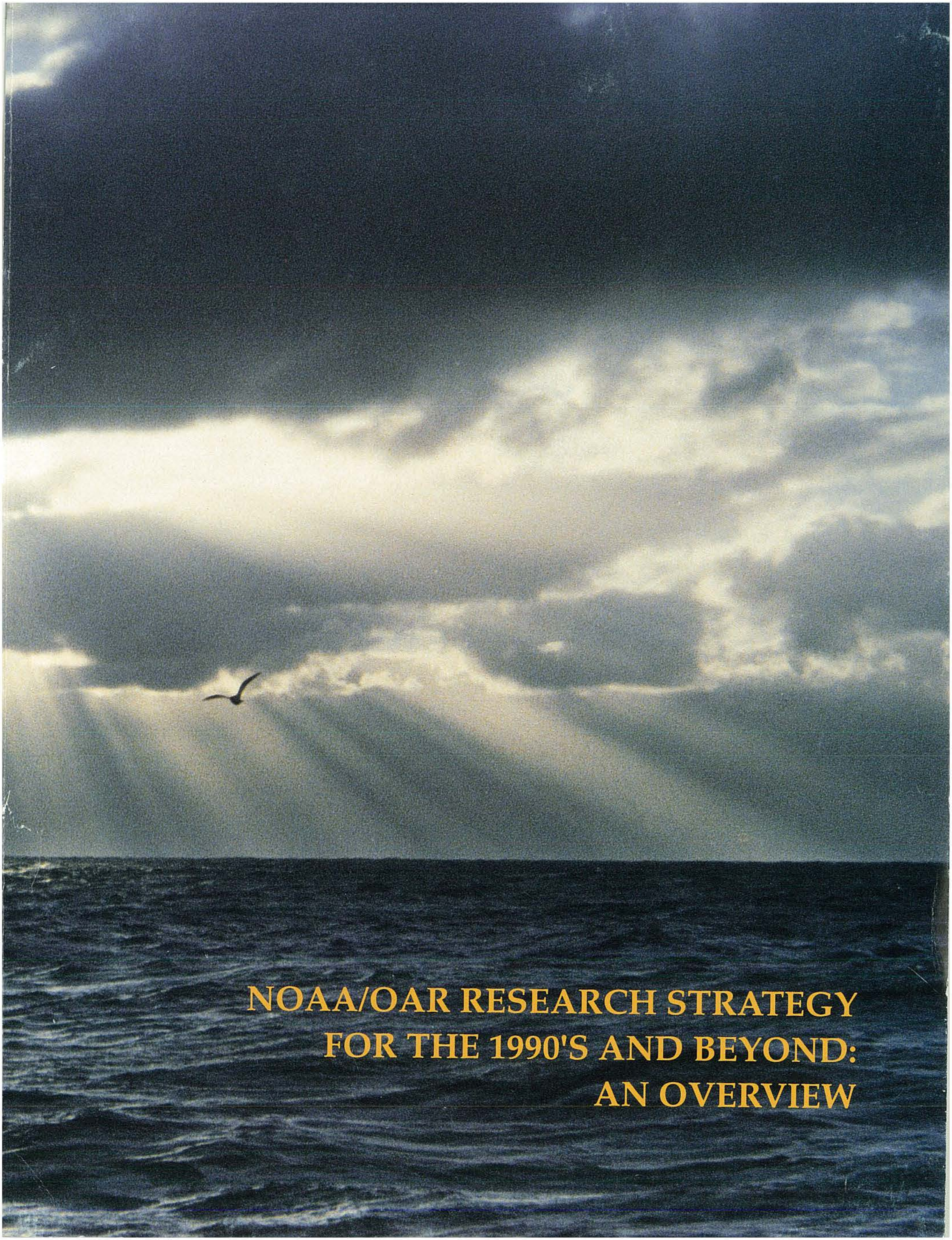

NOAA/OAR RESEARCH STRATEGY FOR THE 1990'S AND BEYOND: AN OVERVIEW

NOAA/OAR Research Strategy for the 1990s and Beyond: An Overview

Produced by the
University Corporation for Atmospheric Research

for the
NOAA Office of Oceanic and Atmospheric Research

Based on a series of
NOAA Symposia and Meetings

Boulder, Colorado
November 1991

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Acronyms

ACCP	Atlantic Climate Change Program, OAR/NOAA
AID	Agency for International Development
AOML	Atlantic Oceanographic and Meteorological Laboratory, OAR/NOAA
ARL	Air Resources Laboratory, ERL/NOAA
ASOS	Automated Surface Observing System
CFCs	ChloroFluoroCarbons
CGCP	Climate and Global Change Program, NOAA
COSPAR	Committee on Space Research (of ICSU)
DDT	DichloroDiphenylTrichloroethane
DNA	DeoxyriboNucleic Acid
DOD	Department of Defence
DOE	Department of Energy
DOI	Department of the Interior
DSV	Deep-Submersible Vehicle
EEZ	Exclusive Economic Zone
ENSO	El Niño-Southern Oscillation
EPA	Environmental Protection Agency
ERL	Environmental Research Laboratories, OAR/NOAA
FEMA	Federal Emergency Management Agency
FWS	Fish and Wildlife Service
GLOBEC	Global Ecosystem Dynamics Program
GFDL	Geophysical Fluid Dynamics Laboratory, OAR/NOAA
GOES	Geostationary Operational Environmental Satellite
GOFS	Global Ocean Flux Study
HRD	Hurricane Research Division, AOML/ERL/NOAA
IARPC	Interagency Arctic Research Policy Committee
ICSU	International Council of Scientific Unions
IGAC	International Global Atmospheric Chemistry Program
IGBP	International Geosphere-Biosphere Program
IJC	International Joint Commission
ITCZ	InterTropical Convergence Zone
IUWDS	International Ursigram and World Days Service
MAR	Mid-Atlantic Ridge
MIZEX	Marginal Ice Zone Experiment

NADW	North Atlantic Deep Water
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite and Data Information Service, NOAA
NEXRAD	NEXt generation weather RADar
NCAR	National Center for Atmospheric Research
NCI	National Cancer Institute
NGDC	National Geophysical Data Center, NESDIS/NOAA
NHC	National Hurricane Center/NWS
NMC	National Meteorological Center, NWS/NOAA
NMFS	National Marine Fisheries Service, NOAA
NOAA	National Oceanic and Atmospheric Administration
NOPPO	National Ocean Pollution Program Office
NOS	National Ocean Service, NOAA
NRC	National Research Council
NSF	National Science Foundation
NSGO	National Sea Grant Office, OAR/NOAA
NURP	National Undersea Research Program, OAR/NOAA
NWS	National Weather Service, NOAA
OAR	Offfice of Oceanic and Atmospheric Research, NOAA
OGP	Office of Global Programs, NOAA
OMB	Office of Management and Budget
ONR	Office of Naval Research
PAHs	Polycyclic Aromatic Hydrocarbons
PCBs	Poly-Chlorinated Biphenyls
PMEL	Pacific Marine Environmental Laboratory, OAR/NOAA
PROFS	Program for Regional Observing and Forecasting Services
RASS	Radio Acoustic Sounding System
RIDGE	Ridge Inter-Disciplinary Global Experiments
SAR	Synthetic-Apperature Radar
SBIR	Small Business Innovative Research Program
SEL	Space Environment Laboratory, ERL/NOAA
SEM	Space Environment Monitoring system
SOD	SuperOxide Dismutase enzyme
SOLTIP	SOLar Transient Interplanetary Phenomena
SST	Sea-Surface Temperature
TIROS	Television and InfraRed Observation Satellite
TOGA	Tropical Ocean-Global Atmosphere
UCAR	University Corporation for Atmospheric Research
UJNR	United States-Japan Natural Resource Panel on Aquaculture
URSI	Union Radio Scientifique Internationale
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VENTS	(not an acronym) Ocean vent exploration program
WOCE	World Ocean Circulation Experiment

Introduction

NOAA was created in 1970 to undertake a coordinated approach to our nation's "immediate and compelling needs for better protection of life and property from natural hazards and for a better understanding of the total environment...[to] more effectively...monitor and predict its actions and, ultimately,...exercise some degree of control over them." (Richard M. Nixon)

As we approach the 21st Century, this mission takes on even greater urgency, with the recognition that we are now involved in the understanding and management of global environmental issues that transcend both international borders and the disciplinary boundaries within which most scientists are trained. To meet this challenge, NOAA must realize its full potential as the Earth-system agency, and must ensure a strong scientific underpinning to its mission responsibilities of environmental prediction and stewardship of living marine resources.

The Office of Oceanic and Atmospheric Research (OAR) provides leadership and scientific excellence in NOAA through its research and development activities. NOAA's activities are the basis for improvements in NOAA's services today, and its changes in direction to meet the opportunities and problems of tomorrow. OAR directs research programs in marine and atmospheric sciences through its own laboratories and offices, as well as through university-based programs across the country.

OAR's research objectives are aligned with the three primary environmental programs of NOAA, listed here with their objectives:

- *Climate and Air Quality—Climate and Global Change*
  - Reliable prediction of seasonal, interannual, and decadal climate variation;
  - Useful simulation and assessment of long-term climate and air-quality changes; and
  - Effective scientific differentiation between natural variability and human-induced changes.
- *Ocean and Great Lakes Programs—Coastal Ocean Program*
  - Reliable marine prediction techniques;
  - Sound scientific bases for management of new marine resources; and
  - Central focus for US undersea science.
- *Atmospheric Research—Modernization of NOAA's Atmospheric Services*
  - Modernization of the national weather services;
  - Reliable and cost-effective prediction techniques; and
  - Improved solar-terrestrial (such as space weather) services.

This overview document is the first in a series of reports to communicate OAR's view of NOAA's opportunities in the critical areas of research for which we have responsibility. Two subsequent reports highlight research strategies for ocean-system studies; one on prediction and resources, the other on use and protection. It is our hope that these and future reports will provide a broad framework for maintaining continuity of research effort and for fostering an intellectual dialogue that will strengthen and help direct the course of NOAA research.

