ocean floor exploration and mapping. Of particular note, these advanced and sophisticated platforms, in conjunction with the sensors indicated above, will afford researchers and operators the capability for even more sophisticated adaptive sampling techniques; preprogrammed "smart" systems will take observations and measurements in a highly optimized fashion.

- *Information Technology* will continue to advance with computer processing speed doubling every 18 months. There will be better frameworks for constructing complex modeling systems, as well as better data management and analysis tools. This will allow NOAA to advance model-based analysis techniques (through data assimilation) that will exploit the data acquired from new sensors. NOAA will employ high resolution, holistic models that include information on land-based activities, estuaries, coasts, oceans, living marine resources and the atmosphere. These holistic models will enable NOAA to describe, understand, and predict the interactions of all parts of the environment at increasingly finer resolution.

- *Telecommunications* will continue to improve in resolution, bandwidth content and availability. GPS, a critical telecommunications technology for support of sensor deployment, will achieve routine 1 cm resolution in the next five years. Global networks will have the capacity to link modeling and ecological information centers seamlessly and effortlessly with service providers and users. The wide availability of personal electronic assistants and enhanced data communications systems will give users the capability to "reach back" to powerful high performance computers, taking advantage of state-of-the-art modeling and forecasting, to meet their own, individual needs. As society becomes ever more dependent on telecommunications, NOAA's space weather forecasts will likewise become more critical to those who manage and depend upon the communication highway.

All of these technologies will be exploited in developing an integrated *Global Earth Observing System of Systems*, GEOSS. Our present observing system is composed of many individual pieces covering a wide range of environmental information needs. Many of these observing systems were built for a single purpose. They have connections to different networks and consist of a variety of data formats and dissemination methods. Integrating these observing systems will enable the analysis and prediction of the state of the atmosphere, land, streams, and oceans, placing special emphasis on the hydrological, biological, geological and chemical cycles that link these elements of the ecosystem.



A Sampling of NOAA's Products and Services in 2025

Fueled by dramatic improvements in the integration of NOAA's information, products, and services, NOAA will provide the American public with easy-to-use, seamless, integrated information products and services that will revolutionize the way Americans lead their daily lives in heretofore unimaginable ways: we will dramatically improve severe event warnings and air quality forecasts; we will offer increasingly confident decadal predictions of climate; we will improve our management of fisheries, estuaries, and protected resources based on ecosystem-level scientific information; and we will make critical environmental information available to individual land, air, and sea vehicles in real time. Highlights of these major advances are provided below.

- ***Severe storm and event warnings will save more lives and property.*** The enhanced information delivery systems of the future will be well coordinated and able to quickly disseminate severe storm and event warnings. The warnings themselves will see dramatic improvements. For example, tornado warning lead times will be on the order of one hour, rather than minutes. Technology like phased array radar, significant improvements in our understanding of mesoscale weather processes and the development of models that embody this understanding will enable this accomplishment. Improvements in storm surge forecasting and increased tsunami monitoring/warning capacity will also greatly minimize loss of life and property damage from these hazards. Our ability to protect the public from tsunami hazards, in particular, will be increased through the development and refinement of model-based propagation and inundation maps and the expansion of deep ocean warning systems.
- ***Air quality forecasting will improve and expand nationwide.*** Air quality models will include not only pollutants such as ozone, but also a whole range of species relevant to "chemical weather" as well as fine particles. The models will cover the entire nation but be adaptable to address local-to-regional health and visibility concerns. In the future, air-quality models will assimilate observations of chemical species, leading to greatly improved systems for protecting the public from emissions from specific point sources, and forecasts will extend out to several days and beyond.

Improved air quality forecasts, in addition to extended prediction time horizons for severe storms, tsunamis, and flash floods will create substantial benefits for U.S. society. More timely and region-specific forecasts, warnings, and use of information will save lives and billions of dollars. [1]

[1] National Center or Atmospheric Research (NCAR), Environmental and Societal Impacts Group, and the Atmospheric Policy Program of the American Meteorological Society, 2001, *Extreme Weather Sourcebook 2001: Economic and Other Societal Impacts Related to Hurricanes, Floods, Tornadoes, Lightning, and Other U.S. Weather Phenomena,* National Center for Atmospheric Research, Boulder, CO.

- ***NOAA will make seasonal to decadal climate predictions with clearly stated levels of uncertainty.*** This accomplishment will be enabled by increased observation data; improved understanding of the earth system; advances in the speed, accessibility and reduced cost of information technology; and the pervasiveness and reduced cost of telecommunications technology.