Ned A. Ostenso
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NOAA

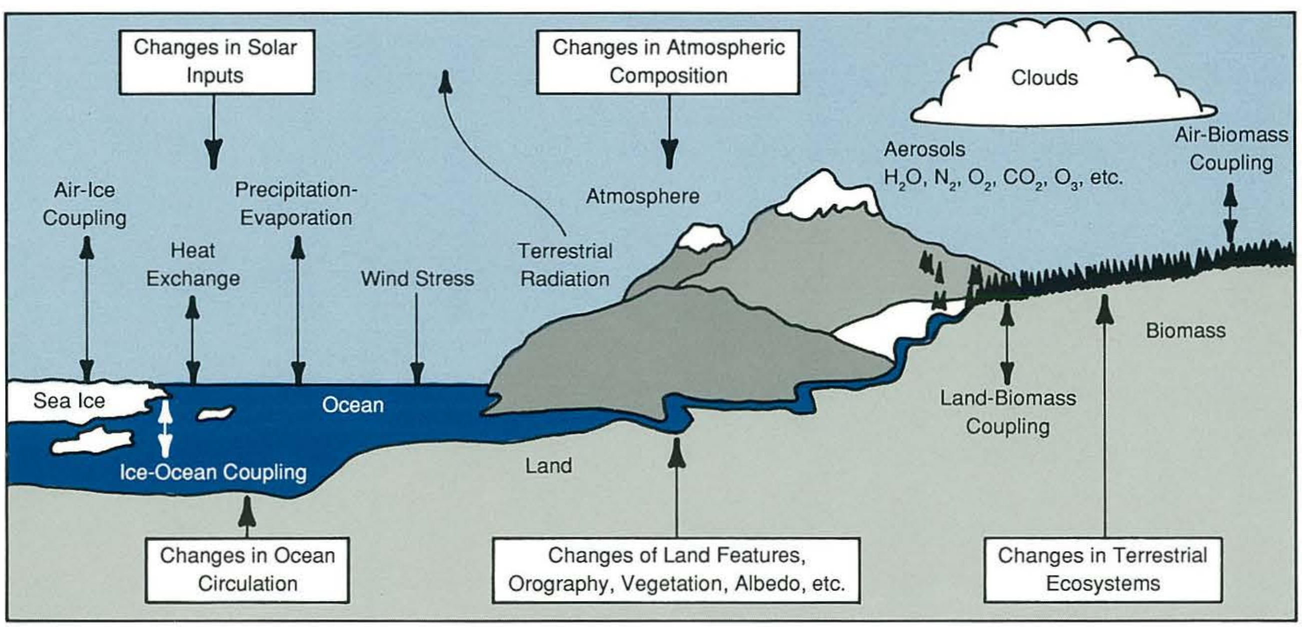
Section I

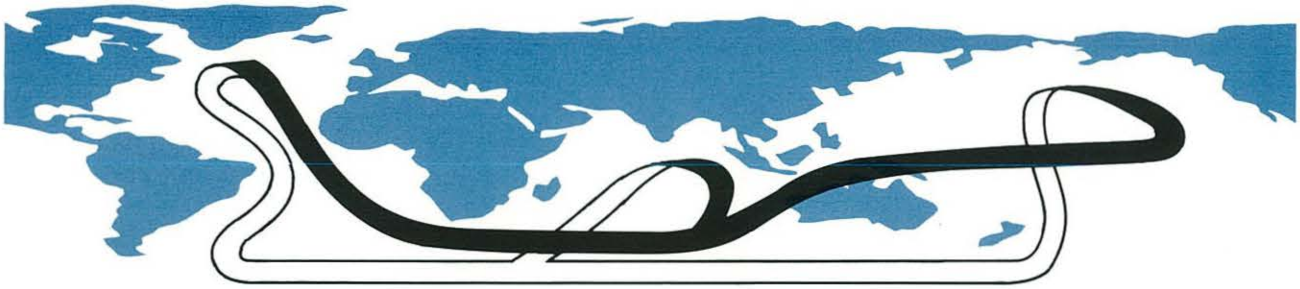
GLOBAL CHANGE

Chapters

Global change, and climate change in particular, have become the focus for national and international discussion. Alteration of the global environment by human activities throughout the world threaten to bring changes to the Earth system. At the same time, natural processes within that system are known to bring about dramatic changes, ice ages for example. The US has recently embarked on a national effort, the US Global Change Research Program, to increase our knowledge and understanding of the many processes at work in the Earth system, both natural and human-produced, to gain a predictive capability, and to establish a scientific basis for policy developed nationally and internationally.

NOAA and OAR are major scientific contributors to this national program. Significant parts of NOAA's mission are to observe and monitor, gain scientific understanding, and develop predictive capabilities. OAR global-change efforts are focused on the total environment, from the ocean floor to the sun. A brief summary of the programs OAR is pursuing in the study of global change is presented in this section.





Ocean Circulation and Global Climate Change

Problem and Opportunity

For several years, concern has been increasing that the Earth's global environment may be changing in ways to which we may not easily adjust. The long-term increase in atmospheric carbon dioxide concentration, the known radiative effects of this and other trace gases, and recent data suggesting significant changes in the Earth's ozone layer are evidence of the potential for major changes in the global climate.

Man is not a passive participant in the global environment. Human activity has reached the scale where it affects the global environment in ways that we do not fully understand. The effects of this activity, coupled with the natural variation of the global climate system, will have profound implications for the future. Changes in the global environment will produce significant economic, social, and political problems which this nation, in cooperation with other nations, must be prepared to address.

NOAA has the responsibility to understand and ultimately forecast interannual, decadal, and longer-term climate change. On these time scales, the transport, storage, and exchange of heat by the surface and subsurface waters of the world oceans, and the mass, momentum, and energy exchanges between the oceans and the atmosphere, are of crucial importance in influencing climate change.

Research Strategy

The climate system can be characterized as a global heat engine having two working fluids (the oceans and the atmosphere) that transport heat mainly from the equatorial tropical zone to the polar regions. One research goal is to understand and predict the behavior of this system (climate) on different time scales.

The research strategy is directed at resolving the following critical questions. The behavior of the system that needs to be understood is defined from current observations and reconstructions of its past behavior. Further understanding is then derived from diagnostic studies of these observations and through numerical simulations of the response of the coupled atmosphere and oceans. Answers to critical questions provided by focused research serve to refine understanding of both the system and the simulation models. Refined models ultimately provide the basis for predictions of the future behavior of the system.

Three broad tasks must be addressed: ocean circulation models must be refined and verified; observational instrument systems must be designed and deployed for ocean climate monitoring; and new *in situ* instrument technology for ocean monitoring must be developed.

The top-level questions about ocean circulation and the global heat engine are:

- What is the heat transport of the oceans (from where to where, and how much)?

- How is the transport performed (what water masses are involved and how is the system driven)?
- How does the behavior vary in time and space?
- How do changing ocean conditions influence the atmosphere, and what ocean features are most important in this respect?

These questions lead to more specific questions which research must address. One specific research question in the study of interannual climate variability concerns the effect of the phenomena associated with the El Niño Southern Oscilation (ENSO) on water exchanges between the Indian and Pacific Oceans.

On interdecadal and longer time scales, some important research questions concern:

- The formation of North Atlantic deep water, and exchanges with the northern branches of the subtropical gyre, in regulating the thermohaline circulation; and
- The identification of feedback control mechanisms in the Atlantic thermohaline circulation, and their role in possibly major and relatively sudden climate changes taking place on the time scale of centuries.

On both interannual and interdecadal time scales, some important research questions relate to:

- Understanding the dynamics of the ocean-atmosphere fluxes of heat, moisture, and momentum, particularly with respect to areas controlling the time-variability of water-mass formation; and
- The relationship of changes of heat content of the equatorial zones and changes in the position of the Intertropical Convergence Zone (ITCZ), and their relationship to climate variability in higher latitudes, particularly in the Atlantic basin.

Why Now?

The world oceans play a central role in climate change, and the problems presented by global climate change are real. Recent scientific advances and planned technological improvement (such as supercomputers and satellite and *in situ* instrumentation systems) now make it possible to take a truly global look at the Earth as a system that includes the world oceans, and, for the first time, engage in a national and international scientific program to understand and predict natural and man-made changes in the global environment.

Benefits

The Earth may face climate and environmental changes on time scales of importance to living generations, their future progeny, and civilization itself. These changes may be due to natural variation, or may be human-induced, such as the effects of increasing CO_2 and ozone levels. Regardless of the source of change, the ability of scientists to predict the direction and magnitude of change will allow nations and international institutions to be better prepared to accommodate to these changes, and to mitigate their consequences. The research strategy laid out for ocean circulation is directed toward providing forecasters and modelers with refined ocean models having predictive capability commensurate with the existing atmospheric models, and to support development of coupled models of the two fluid systems.

Interactions

Studying the role of ocean circulation in global climate change requires the resources of many national and international agencies. Coordination of the required activities has begun within and outside NOAA. Within NOAA, OAR, NOS, and NESDIS are cooperating in a program to monitor upper-ocean properties using volunteer observing merchant ships. NOAA scientists are working with NSF-funded investigators to design and implement studies of upper-ocean circulation, and to devise new technology to monitor important ocean currents. Much of this work falls under the sponsorship of two internationally-coordinated programs; the Tropical Ocean-Global Atmosphere (TOGA) Program, and the World Ocean Circulation Experiment (WOCE). Several OAR scientists are members of national and international TOGA and WOCE planning and implementation committees to ensure maximum cooperation. Finally, OAR investigators are working directly with Chinese, Ecuadorian, Chilean, French, and West German scientists in regional studies of the role of ocean circulation on global climate.

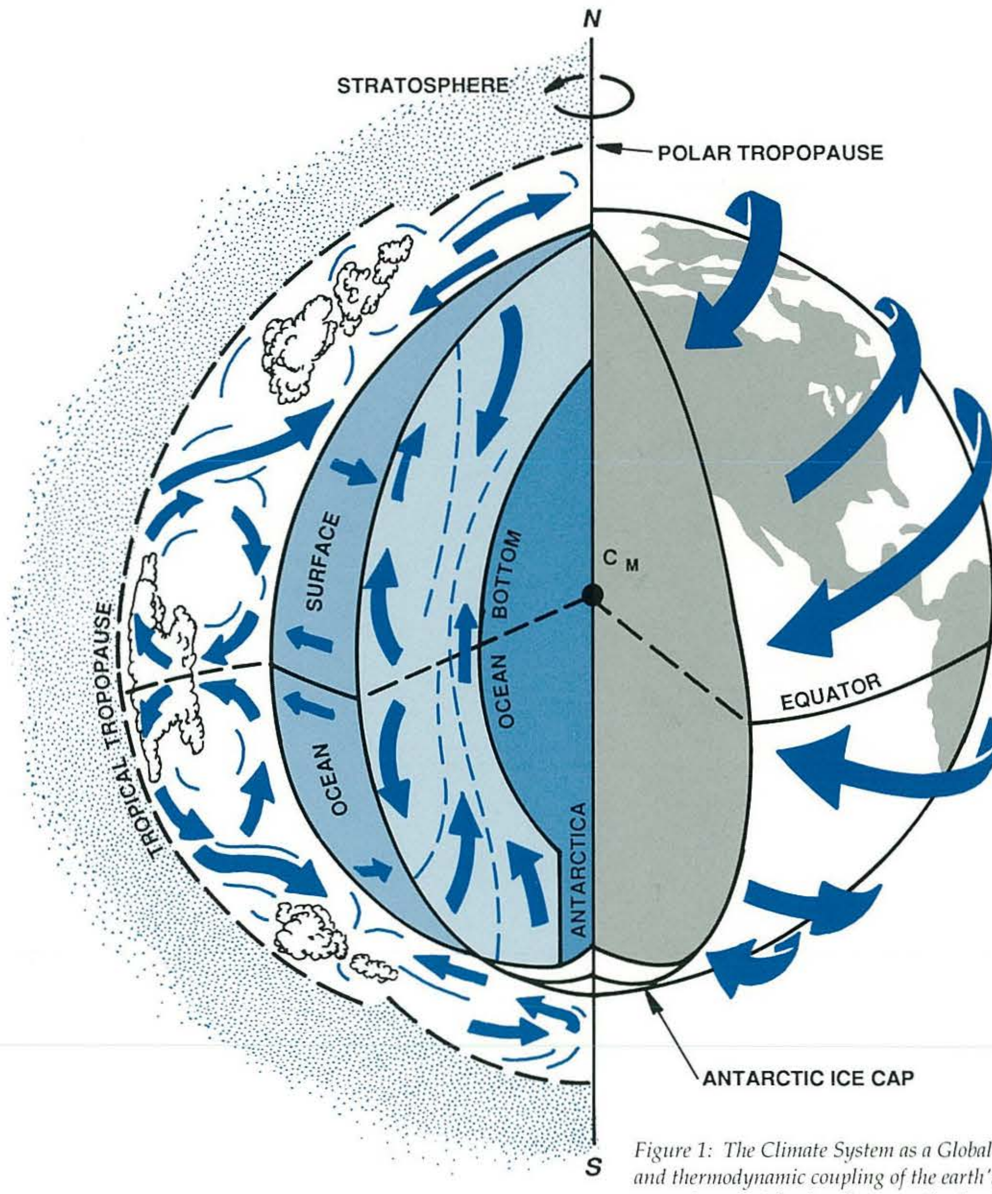
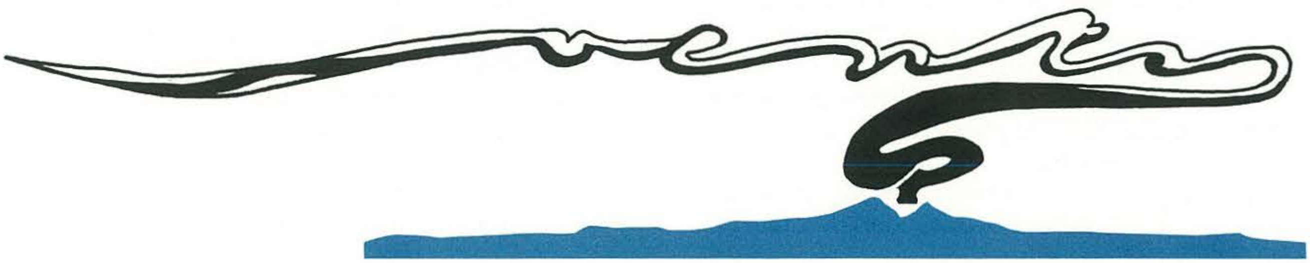


Figure 1: The Climate System as a Global Heat Engine. The dynamic and thermodynamic coupling of the earth's atmosphere, oceans, cryosphere, and land surface provide the global heat transport of the climate system.



Hydrothermal Venting on a Global Scale: Vents

Problem and Opportunity

Ocean basins can no longer be considered merely passive sinks for materials transported to them by subaerial erosional processes. Indeed, ocean basins, by virtue of containing the worldwide spreading-center seafloor system, are now known to host active processes that have significant effects on the chemical, heat, and mass budgets of sea water. Just as plate tectonics revolutionized Earth sciences in the 1960s, dynamic processes now known to occur worldwide at spreading seafloor centers, hydrothermal venting processes in particular, are becoming an analogous focus for marine science in the 1990s.

Hydrothermal venting affects the chemical and thermal composition of the global ocean through long-term input of heat and numerous dissolved chemical elements and compounds, including silica, iron, phosphorus and carbon dioxide. The global ocean budgets of silica and phosphorus, for example, are especially important because they are micronutrients which play major roles in the biogeochemical cycles of the sea. Hydrothermal venting is also directly responsible for the evolution of a major globally distributed, and heretofore unknown, vent-fauna ecosystem.

Research Strategy

An unequivocal demonstration of hydrothermal influence on the regional thermal and chemical budgets of major portions of ocean basins would allow NOAA to take a major step forward in quantifying the global significance of submarine hydrothermal venting.

The central operating hypothesis that OAR can test is that hydrothermal venting plays a major role in controlling chemical and thermal budgets of the world ocean and may be an important factor in understanding long-term climate change. Testing this hypothesis requires work in four principal areas:

- Regional transport of conservative and nonconservative hydrothermal emissions;
- Hydrothermal emission loss rates from the water column;
- Temporal variation of hydrothermal emissions at time scales of hours to greater than 105 years; and
- Source strength of hydrothermal emissions integrated over ridge segments and their relationship to underlying geologic structure and processes.

These research efforts will help determine, and allow prediction of, the effects of hydrothermal venting on the chemistry of the ocean. These effects will be studied at distances ranging from meters to several hundred kilometers from active hydrothermal sources. Far-field (>100 km) studies will focus on the regional extent, age, and evolution of chemical anomalies. Mid-field (1 km to 100 km) investigations will focus on the axis of seafloor spreading centers and their segmentation. Near-field (< 1 m to 1 km) investigations will concentrate on detailed geologic analysis and mapping of targeted vent fluids, and temporal and chemical studies of vent emissions.

Why Now?

Seafloor hydrothermal venting, which was discovered in the late 1970s, is now known to be a global phenomenon. The full range of seafloor spreading-center processes, and the magnitude of their effects throughout the world ocean, are still being discovered. Investigations are clearly showing that these processes are not isolated but are distributed throughout the world ocean. It is also clear that these processes have persisted as fundamental contributions to ocean chemical budgets for hundreds of millions of years. Recent results suggest positive correlations between major tectonic-plate motion changes, increases in seafloor hydrothermal activity (with accompanying changes in chemical fluxes to the ocean), and long-term climate change. NOAA, in collaboration with other government and academic investigators, is studying regional chemical and thermal oceanographic effects in the North Pacific that are the result of hydrothermal activity along the seafloor spreading-center systems off the west coast of the US. NOAA has also confirmed venting from other spreading centers as well, including the slow-spreading Mid-Atlantic Ridge (MAR) and the fast-spreading East-Pacific Rise.

Most recently, NOAA has discovered an entirely new type of hydrothermal activity. In 1986, and again in 1987, NOAA researchers detected and studied large episodic bursts of hydrothermal activity over the Northern Pacific seafloor spreading center, which, in a single event, vented quantities of heat and mass equivalent to the continuous annual hydrothermal output of other entire ridge segments. These and other discoveries compel NOAA to continue, and to expand, its unique national role for quantitatively understanding and predicting global effects of hydrothermal processes.

Why NOAA?

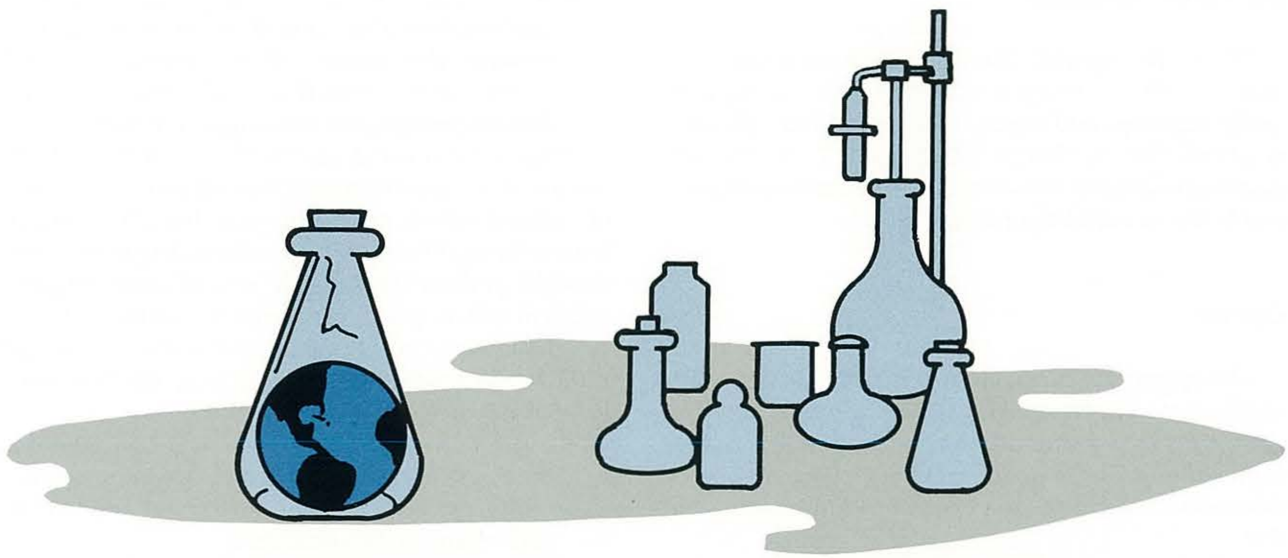
NOAA's research mandate includes the responsibility to understand and assess global chemical processes that continually alter the composition of the oceans, their sediments, and their life. The remoteness of the deep-ocean seafloor spreading centers requires expensive and very sophisticated research platforms and instrumentation. In addition to its research responsibilities, NOAA has unique facilities for undertaking the necessary field work to understand ridgecrest processes. These facilities include highly specialized research vessels, manned and remote-controlled submergence vehicles, high-resolution bathymetric and photographic systems, and prototype vent-chemical monitoring and vent-fluid sampling systems.

Benefits

Among the benefits of NOAA's hydrothermal research are a better understanding of the chemical and thermal composition of the oceans and their influence on the atmosphere and climate, new numerical models for chemical and thermal fluxes in the oceans, acquisition of critical data for establishing models for circulation of heat and chemicals in the ocean, and development of deep-sea technology which will make it feasible to address the global scope of hydrothermal impact.

Interactions

NOAA's research in hydrothermal processes is a joint effort of the Environmental Research Laboratories (ERL), Sea Grant, and the National Undersea Research Program to investigate recently-discovered chemical and thermal impacts of hydrothermal venting on the global ocean environment. For the past five years, this 'VENTS' hydrothermal research has been focused primarily on northeast-Pacific spreading centers where important new venting processes have been discovered, including episodic pulses of large-scale hydrothermal activity. Both the USGS and NSF are also supporting research on ocean-ridge processes, and NOAA participates in ongoing collaborative research with many scientists supported by both agencies. Virtually all NOAA/VENTS program cruises, both surface-ship and submersible, include scientists from other government agencies, and from universities participating in interdisciplinary experiments. There is similar collaboration on shore-based studies and instrumentation development. This remarkable and exceptionally close scientific collaboration has nurtured the development of a coherent research program on ridge processes in all three agencies; NOAA is especially well-linked to research planning in NSF's RIDGE program. The hydrothermal research emphasized in each agency (NOAA/VENTS, ocean effects; USGS, hard mineral resources; NSF/RIDGE, multi-disciplinary but with strong emphasis on geology and geophysics) fosters long-term, mutually-beneficial partnerships. In addition, the MAR site is an opportunity for fulfilling our commitment to the US-France Bilateral Accord by including French scientists in the Atlantic Basin hydrothermal research.



Marine Chemistry, Biology, and Climate

Problem and Opportunity

For many years, the industrial nations of the world have been releasing large quantities of carbon dioxide and other greenhouse gases into the atmosphere. Recent studies suggest that in addition to carbon dioxide, both ozone and the sulfur released in the marine sulfur cycle may have large roles in global climate change. Unfortunately, the extent of the resulting global climate change can only be approximated. Because of the potential consquences, this lack of predictive precision could be disastrous.

Ozone in the atmosphere functions as an important oxidant, a precursor to highly reactive chemicals, and as a significant absorber of ultraviolet and infrared radiation. The oceans are now thought to be not only a sink for ozone, but possibly a storage reservoir for ozone and a source of ozone precursors. Because of the absorption properties of ozone, pathways for production and destruction of this molecule need to be more fully understood if global climate changes are to be predicted accurately. Evidence implicates the ocean surface and the marine boundary layer as major contributors to these processes.