Climate-related products will move increasingly towards outlooks on regional scales that are accompanied by well-described uncertainties. NOAA will conduct and sponsor research to improve our understanding of key processes aimed at reducing uncertainty in predictions, as well as provide a better understanding of predictability and prediction limits. Probabilistic statements about climate outcomes will become standard, and they will be framed in ways that improve their utility for decision-makers and public use.

An improved appreciation of the applicability of seasonal climate forecasts will allow resource managers to better mitigate agricultural and other impacts from flood/drought, promote better water resource management, and combat temperature-sensitive disease propagation. Weather- and climate-sensitive industries account for nearly $3 trillion annually, ranging from finance, insurance, and real estate services, to retail and wholesale trade manufacturing[2]. Other industries that rely either on consumptive and non-consumptive water use, such as agriculture, power generation, water supply and sanitation, flood control, and navigation, are pillars of the economy, yet many of the country's large reservoirs are rarely used to full capacity, due in part to the limited accuracy of present-day seasonal climate and stream flow forecasts.

- ***NOAA will provide the scientific underpinning for an ecosystem approach to management of coastal and ocean resources such that complex societal choices are informed by comprehensive and reliable scientific information.*** Our vision includes a sound scientific basis for an array of ecosystem indicators with known meaning, a highly automated observing system to measure indicators, and models that evaluate tradeoffs between multiple sources of ecosystem stress and type of societal costs and benefits. In short, we envision the transition of research into a scientific knowledge rich, and technologically and computationally intense, system of decision support tools that provide relevant, responsive and reliable scientific advice and information products making an ecosystem approach to management operational.

Ecosystem research will enhance understanding of physical/chemical/biological interactions and the ability to link ecosystem capacity and models to environmental variability and change. This understanding is critical to reducing uncertainties asso-

[2] Dutton, John A., *Opportunities and priorities in a new era for weather and climate services,* Bulletin of the American Meteorological Society, September 2002, volume 83, no. 9, pp 1303-1311.

ciated with ecosystem structure and function. Observing capability will be refined, and new models of physical/biological coupling at various space and time scales will be produced. Understanding of trophic, multi-species links will be advanced, and eventually fully coupled with climate variability and change. Building on this information, NOAA will produce operational forecasts for a suite of ecological conditions including fisheries, anoxia, harmful algal blooms, beach closings, and water quality.

Building better coastal and ocean decision support tools and exploring our vast ocean resources will support the nation's transformation to ecosystem-based management approaches. Key issues are to better manage coastal resources, reduce/mitigate human impacts, ensure sustainability, and improve human health and quality of life. Improved science-based information will allow us to better manage problems such as variable seafood production, harmful algal blooms, coral reef bleaching events, and ecosystem deterioration by alien and invasive species.

- ***NOAA will lead major programs to explore the oceans to benefit the nation.*** The world's oceans remain a largely unexplored and unknown opportunity for mankind. Ocean exploration will increasingly characterize the unknown physical, chemical, biological, and geological aspects of our seas, providing new hypotheses in ecosystem and climate research. Discovery of lost shipwrecks and other submerged cultural resources will help modern civilization understand its past, and possibly resolve current mysteries. The oceans will present unexpected opportunities to benefit mankind—perhaps pharmaceuticals mined from ocean biota, new sources of energy generation, and new food resources. Ocean exploration will foster the testing and development of new sensors and platform technologies and will continue to be on the frontier of our understanding of ocean processes and resources.

- ***Weather, location, topographical, and other relevant environmental information will be made available to individual land, air and sea vehicles in real time.*** This accomplishment will be enabled by advances in information and telecommunications technologies including high resolution GPS. 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.[3] In addition to the tragic loss of life, significant delays in arrivals of people and goods (trucking, rail, transit, air, pipeline, ferry, and airport ground transportation factors) result in considerable economic costs. Adverse weather is responsible for about 70 percent of aviation delays—costing about $4.2 billion annually, much of which could be avoided with better observations and forecasts.[4] Improved transportation forecasts and guidance will help reduce accidents and help save significant costs.

  Research to address transportation needs will integrate real-time observations, atmospheric and oceanographic nowcasts/forecasts, and position-tracking

[3] Lombardo, Louis, 2000, of the National Highway Traffic Safety Administration. *Overview of U.S. Crashes & Environment*. Presentation at the WIST II Forum, December 4–6, 2000. Available on the web site of the Office of the Federal Coordinator for Meteorology and Supporting Research, at: http://www.ofcm.gov/wist2/presentationstartpage1.htm.