In yet another way, the oceans may play a major role in the modulation of world climate: very recent data suggest a link between ocean productivity and climate that is mediated by the marine sulfur cycle. Phytoplankton are a major source of volatile sulfur in the marine troposphere. Preliminary evidence suggests that fluxes of these sulfur compounds are correlated with precursors to cloud formation. This mechanism for biological regulation of climate must be explored if global climate changes are to be predicted accurately.

These new advances only compound a problem that was recognized years ago. Carbon dioxide is in continuous flux, being added to the atmosphere through processes such as combustion of fossil fuels, chemical weathering of rocks, and decomposition of organisms; and being removed from the atmosphere through formation of carbonate rocks, incorporation into organisms, and other processes. Present budget models of CO_2 are not adequate: the destination of much of the carbon in flux cannot be identified. The largest CO_2 sink appears to be the oceans. While the general areas where CO_2 is absorbed or released by the oceans are known, seasonal exchange cycles and rates, and the transport rates of CO_2 to the deep ocean waters through advection or biological transport are still poorly understood.

On a global scale, the ocean margins are one of the most biologically productive areas and therefore important for fixation of atmospheric carbon. The ocean margins may account for some of the deficits seen. Carbon fixed by marine organisms in the coastal margins becomes part of the flux of particulates that gradually travel to the continental shelf to be buried in the sediments. Anthropogenic nutrient runoff may further augment fixation of CO_2 in coastal margins, thus increasing their importance.

Research Strategy

Only when global climate models accurately include all the dominant variables can a complete understanding, and hence a truly predictive model, of global climate change be attained. To reach this understanding, the research must concentrate on several levels in each important area.

Ozone

The magnitude of ocean sources and sinks of ozone are the basis for the major questions that need to be addressed for a more complete understanding of the contributions of the ozone facet of climate research. Research to be conducted should include studies of the:

- Transport and distribution of ozone in the troposphere, including the marine boundary layer; and
- Role of ocean productivity as a source of ozone precursors in the marine boundary layer.

Carbon dioxide

We need to understand the flux of carbon dioxide between the sea and air, particularly as a function of ocean region and season, and over time as a result of past increases in atmospheric CO_2. This will help us predict change in the future. To fully understand these fluxes we need to:

- Expand programs to understand the temporal and spatial variation of CO_2 in the atmosphere;
- Investigate the invasion of anthropogenic tracers through the ocean thermocline at periodic intervals;
- Establish a series of Pacific Ocean sites for ongoing seasonal measurements of transient tracer fluxes in key areas of the ocean from the tropics to the polar regions;
- Conduct a series of long ocean transects to determine secular changes in the amount of carbon stored in the ocean;
- Measure CO_2 exchange between the ocean and the atmosphere, with particular emphasis on the Southern Ocean and on the temporal and spatial variation in CO_2 exchange due to biological productivity;
- Establish time-series measurements of critical CO_2-system parameters in the water column; and
- Initiate and continue studies of major ocean forcing functions that control the exchange of CO_2 between the oceans and the atmosphere (such as deep-water formation, ENSO events, and exchange processes at convergence zones).

Additional research on the flux of carbon should concentrate on determining the relative importance of carbon fixation, and subsequent burial of that carbon, in the regulation of tropospheric levels of carbon dioxide, and on the possible role of anthropogenic nutrient enhancement in accounting for the CO_2 deficits encountered in the present carbon-dioxide budget models. To answer these questions, the following lines of research need to be pursued:

- Examination of existing models to determine the knowledge needed to increase their applicability; research results and model predictions and adequacy can be tested;
- Identification of temporal trends of the variation in ocean circulation using synoptic, remotely-sensed data; and
- Determination of the important processes involved in CO_2 fixation and particle development, and in the settling and transport of those particles, through sampling regimes in coastal margin areas.

Sulfur

The role of sulfur in global climate needs to be examined. Although recent data imply a connection with volatile marine sulfur (mostly as dimethylsulfide), no definite causal relationships connecting the two phenomena are known. Research efforts to determine the existence of any causal relationships and the magnitude of those relationships, if they exist, must include:

- Measurement of the concentrations of relevant sulfur compounds and cloud-condensation nuclei, plankton speciation and productivity, cloud albedo, and other important oceanographic and climate variables;
- Determination of the physical, chemical, and biological variables that control planktonic production of these sulfur compounds;
- Identification and quantification of the reactions relating these compounds with the formation of cloud-condensation nuclei; and
- Production of models linking changes in ocean productivity, global albedo, and climate change.

Why Now?

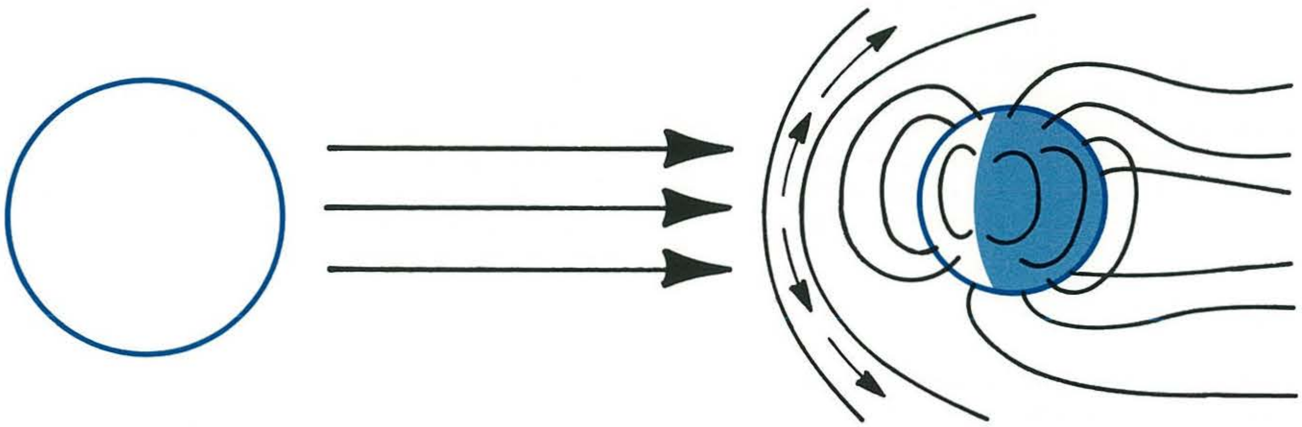
Since the start of the industrial revolution, atmospheric levels of carbon dioxide have been increasing due to the burning of fossil fuels. As the concentrations of CO_2 and other greenhouse gases increase in the atmosphere, global warming is anticipated. Estimates of future CO_2 concentrations suggest that atmospheric levels are increasing at an accelerating rate. A mean global temperature increase of only one degree Celsius could have profound effects on the world climate. With new avenues of research now opened by the elucidation of possibly significant climate modulators such as ozone and sulfur, the probability of predicting climate change is greatly enhanced.

Benefits

The results of these investigations, if successful, will allow prediction of global climate change caused by disturbances in the biogeochemical fluxes in the world oceans. In addition, the role of human-induced increases in CO_2 concentrations can be better assessed. World food production, supply and demand for energy, all ecosystems, water resources, and human health can be significantly affected by even slight global warming. If these changes in global climate can be predicted, then preventive measures and informed preparations may minimize the potentially drastic effects.

Interactions

These research programs are part of NOAA's Coastal Ocean Program, and of NOAA's Climate and Global Change Program, which is a major participant in the US Global Change Research Program. Major NOAA interactions are with the NSF's World Ocean Circulation Experiment (WOCE) and Global Ocean Flux Study (GOFS) programs, the National Center for Atmospheric Research (NCAR), NASA, EPA, DOE, and the Minerals Management Service of DOI. Within NOAA, major participants are OAR, NOS, and NESDIS. The academic community will make major contributions to the programs through Cooperative Institutes at the Universities of Colorado, Miami, and Washington, and through the National Sea Grant College Program.



Earth in the Space Environment

Problem and Opportunity

Wrapped in the protective cocoon of its magnetic field, Earth is continually swept by the ionized gases and magnetic field of the solar atmosphere, blowing past at a million miles per hour even in quiet times. An increase of solar emissions directed earthward can strongly modify the energetic environment around Earth—by many orders of magnitude—and damage human technological systems. Though the total energy output of the sun is not much affected by these outbursts, the near-Earth environment is sensitive to the solar energy in short wavelength bands and some particle energies, and these fluxes vary enormously.

Sufficiently severe solar outbursts and geomagnetic storms cause great economic loss. They disturb the upper regions of Earth's atmosphere, disrupting radio communications, shortening the life of Earth-orbiting satellites, and, temporarily, the ability of satellites to maintain precise orientation and pointing. In addition, they cause power-transmission outages, failure of satellite navigation systems, computer upsets on spacecraft, and radiation hazards to people and equipment flying at high altitudes and latitudes.

NOAA has the responsibility to monitor solar outbursts and their terrestrial consequences and to develop a predictive understanding of them. Disseminating space-environment monitoring and prediction information—much as the National Weather Service does for meteorology—enables system operators to avoid or mitigate the economic losses and the inconvenience to their customers that otherwise would result from variation in the space environment. Also, NOAA needs to understand if and how variation in solar output drives weather and climate variation on Earth; and what causes both the short-term and the long-term solar variability.

Research Strategy

NOAA's strategy to understand Earth in the space environment is spelled out in a 10-year plan for solar-terrestrial research, published in 1987. This plan acknowledges how sparsely the space environment is being sampled at present. It calls for increased viewing of the sun and interplanetary space from ground and space instruments, and increased *in situ* sampling of the near-Earth space environment and the solar wind. With these new data, there will be inputs for physically-based, predictive numerical models of the processes at work in Earth's space environment. The plan calls for increased efforts to understand the connection between solar disturbances and Earth's geomagnetic field. It is not yet known why a solar disturbance sometimes passes harmlessly by, and why at other times an apparently similar disturbance creates a violent geomagnetic storm as it encounters Earth's magnetic field.

NOAA also must investigate the coupling between the thermosphere (the upper layer of Earth's atmosphere which varies in response to solar and geomagnetic activity) and the troposphere where mankind lives. The amount of energy deposition in the upper atmosphere, and its variation with time and location, are being investigated. These patches of deposited energy power thermospheric winds and compositional changes, and they generate electric currents which perturb the magnetic field at Earth's surface. Do these variations extend to the bottom of the atmosphere to affect weather and climate?

Why Now?

Mankind's technological sophistication and use of space are ever-growing. Solar cycle 22 threatens to reach activity levels never before recorded by man; and activity is expected to be intense for the next few years. Our abilities to design, build, and fly sensors in the space environment, and to process the data from them, have matured remarkably in the last few years. The greater needs of increased numbers of users of space-environment services; the greater threat of outbursts from the active sun, with resulting geomagnetic storms; the increased capacity to fly and use sensors; and the ability to create physically-based models with predictive capability, all imply that now is the time to try to understand how and why variations in solar output occur, how they propagate to Earth, and how they produce terrestrial effects.

Why NOAA?

The multi-agency Federal Plan for Meteorological Services and Supporting Research, 1989-1992, published by the Office of the Federal Coordinator for Meteorology and Supporting Research, calls for NOAA's Space Environment Laboratory to be the focal point for the nation's civil space-environment service. By agreement of all federal agencies, NOAA is to monitor the space environment, predict space-environment characteristics, and provide this information to civilian users and to the Department of Defense. By agreement, NOAA is also to perform appropriate research to improve its services. The US National Space Policy of 1988 mandates that "...NOAA will gather data, conduct research and make predictions about the Earth's environment... ." In addition, the IUWDS of the International Council of Scientific Unions has designated the Space Environment Laboratory as the World Warning Center (among its six Regional Warning Centers) for the space environment. NOAA has a strong mandate to offer services and pursue research in the space environment.