[4] *2002 State of the U.S. Airline Industry: A Report on Recent Trends for U.S. Carriers*, Air Transport Association, Washington, DC, 2002.

information with enhanced interactive visual, electronic, and automated decision-support tools and services. Research will focus on improving the skill, applications, and uncertainty estimates of the models; positional accuracy; and data visualization methods, particularly in the development of new electronic navigational charting products.

Improved navigational tools, real-time observations, and nowcast/forecast oceano-graphic products coupled with GPS-assisted navigation will provide society with safer and more efficient ports, thus increasing capacity while not decreasing margins of safety to humans, port infrastructure, or to critical habitat and ecosystems.

A Sample of NOAA Products and Services in 2025

	*Forecasts and mitigation strategies related to: anoxia/hypoxia, harmful algal blooms, beach closings, invasive species, waves, air/water quality and quantity* *Ecological assessments and predictions of impacts from climate change (e.g., coral bleaching)* *Decision support tools for adaptive, ecosystem-based management of fisheries, coastal development, and marine resources* *Improved assessments of sea level change on coastal resources and ecosystems* *Better integration of observing system data for coastal ecosystem manager use* *Fishery productivity forecasts that incorporate the effects of climate change*
	*Improved intra-seasonal to seasonal to decadal forecasts utilizing Earth System models* *Water resource & drought forecasts including nutrient runoff* *Weather-related disease forecasts (e.g., malaria, SARS, West-Nile virus)* *Projections of sea level change* *Scenarios for future climate mitigation and adaptation studies – including land use changes* *Decision support climate information and assessments*
	*Work with partners to provide neighborhood-level weather forecasts and 10-14 day forecasts as accurate as current 7-10 day forecasts* *Severe thunderstorm and tornado track forecasts at the sub-county level with one hour or more lead time* *Sophisticated air-quality and chemical composition prediction models on regional- and continental-scale air quality and atmospheric chemistry predictions* *Improved stream flow forecasting models that cover flow levels from droughts to floods, including interactions with groundwater, water resources applications, estuaries and coasts* *New soil moisture forecasting models for agricultural applications and mudslide warnings* *Improved systems for protecting the public from emissions from specific point sources*
	*Real-time atmospheric delay models (tropospheric and ionospheric) to improve real-time GPS positioning at cm-level accuracy* *Higher spatial resolution & accuracy for survey data to support safe navigation and ecosystem studies* *Vehicles/vessels that detect & respond to changing conditions; real-time access to weather information & route-planning tools* *Advanced real-time observational systems coupled with electronic charts, navigation systems, & forecast models* *New tools, technologies and procedures enhancing safety & capacity in air traffic management practices* *Decision support tools to affect transit time, delivery reliability, efficiency, cost of goods transported, and the health of the environment*

Current State of NOAA Research

To place our vision for future research in context, it is worth examining the current state of research in NOAA as framed within NOAA's existing Mission Goal structure (ecosystems, climate, weather and water, commerce and transportation):

***Ecosystems**:* Possibly our most under-appreciated challenge involves understanding ecosystems where human activity has a principal impact on their dynamics. NOAA has made dramatic strides in the ecosystems area: discovering new habitats (sea mounts, deep sea vents) and exciting new biota with unique chemistries, protecting marine mammals, regulating fish stocks, managing coastal habitats, and raising the awareness of oceans and coasts by the American public. However, we need to better understand the cumulative effects on natural systems of unprecedented human growth and development and to create effective means of mitigation so as to sustain ecosystem function. NOAA presently supports or conducts numerous ecosystem-based studies ranging from physical modeling to ecosystem characterization and habitat restoration. Our predictive capability, though, is limited, as is the degree of integration across disciplines. The forcing mechanisms and links between the physical environment and the biosphere must be further explored, studied, and monitored to improve our understanding of fisheries productivity and our management of coastal resources.

The commercial fishing industry adds approximately $28.5 billion in economic value to the national economy every year.

In addition to other benefits, worldwide agriculture benefits of better El Niño forecasts are at least $450 to $550 million per year

***Climate**:* Climate science has been revolutionized in the past decade. NOAA has helped plan and sponsor the world's most extensive program of scientific research, monitoring, data management, and assessment for climate change and variability. Results include the global characterization of important aspects of Earth's environment; the development of decadal-scale global observations; and significant improvement in the capability of models to project the future evolution of the Earth system, as evidenced by improvements in their ability to simulate variability in the present and recent past. We have made great strides in understanding the El Niño phenomenon, but we have a long way to go to make seasonal forecasts consistently accurate. NOAA uses its global climate models to project future climate change, but uncertainties remain large because of insufficient knowledge about the components of Earth's climate system and the interactions among them. The cycling of water and of carbon through the

climate system, long known to be major factors in climate change, is poorly modeled today. Yet, this information is critical to America[5]: U.S. industries that are sensitive to weather and climate events account for one third of the Nation's Gross Domestic Product (GDP)[6], making future changes in climate of vital importance to project and account for in our social and economic planning. NOAA scientists made key contributions to understanding the cause of the depletion of the stratospheric ozone layer, but much remains to be done in predicting the future course of ozone depletion in the context of a changing future climate. Fundamental, long-term research on a broad range of global change issues is, therefore, called for in the next 20 years.