Benefits

Users of systems affected by solar and geomagnetic variation range from consumers of electric power to watchers of television news; from civilian and military mariners and aviators using satellite navigation for fixing their positions to space-mission planners deciding when to launch or whether it is safe for astronauts to perform an extravehicular activity. Mitigating losses of electric power, high-frequency radio communications, weather satellite information, and the like—or at least being aware of the impending loss so alternatives can be pursued before the loss occurs—would provide great economic benefit to the nation. When solar variation can be predicted and when the effect of solar variation on the near-Earth space environment can be predicted, then these and other affected human activities can be abandoned, deferred, or substituted prior to arrival of harmful solar activity at Earth.

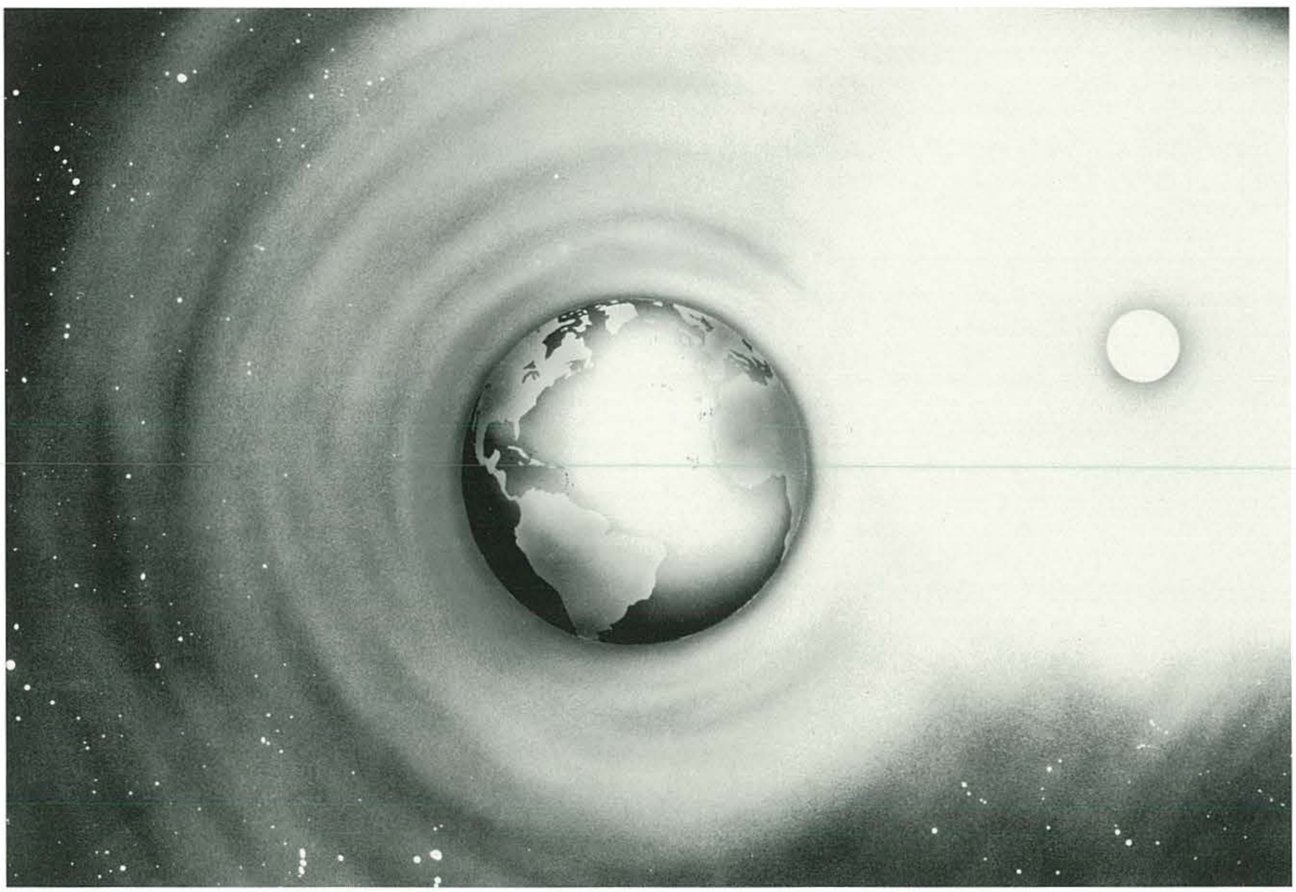
If a mechanism can be found that links regional terrestrial climate to solar output—some studies have suggested a 7°C swing in average winter temperature between solar activity minimum and maximum—the economic benefits to farmers in the region are almost incalculably large. Understanding the mechanism and having good long-term solar forecasting could allow farmers to make appropriate selections of crops based on predictions of temperature, length of growing season, and precipitation.

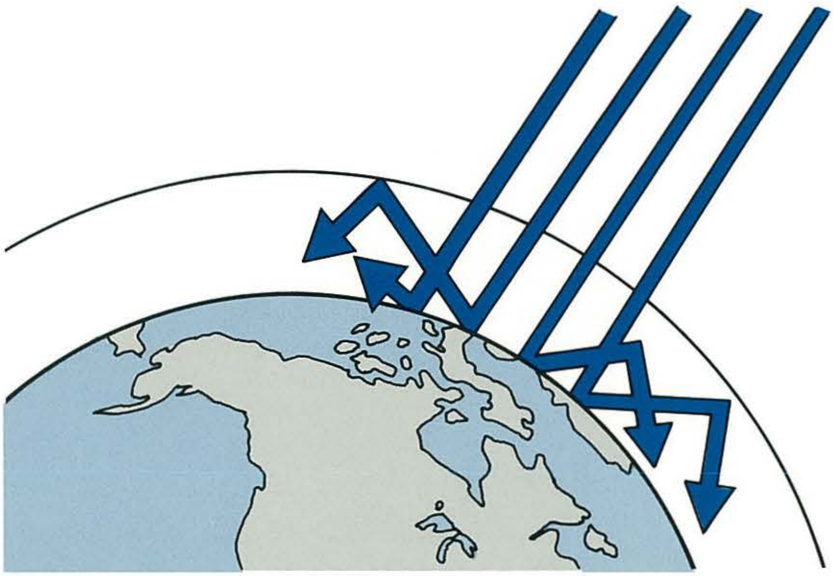
Interactions

Within NOAA, the Space Environment Laboratory (SEL) works closely with NESDIS, which provides the Space Environment Monitoring System (SEM) on the NOAA GOES and TIROS satellites. The SEM system provides data essential to SEL's service and research functions. NESDIS/NGDC also provides data-archive services for much of the data acquired and used by SEL. Within the federal government, SEL works closely with the Department of Defense Air Weather Service, which shares the responsibility for the operation of the Space Environment Services Center and provides complementary resources including six solar observatories around the world. The laboratory also maintains extremely close relations with NASA, which provides data from scientific satellite missions for research purposes, and makes extensive use of SEL's services to support the manned as well as unmanned missions in space. The Departments of Energy and Transportation also make significant use of SEL's services. The space-environment services of all federal agencies are overseen by the Federal Coordinator for Meteorological Services and Supporting Research.

SEL has formal representation on the National Academy of Sciences Committee for Solar-Terrestrial Research, the Committee on Geophysical Data, and the Committee for Solar and Space Physics.

Internationally, SEL is a World Warning Center of the IUWDS, and participates actively in many programs organized by international scientific organizations (such as FLARES 22, MAX '91, SOLTIP and COSPAR-organized campaigns).





Long-Term Climate Diagnostics and Prediction

Problem Opportunity

In recent years, it has become almost universally recognized that the greenhouse effect is real and that the Earth's climate will most likely warm significantly in response to global increases in various greenhouse gases. However, within the climate-research community it has become clear that many important details of the impending climate change remain significantly uncertain. This uncertainty hinders our current ability to make focused and cost-effective policy decisions and regulatory actions.

There is now an unprecedented opportunity to achieve significant improvements in our ability to predict and diagnose changes in the climate system. Many nations are recognizing that a much more sharply focused program in systematic, long-term measurements of appropriate quantities will be required. Steady advances in modeling capability and supercomputer power provide the promise of significant improvements in the accuracy of climate analyses and predictions.

Research Strategy

An optimum NOAA strategy for tackling these problems requires a balanced program of research involving long-term measurements, data analysis and diagnosis, and climate modeling. It requires that we maintain state-of-the-art supercomputing facilities, a world-class modeling team, and facilities for acquiring the needed measurements.

Improvement in understanding climate change requires significant advances in the coverage and quality of systematic, long-term measurements of the atmosphere/ocean/ice/land-surface system. Presently, there are serious measurement deficiencies that need careful attention. In all parts of the system, long-term measurements are inadequate because of insufficient data coverage, sporadic measurements, unmeasured key variables, inadequate instruments, and instrument calibrations too coarse to resolve small trends on time scales exceeding decades.

These long-term datasets need to be carefully accumulated, maintained, checked, analyzed, and diagnosed for scientific content. When that is accomplished, the process must inevitably be repeated in response to newer insights and higher standards. Commitment to this all-important process must be increased; without such commitment, the cost-effectiveness of global observational systems will remain seriously short of their potential.

The NOAA commitment to research in climate modeling and climate processes commands a position of great strength for attacking the next generation of problems. Improvements in modeling ocean circulation and atmospheric physical processes such as clouds and radiation promise significant new advances. Increases in supercomputer power will allow, for the first time, attacks on the key problems of regional climate change and natural climate variability.

It is clear that systematic climate change will inevitably occur in the presence of significant natural climate variation on a range of space and time scales. Understanding natural climate variability both observationally and theoretically is an essential part of the attack on the greenhouse problem. The role of natural variation becomes even more crucial when assessing the predicted versus the realized signals of climate change in smaller regions, such as major lake systems or specialized agricultural districts.

Furthermore, we must give attention to the effects of climate change on hydrological, limnological, chemical, biological, and social processes. This will allow realistic relative assessments of regional changes and natural variation of climate and interdependent processes. It will also allow proper anticipation of regional impacts, both physical and social.

Finally, we must seek more creative ways to synthesize these previously-diverse research topics into a unified understanding of the climate system and how and why it is changing. This will be required to implement effective policies for social and economic adjustment and impact prevention.

Why Now?