During the period of 1980-2003, the United States sustained 58 major weather or climate related disasters, with damages and costs exceeding $350 billion

***Weather and Water**:* One of the scientific success stories of the 20th century is the development of numerical weather prediction, and today NOAA produces weather forecasts of proven utility out to a week. On the other hand, tornado warnings are not issued on the basis of forecasts, but rather upon observed evidence. Today's science and technology do not allow scientists to describe the genesis of a tornado, model it, and predict its path—a capability that could save many additional lives. Similarly, while we have dramatically improved the prediction of the track of hurricanes in recent years, our forecasts of their intensity, storm surge, and associated rainfall are less skillful. We provide incipient forecasts of regional air quality in some locations, but we cannot yet predict atmospheric composition on continental scales. In addition, our forecasts of water resources are currently limited to flooding conditions. To be more effective, NOAA will need to enhance its system of information delivery and dissemination. With improved weather information that is effectively delivered in the future, NOAA can not only reduce the costs associated with weather disasters, but also increase economic and human benefits, particularly through increasing the forecast accuracy of precipitation and water availability.

[5] Weiher, Rodney, ed. *Improving El Niño Forecasting: The Potential Economic Benefits*, NOAA, U.S. Department of Commerce, 1997.

[6] Dutton, John A., *Opportunities and priorities in a new era for weather and climate services,* Bulletin of the American Meteorological Society, September 2002, volume 83, no. 9, pp1303-1311.

By 2010, air passenger traffic is expected to increase to one billion annually, a 50 percent increase from 2001

Commerce and Transportation: The development and implementation of new technologies in the recent past has led to significant advances in safety and efficiency by aircraft, shipping, and ground transportation. There has been a steady decline in weather-related aircraft accidents in the past two decades, in part due to improved understanding and prediction of hazardous weather such as microbursts and icing. The advent of Global Positioning System (GPS) technology has also helped, yet the ability to acquire and process sufficient quantities of timely survey data for ship and land transportation routes, as well as for ecosystem assessment, is severely lacking. Remote sensing technologies and data fusion techniques, although constantly evolving, are presently not able to provide timely updates for navigational products, which also limits the potential of habitat characterization studies. Currently unmet needs include well-organized infrastructure information, charts, maps, and environmental analyses required to handle the increased size and number of vehicles and vessels currently taxing the limits of existing roads, channels, and bridge and cable clearances. How these increased loads may affect the ecosystems being traversed is of increasing concern. These requirements demand advances in electronic navigational products; expanded mapping capabilities and operations; new visualization tools; transportation monitoring systems; and the use of hydrodynamic models using real-time and predicted water level, current, and water density fields.

A New Paradigm for Predicting Changes in Global Ecosystems

Given the current state of research, our vision for the products and services that NOAA will provide in 2025 requires significant advances in the activities that support our mission:

- *Monitor and Observe* the land, sea, atmosphere, and space to create an observational and data collection network that tracks Earth's changing systems.
- *Understand and Describe* how natural systems work together through investigation and interpretation of information.
- *Assess and Predict* the changes of natural systems and provide information about the future.
- *Engage, Advise, and Inform* individuals, partners, communities, and industries to facilitate information flow, assure coordination and cooperation, and provide assistance in the use, evaluation, and application of information.
- *Manage* coastal and ocean resources to optimize benefits to the environment, the economy, and public safety.

As we move further into the 21st century, a substantive integration of research across the current mission goal structure is paramount. The weaving together of NOAA's

research for predicting changes in global ecosystems will largely be accomplished through data assimilation and models. NOAA uses models that depict the initial state of a system and project future states (forecasts) based on the laws of physics and thermodynamics or similar principles, along with an estimate of the forces or boundary conditions operating on the system. At present, models have been developed for the atmosphere, oceans, and to a lesser extent the biosphere. Although some success is being achieved in linking these models together to forecast the evolution of the full Earth system, truly holistic models that account for the interactions among all the components of the planet's ecosystems still elude us. These kinds of models and the forecasts they will produce are substantially different from what NOAA now provides the nation, and the creation of such holistic, Earth system models is a major goal of NOAA research in the next 20 years.