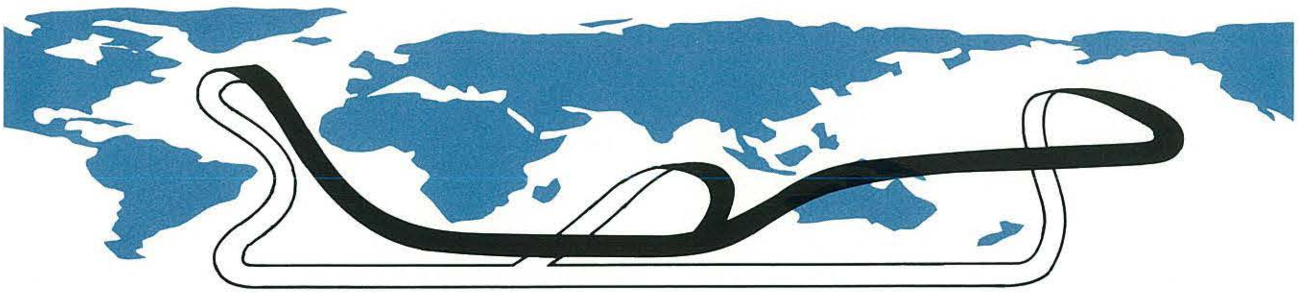
Rarely is the justification of a major research thrust more obvious. The problem is well defined and already highly visible to the public and to business and government leaders. Climate theory and modeling capabilities have progressed to the level that substantial advances will result from a sustained, focused research investment. The measurement and instrumentation challenge is clear. The plans, institutional resolve, and the financial commitments to meet this challenge are forming. The technological and intellectual capabilities are available now and are increasing. It is likely that the emergence of NOAA depends crucially upon its ability to sustain a coherent attack on this dominant global-scale environmental problem.

Benefits

The principal benefit to be realized is a sharply-improved information base for global-policy decisions. Many studies have shown that the values added in this arena, relative to incremental costs, are enormous. Even the most conservative analyses show benefit/cost ratios well into the hundreds. Detailed climate-change prediction capability provides the necessary input for possible mitigative legislation. In addition, it provides input to planning for social adjustment to climate change.

Interactions

Climate prediction and diagnosis are major goals of NOAA's climate activities. Currently, major efforts spanning the range from seasonal prediction to decadal climate change are being carried out in increasingly integrated ways in OAR at both its GFDL and the Climate Research Division of the Climate Monitoring and Diagnostics Lab, and in NWS at the National Meteorological Center. In addition, NOAA's Climate and Global Change Program has supported work which enhances the programs within these institutions and their interactions with the academic community.



Atlantic Climate Change

Problem and Opportunity

The rate at which greenhouse warming will occur is a critical unknown in mankind's ability to react to climate change. Predictions based on models indicate global warming ranging from 1.5°C to 4°C in response to a doubling in greenhouse gases. However, whether this warming will occur in 50 or 100 years is not certain. Part of this uncertainty is related to an inability to predict the natural variation of atmospheric temperatures. Hemispheric temperature changes approaching 1°C over a time span of 50 years have been observed in the past century. Since the natural and anthropogenic greenhouse effects are additive, the phase of the natural cycle (Are background temperatures rising or falling?) will determine, in part, how rapidly global warming proceeds. To predict the effects of natural climate variation at periods ranging from interannual to decadal and longer requires an understanding of the role of the ocean in driving climate change. Studies in the Pacific have shown that sea-surface-temperature (SST) variation in this basin significantly affects global climate. The Atlantic Ocean also seems to be a major player in establishing global climate change at various time scales. However, the present understanding of the Atlantic's role in climate change is much less developed than that of the Pacific.

The Atlantic sector has several advantages for understanding climate change. The wealth of historical data, the strength of the thermohaline signal in terms of water-mass formation, and the magnitude of surface-temperature anomalies make this an obvious region of focus. The atmospheric response and its role in the air-sea coupled problem, of course, demand a global analysis.

From a climate viewpoint, the direction and intensity of the thermohaline circulation are highly significant, because of the large transfer of heat from the South to the North Atlantic, a transfer that extends to very high latitudes. Modeling experiments suggest that the thermohaline circulation of the ocean may have more than one equilibrium state, as illustrated in the 1988 coupled ocean-atmosphere model of Manabe and Stouffer. Their global coupled model has two equilibrium climates. In one case an active thermohaline circulation exists in the North Atlantic, corresponding to today's climate. In the other case, fresh, relatively-cold surface waters dominate the northern North Atlantic and the thermohaline circulation is almost nonexistent. These studies raise interesting questions about the stability of the Atlantic thermohaline circulation, its possible variation in the recent past, and how the thermohaline circulation might be modified by greenhouse warming.

Research Strategy

The Atlantic Climate Change Program (ACCP) is a study of climate variation related to thermohaline processes in the Atlantic Ocean. It is a joint undertaking by atmospheric scientists and oceanographers, based on three areas; modeling, examination of datasets, and long-term measurements of thermohaline processes in the Atlantic Ocean. The ACCP is envisioned as a balanced effort in each of these areas.

Recent geological findings and ocean-atmosphere coupled-model results have provided new insights into the sensitivity of global climate to Atlantic thermohaline processes. Preliminary experiments with atmospheric models have shown significant response in the global atmosphere to realistic sea-surface temperature anomalies in the Atlantic. An initial emphasis of the program will be to confirm these atmospheric results and provide more details. Observations show that sea-surface-temperature anomalies in the Northwest Atlantic are modulated by wind and irregular seasonal thermohaline convection. A particularly important question is why these anomalies persist over many years. The low heat capacity of the atmosphere implies that these anomalies are intimately tied to changes in the thermocline structure of the ocean and its feedbacks to the atmosphere. Therefore, the focus is on the thermohaline circulation in the Atlantic and its interaction with the atmosphere. The signal is strong, and the historical database is superior to that existing in any other region of thermohaline convection.

The scope of the atmospheric component of the program must be global, while the oceanographic monitoring and measurements would be restricted to the Atlantic in view of indications that this region of the ocean plays a major role in regulating long-term climate variability.

Why Now?

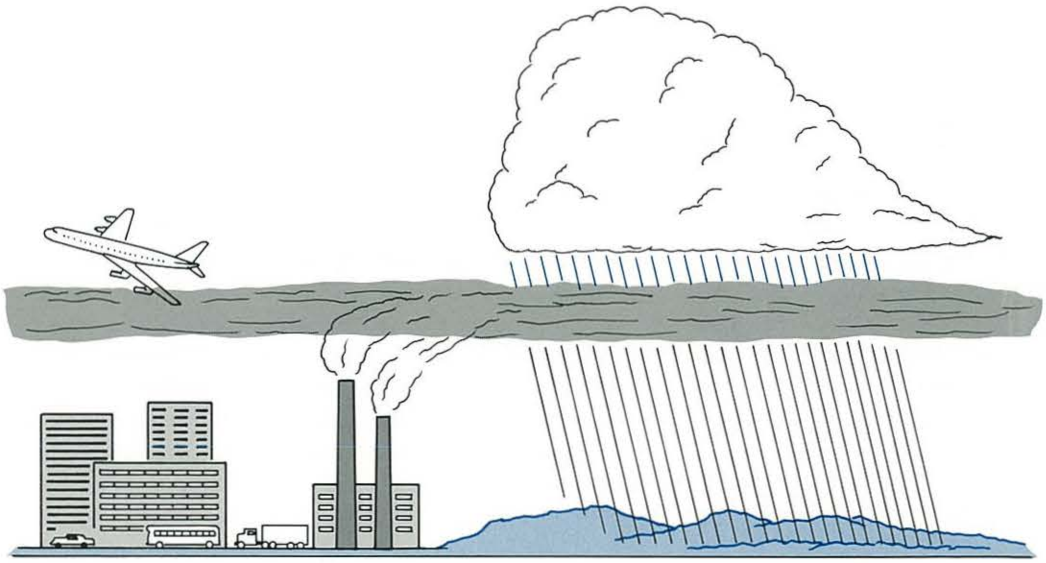
The strong interest in the potential effects of greenhouse warming dictate attention to those processes contributing to natural variation on the longer time scales appropriate to the problem. Evidence from historical data, paleoclimate studies, and modeling all point to a strong climate signal in the interaction of the Atlantic and the global atmosphere. Research attention to this signal may yield the most rapid payoff in the prediction of the long-term evolution of the climate system, in much the same manner as a focus on the Tropical Ocean-Global Atmosphere (TOGA) interactions is presently yielding advances in ENSO prediction capability.

Why NOAA?

The model in the TOGA Project of a partnership between NOAA, other federal agencies, and universities, has been quite successful in matching the abilities of different institutions toward a climate-prediction goal. The same model is envisioned for the Atlantic Climate Change Project, in which NOAA's strengths in monitoring, modeling, and data analysis are paired with extramural oceanographic and meteorological abilities.

Interactions

A Science Plan for the ACCP has been published, and presentations of the program have been made before the NOAA Panel on Climate and Global Change, the NAS Ocean Studies Board, and the US WOCE Science Steering Group. Interactions with the NAS Ocean Studies Board and the Climate Research Committee will foster an awareness within the broad scientific community, and provide potential for recognition as a national effort. In addition, ACCP is being considered by WOCE as a possible US contribution to WOCE Core 3 efforts. Initial funding of the program has been obtained from the Climate and Global Change Program.



Global Chemical Change

Problem and Opportunity

For much of this century, we have known that human activities can degrade air quality in cities and in large industrialized regions. Urban smog and acid rain are in the lexicons of scientists and decision makers alike. Over the past decade, it has become clear that the chemical reach of humankind has extended throughout the global atmosphere.

The evidence for this dubious achievement is compelling. Global atmospheric methane concentration has increased dramatically during the industrial era. Similarly, the purely synthetic chlorofluorocarbons (CFCs) have become a ubiquitous and growing component of the atmosphere in the few decades since their development. There is growing evidence that tropospheric ozone, a product of pollutant photochemistry, is increasing over large temperate continental areas and perhaps throughout the entire Northern Hemisphere.

The atmosphere has already shown us some of its responses to this global chemistry 'experiment.' We know that our use of CFCs has created a new, semipermanent, continent-sized global feature, the Antarctic ozone 'hole.' As a result, further regulatory restrictions on CFCs are being discussed. Other atmospheric responses, such as a gradual reduction in the basic oxidative cleansing capacity of the atmosphere, remain hypothetical, but disturbingly possible.

The dialogue between science and policy is now encompassing the global arena, and it includes the chemical perturbation of the atmosphere as a high-priority subject. The challenge before the policy community is to act responsively and responsibly. The challenge before NOAA and the atmospheric chemistry community is to build a demonstrably sound predictive capability of the global processes involved, providing a defensible basis for decision making. The current observational and theoretical-scientific capabilities place that goal within striking range.

Research Strategy

NOAA's global chemistry research has addressed this goal with a blend of five components, each with special NOAA emphases:

- Instrument development: to provide an assessed capability for characterizing the chemical content of the atmosphere. Current progress in observing chemical processes in the global atmosphere is severely limited by inadequate instruments, particularly for highly-reactive chemical species. The other four components are also adversely affected by this limitation;
- Long-term global observations: to discover and define the trends of the chemical changes that are occurring on global scales. The emphasis is on the 'source' gases, such as carbon dioxide, methane, CFCs, carbon monoxide, and the nitrogen oxides, whose emissions constitute forcing agents on the chemical balance;

- Field campaigns: to characterize the key processes and mechanisms that induce, respond to, and result from chemical change. Key current limitations are the inadequate characterization of ozone-related chemistry, surface exchange processes, and the interplay of dynamics and chemistry, both in continental and ocean areas;
- Focused laboratory studies: to establish the fundamental properties of selected photochemical transformations. The emphases are on the rate coefficients and temperature and pressure dependances of ozone-related chemistry, both gas-phase and surface-induced chemistry; and on the development of measurement standards to ensure high-quality data; and
- Model development: to diagnostically build and test, via observation-prediction comparisons, a developing picture of global chemical change, and then to use that progressively improving picture of global processes to predict the consequences of chemical perturbations of the atmosphere. These predictions are a crucial end-product of the NOAA endeavor. They are the basis for scientific input to policy decisions, namely, defensible cause-and-effect scenarios on which sound response strategies can be based.