Partners in Achieving the NOAA Vision

NOAA is committed to collaborating with its current partners and seeking new partners to achieve its vision. With future advances in NOAA's high performance computing capabilities, models will be easily accessible to NOAA's research partners in universities, the private sector, other federal agencies and the international community. Advances in computer technology will allow more distributed modeling activity. This widespread computing and model accessibility (whether centralized or not) will create a rich intellectual environment that will accelerate our ability to understand, describe, assess and predict the environment.

Operational Partners

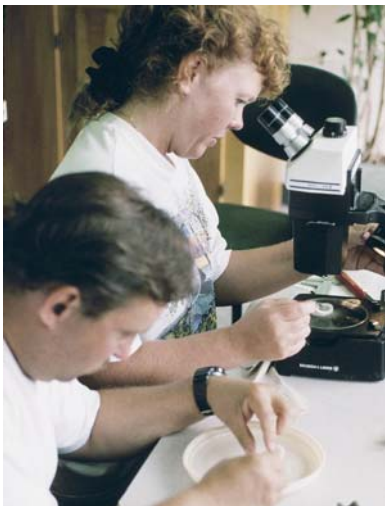
- At the federal level NOAA will continue to work with the National Aeronautics and Space Administration, the Departments of Defense, Interior, Homeland Security and Energy, the Environmental Protection Agency, and others to gather, analyze, and share environmental data.
- At the state and local level, NOAA will continue to work with emergency managers, water resource managers, fisheries conservation managers, coastal zone managers, and pollution monitoring and abatement experts.
- NOAA will work with non-governmental organizations that are committed to land, estuary, ocean and living marine resource management.

Scientist collects marine organisms at low tide at Padilla Bay National Estuarine Research Reserve.

- NOAA will continue to provide research products and information for collaborative use by the Private Sector.

Research Partners

- NOAA's federal research partners will continue to include NASA, NSF, EPA, DOE, DOD, and many others.
- NOAA will continue to have broad and symbiotic research relationships with universities through the National Sea Grant College Program, the National Undersea Research Centers, the system of National Estuarine Research Reserves, Cooperative Institutes, and substantial research grants.
- NOAA will also work with the private sector through computing and contracts to create and deploy new environmental sensors.
- NOAA will also collaborate with international partners both to learn and to share research results and techniques.



Scientists conduct research at the NOAA Restoration Center.

Educational Partners

- NOAA will continue to depend on its collaborations with universities to advance mission-critical ideas through research and to train the environmental scientists and mangers needed by NOAA and the rest of the nation.
- NOAA will explore establishing a postdoctoral research program for oceans and the atmosphere to increase the availability of environmental researchers. The National Sea Grant College Program, the Coastal Zone Management Act, and the National Marine Sanctuaries Act provide formalized opportunities for NOAA to support educational institutions and learn from them.
- NOAA will continue to provide lesson plans and other tools for teachers to use to bring the excitement of oceans, coasts, the atmosphere, and the global ecosystem to the classroom.
- NOAA will expand its formal and informal education resources offered to the public and K-12 schools to increase awareness of the importance of healthy oceans and atmosphere.

NOAA Partners for Success: The design and deployment of NOAA Doppler radar in the mid-1990s illustrates the critical dependence of operational advances on research and partnership collaborations. The NOAA Doppler radar was developed jointly by NOAA, the Department of Defense (DOD), and the Department of Transportation (DOT) and was based on research supported primarily by the National Science Foundation and the Department of Defense in the 1970s and 1980s. The specific design and operating parameters of the NOAA Doppler unit was a result of research within NOAA and on contract to private sector organizations. Deployment of the NOAA Doppler radars to NOAA, DOD, and DOT locations provided a more detailed and richer description of the weather. These descriptions energized research in NOAA and universities that enabled enhanced understanding and allowed significantly better predictions of the weather. From 1994 to 1999, NOAA improved its average advance warning time for tornados from 6 to 11 minutes. In that same 5-year period, NOAA was able to improve its average advance warning for flash floods from 18 to 42 minutes.

Refining the NOAA 20-Year Research Vision

This document presents a 20-Year Research Vision of NOAA based on how NOAA advances its ability to predict the global ecosystem, the current state of NOAA research, an assessment of external influences on NOAA, and an assessment of technical opportunities for NOAA.

The 20-Year Research Vision will be updated in conjunction with NOAA's planning process. As part of this process, NOAA will solicit comments, thoughts and challenges to this Research Vision. NOAA believes that its Research Vision will benefit from the active participation of our partners in its further development.