Why Now?

Understanding global chemical change has a strong element of timeliness. Global monitoring must begin soon to establish an adequate baseline of secular trends. State-of-the-art instrument development and standards for calibration must precede measurement programs. Field campaigns in remote areas must define the natural processes and background atmosphere before extensive anthropogenic global perturbations eliminate that possibility forever. The current research in atmospheric chemistry has defined both the problems being faced and the approaches required to address them; the community is poised for further successes, such as obtaining an explanation of the Antarctic ozone hole in a scant three years after its discovery, which has proven exceedingly timely input to the debates on further restrictions on CFCs.

Why NOAA?

NOAA has the mission, facilities, expertise, and established track record in observing, understanding, and predicting global chemical change. It operates four global baseline observatories and conducts other worldwide monitoring of tropospheric and stratospheric constituents. It is the only civilian agency with oceanic and atmospheric components. NOAA has led, participated in, or supported most of the recent major field campaigns addressing key environmental chemical phenomena such as polar ozone losses. Few other agencies have a chemical-kinetics laboratory addressing atmospheric transformations. NOAA's theoretical modeling has focused on the interplay of chemistry and dynamics and has extended the agency's long-standing weather and climate prediction mission to include global chemical change.

Benefits

The primary benefit from an improved predictive understanding of the causes, mechanisms, and atmospheric consequences of chemical change is straightforward: better decisions. Specifically, the systematic development of understanding of the fundamental processes involved in global chemical change, in contrast to the crisis response common to past air-quality problems, will yield:

- Predictions with better-quantified uncertainties, decreasing the calls by decision makers for 'one-armed scientists;'
- Less chance of over-regulation of industry, avoiding loss of international competitiveness; and
- More extensive information available to make early decisions on the presently unidentified environmental issues that lie in wait for both scientists and policy makers.

Interactions

NOAA's global-chemistry research is a strong component of national and international efforts. Coordination occurs at a hierarchy of levels. Nationally, NOAA, NASA, NSF, industry, and universities have jointly tackled many programs and campaigns that have focused on global chemical phenomena: Antarctic and Arctic stratospheric ozone depletion, remote-area tropospheric chemical processes, Arctic pollution phenomena, monitoring of stratospheric change, and instrument evaluation campaigns. The interactions have ranged from collaboration between principal investigators to joint planning of goals, strategies, and support. Internationally, NOAA has been a supporter of the emerging International Global Atmospheric Chemistry Program, which now forms one of the major thrusts of the International Geosphere-Biosphere Program.

Global Change: Observational Capabilities for the 1990s

Problem and Opportunity

At the heart of NOAA's mission is the forecasting of atmospheric and oceanographic conditions. Unique among the agencies, this central focus requires that NOAA "...describe, monitor, and predict conditions in the atmosphere, ocean ... to issue warnings against impending destructive natural events." Global change represents both a transcendent forecast problem and an opportunity that will challenge us in the 1990s and beyond.

Central to the prediction of climate and global change is the development of models of, and monitoring strategies for, Earth-system behavior. Global modeling strategies inherently rely on sets of parameterizations of sub-grid-scale atmospheric and oceanic processes that lie beyond the numerical capabilities of modern computers. Process-validation studies require *in situ* observations using chemical, dynamic, and thermodynamic sensors. Accurate parameterizations are predicated on accurate observations. Global monitoring strategies depend on observational capabilities that require such a density of data in both space and time that they can preclude the use of most conventional *in situ* point sensors, and demand the development and application of new generations of remote sensors based on acoustics, radar, lasers, and radiometers in ground- and ocean-based integrated systems linked by satellite. Such global monitoring by remote probes is essential both to initialize and to verify numerical simulations of planetary behavior. Routine monitoring of the full spectrum of climate variables requires continued development of *in situ* instruments and calibration standards, and places severe demands on the reliability of future remote-sensing systems.

NOAA has long been at the forefront of developing new observational technology and networks. As an agency it must now seize the initiative to develop the next generation of operational sensors to monitor the vital signs of the planet, for inclusion in world survival strategies. Computer technology currently available to modelers far exceeds the capacity of the world's measurement networks to either initialize numerical simulations or to verify model predictions. We must move rapidly and forthrightly, with scientific rigor, to bridge this observational gap.

Research Strategy

Because the research necessary to understand and predict global change requires accurate observations over a wide range of spatial scales, from *in situ*, through mesoscale, and up to global scale, a new generation of measurement tools with advanced abilities is needed. Observing and sampling systems will have to provide accurate and reliable calibrated measurements of the important parameters characterizing the state of the atmosphere, and its interaction with the land and ocean.

Fortunately, development of new observational capabilities for the 1990s has a strong foundation in the research of the 1980s. Many new remote sensing and *in situ* techniques incorporating optical, radio, chemical, and acoustic methods have been demonstrated in recent years. These include lidar measurements of winds and chemical species, radio-acoustic temperature sounding of the ocean and atmosphere, radar wind and wave profiling, and fast-response *in situ* sensors of critical atmospheric gases.

To be useful in long-term monitoring and measurement of sensitive parameters for atmospheric process studies, instrumentation must be remotely-controlled or unmanned, and meet rigorous standards of precision, repeatability, stability, and reliability. All instrumentation developed for global-change research should undergo a detailed evaluation process that includes intercomparison, calibration, and assessment of long-term stability. In some cases, international calibration facilities need to be established to provide continuity and standardization.

Why Now?

Recent breakthroughs in remote sensing and in *in situ* techniques such as optical absorption and chemiluminescence, lidar, radio-acoustics, and radiometry have expanded the capacity of older technologies to the point that truly comprehensive and truly global datasets, for the first time, now appear feasible. However, development of new fully-operational observing systems, from conception to engineering, assessment, and deployment, requires long lead times. For an improved, stand-alone, observational capability to be routinely available in the mid-to-late 1990s, a concentrated development effort must start now.

Benefits

Global research is very much limited by a lack of adequate observations and measurements. Our research strategy, advanced to develop the next-generation observational competence, is aimed at improving our understanding of atmospheric and ocean processes. This will lead to the improvement and verification of model predictions, and ultimately, to more-informed decisions by policy makers. Maintaining and improving the quality of life for planetary citizens depend on our success in accurately quantifying our physical and chemical environment.

Interactions

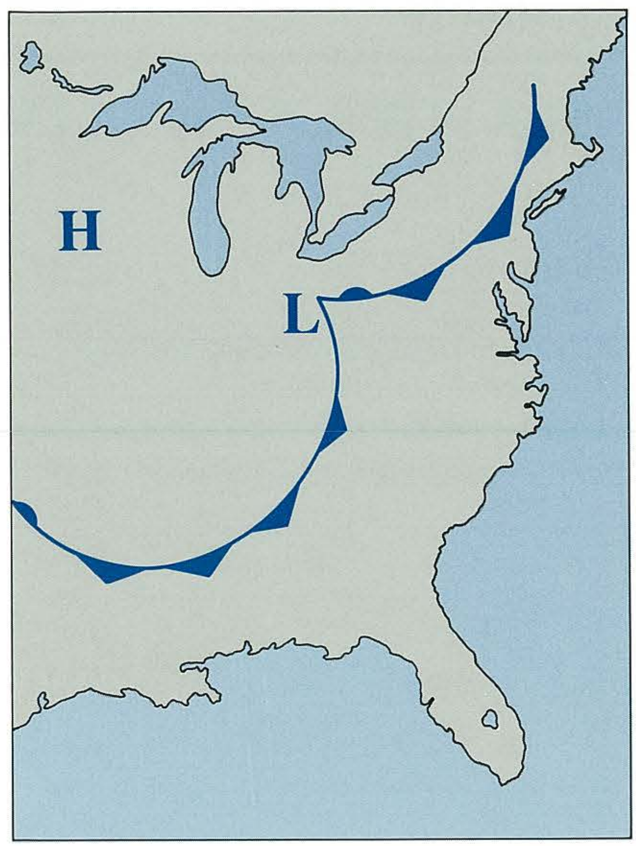
Our research has many natural linkages both within NOAA and with other agencies. Some of the instrumentation to be developed and tested will be a part of a modernized, next-generation observing system to improve weather forecasting. Other components have been and will continue to be developed as part of NOAA, NASA, and NSF interactions in large field campaigns to study the chemistry and dynamics of remote areas, such as Antarctica, with modern *in situ* instruments. Because surface-based observing systems are critical for calibrating and augmenting satellite measurements of atmospheric and oceanic parameters, future systems development will strengthen the interaction between NOAA instrument researchers and their NASA counterparts.

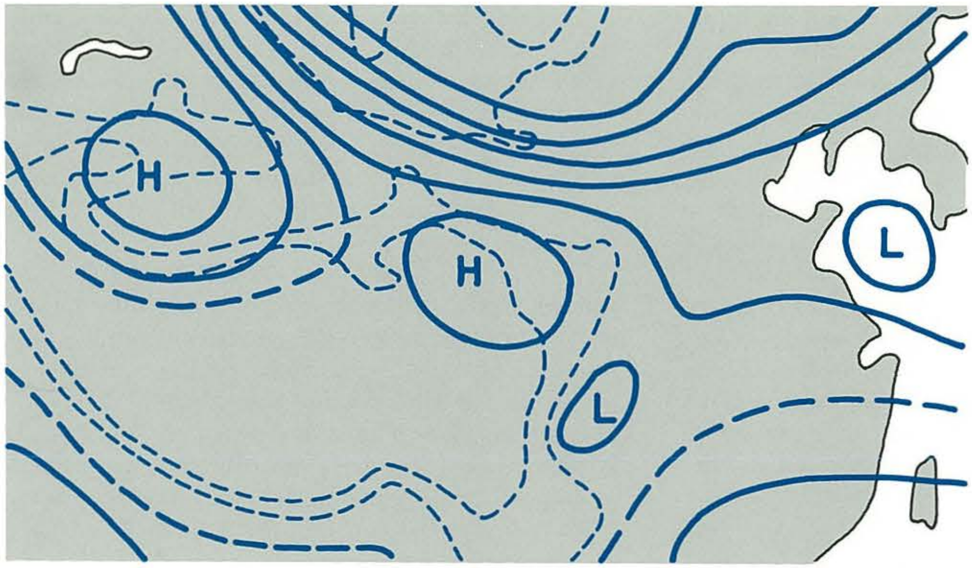
Section II

WEATHER AND CLIMATE SERVICES

Chapters

The Office of Oceanic and Atmospheric Research contributes substantially to one of NOAA's most important service missions, that of providing public weather warnings and forecasts for periods of minutes and hours out to as long as a month. The atmospheric-research programs of OAR provide the necessary scientific foundations upon which improvements to weather and climate services are built. Several important scientific advances, and the imminent deployment of new-generation computers and high-powered remote observing systems, will provide opportunities for dramatic upgrades to our services during the coming decade. The potential exists for marked improvements in the time and space specificity of warnings of life-threatening severe storms, and in extended-range forecasts for periods as long as an entire season. The economic and social benefits of such advances will touch many areas of public, private, and commercial life. This section describes the OAR program areas that support NOAA's weather and climate services.





Monthly and Seasonal Weather Prediction

Problem and Opportunity

NOAA's mission is to provide the nation with meteorological and hydrological services to protect life and property and to enhance the national economy. A service of the National Weather Service is to forecast monthly and seasonal temperature and precipitation. At present, the accuracy (skill) of these forecasts is low. More accurate extended-range forecasts would be immediately valuable to agriculture, construction, commerce, energy, and government. The research activity described here supports development of these high-payoff improved forecasts.

It is well known that there is a limit to the length of time over which deterministic forecasts of the atmosphere can be made. This limit depends partly on the uncertainty in the initial state of the atmosphere, partly on the rate at which errors in the smaller spatial scales of the atmosphere contaminate the information contained in the larger spatial scales and partly on inaccuracies in the way we physically describe, or model, atmospheric processes. Using the most sophisticated weather-forecasting systems available, current estimates for the limits of predictability are from 10 to 14 days. Much work has been done in the US and in Europe over the last decade to extend the range of forecasts, and at present, skill extends to six to seven days. In these forecasts, the detailed state of the atmosphere is predicted out to the time when skill is lost.

It has been recognized for many years that there is skill in some forecasts, such as averaged pressure fields, for times longer than the limit of deterministic prediction. For example, statistical methods have been used to predict monthly or seasonal mean pressure, temperature and precipitation distributions. While the skill of these methods is low, not much better than chance, it is nonetheless positive. More recently, it has become clear that deterministic methods can be used to produce forecasts which have greater skill than those produced by previous methods. These improved prospects are due to several factors, including the development of improved general-circulation models which simulate the behavior of the atmosphere in a more realistic way than could be done previously, the availability of increased supercomputing power necessary for running these models, and improved data necessary for a better determination of the initial atmospheric state.

Research Strategy

The evolution of the state of the atmosphere depends on forcing from boundary conditions (ocean and land surfaces) and on the initial conditions of the atmosphere. Changes in the ocean surface temperatures, for example, will change the distribution of heat going into the atmosphere, and these changes will affect atmospheric circulation. Even in the idealized case of constant boundary forcing, however, the atmosphere will evolve differently if it were started from different initial conditions. The problem is further complicated by the fact that boundary forcing is affected by changes in atmospheric circulation: the ocean-atmosphere system is coupled. Until now, weather forecasting has been done with the assumption that the role of boundary forcing is secondary to the role of internal dynamics within the atmosphere. For short times, say up to a week, this is a very good approximation. For longer times it becomes less valid. For short time scales, the boundary forcing is relatively constant. For monthly and longer times, however, it is clear that significant changes can occur. Monthly and seasonal changes in ocean surface temperature distributions are sometimes sizeable.

Another factor affecting the quality of extended-range forecasts is systematic error in atmospheric general-circulation models. In the shortest times, the main processes affecting the evolution of the atmosphere are adiabatic fluid dynamics. In longer times, say, after a few days, the role of thermodynamics becomes more important. Representations of thermodynamic processes within the atmosphere (such as convection and cloud-radiation interaction) have become more accurate over the last decade, but they are still far from adequate. Consequently, the models do not behave as perfect representations of nature, but rather drift toward their own biased circulation features. This modeling 'climate drift' significantly affects the quality of extended-range forecasts even on the time scales of days, and over the course of a month or a season the drift can be so severe as to completely destroy the skill of the forecast. Therefore, improved models based on sound understanding must be developed to minimize this problem.

Three main topics are ripe for investigation in extended-range forecasting: 1) the role of uncertainties in initial conditions; 2) the role of forcing from boundary conditions; and 3) the role of model errors. In addition, there is a basic need for the development of an improved methodology for extended-range forecasting. Preliminary experiments have investigated the predictability of monthly- or seasonally-averaged quantities. These might not be the most accurately predicted quantities. There is at least one prominent low-frequency fluctuation in the atmosphere; the 30-60 day oscillation. Perhaps better forecasts could be made by focusing on the time scales of such naturally-occuring phenomena, and predicting over the life cycle of one such event, rather than over an arbitrarily-defined period of time, such as a month.

Progress can be achieved most quickly for predictions on the order of a month or less. Preliminary experiments have shown that anomalous boundary forcing is dominated by initial conditions over this time scale. Therefore, the primary task is to develop a methodology, and investigate in more detail the accuracy and the expected level of error in the forecasts.

For seasonal time scales, model development to reduce climate drift is crucial. An adequate coupled ocean-atmosphere general circulation model, and methods of verification, must be developed; and methods for initializing the combined ocean-atmosphere system must be discovered. As progress is made on modeling these components of the coupled system, other components (sea ice, snow cover, land-surface processes) can be added to make a more comprehensive model.

Why Now?

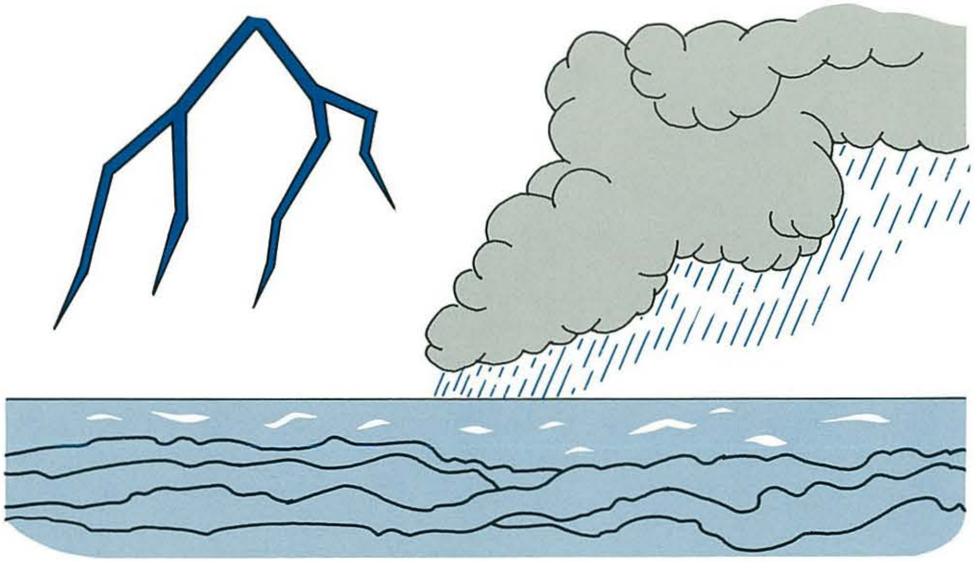
Prediction is NOAA's primary mission. A panel of the National Academy of Sciences has examined the prospects for increased skill in extended-range forecasting and has concluded that the time is ripe for a vigorous national effort in this area. Recent progress in database management, computer power, and atmospheric understanding have brought us to the point where improved forecast products can be made available in a relatively short time. A concerted effort is necessary now to capitalize on this progress. Many of the problems that will be faced in monthly and, especially, seasonal prediction are common to the longer-time climate predictions. Interannual prediction is a goal of the Tropical Ocean-Global Atmosphere (TOGA) Program, and decadal-to-century prediction is a goal of the Climate and Global Change Program. These efforts will require even more comprehensive models than those to be developed for seasonal prediction. However, improvements in the models necessary for seasonal prediction are essential for the success of the more comprehensive models as well. The history of large-scale weather forecasting shows that progress is made on the shortest times first, and then extends to longer and longer times. We expect that monthly and seasonal prediction may be a logical, and even necessary, precursor to prediction on the longer time scales that form the core of NOAA's Climate and Global Change Program.

Benefits

Studies have shown that small increases in skill in extended-range forecasts will have a large positive economic impact and can lead to significant gains in national productivity, economic efficiency, and market stability. For example, weather-related losses to the economy for the severe winter of 1977-78 have been estimated at $36 billion, and losses due to the drought and heat wave of summer 1980 at $18 billion. Savings from only modestly-improved forecasts in these cases are conservatively estimated to be at least 0.4%, or over $140 million for 1978 alone. In more typical months and seasons, the potential savings is at least $10-15 million per year. These studies have assumed only modest improvements in forecast skill. Because of developments in dynamical techniques, the propects for substantial increases in skill are good. The economic benefits are therefore likely to be greater in the future.

Interactions

The organizations within OAR's Environmental Research Laboratories that are involved in this work are the Geophysical Fluid Dynamics Laboratory and the Climate Research Division of Air Resources Laboratory. Both groups have strong ties to the National Meteorological Center of NWS. Outside collaboration has also been developed with scientists at the National Center for Atmospheric Research and several universities.



Mesoscale Weather Prediction

Problem and Opportunity

The United States experiences more severe local and regional storms than any other country in the world, underscoring the need for improved forecast and warning services. Devastating weather events, such as the infamous Presidents' Day snowstorm of February, 1979; and the crash of Delta Flight 191 in a thunderstorm at Dallas-Fort Worth in 1985, received extensive media coverage and national attention. However, many lesser events, not reported nationally by the media, produce large, cumulative social impacts and economic losses. For example, virtually all business activities (agriculture, power, transportation, shipping, state and local governments, and general commerce) are adversely affected by intense winter cyclones that bring hazardous weather conditions to the entire country. Although our skill in forecasting the general flow patterns of the atmosphere has increased dramatically during the past two decades, we lack the ability to forecast, even a few hours in advance, precisely where small areas of extreme weather will be embedded within large-scale storms.

Although one of NOAA's most important service missions is to provide public forecasts and warnings of extreme weather, our researchers and forecasters have not historically had operational systems to observe the time-continuous evolution of mesoscale weather (we use 'meso' to mean middle, which refers to all weather phenomena and processes smaller than large cyclones and larger than individual thunderstorms). Weather events that occur in this mesoscale spectrum range from tornadic thunderstorms to flash floods and heavy local snowfalls. Inadequacies in our forecasts and warnings make it clear that mesoscale weather phenomena remain poorly understood.

The imminent deployment of new remote-sensing technologies (Doppler radars, automated surface-observing stations, wind profilers, and new-generation weather satellites), and the planned acquistion of new-generation supercomputers, provides NOAA an opportunity for accomplishing mesoscale research that will lead to a much-improved understanding of severe weather processes. This new mesoscale knowledge will be essential if the modernized and restructured National Weather Service is to effect extensive improvements in operational weather services.

Research Strategy

Mesoscale weather processes are short-lived, unstable phenomena that are not well represented within existing large- or small-scale theoretical frameworks. The most important scientific questions to be addressed focus on understanding the interactive nature of physical processes that act in concert, but on differing scales, to produce severe local storms. The broad research goal must be to develop comprehensive observation capabilities that will support efforts to define theories of mesoscale behavior, to model those behaviors, and to determine the extent of their predictability. The ultimate validation of this science will occur when we are able to make useful numerical forecasts of the development and evolution of mesoscale weather events.

To make progress toward these well-defined and ambitious goals requires highly coordinated advances in four important, specific areas:

- We must obtain nearly continuous, comprehensive measurements of the atmosphere at the mesoscale to complement the routine large-scale and global observing systems. While several important new remote-sensing systems are being implemented currently by NOAA, advances in techniques to monitor detailed horizontal and vertical wind, and the temperature and moisture structures of the atmosphere are essential to complete a mesoscale observing system. As we enhance our mesoscale observing capabilities, we must carefully archive these data and make them easily available not only to NOAA scientists, but to the entire atmospheric science community;
- Diagnostic studies of widely varying types must be designed and accomplished to build the knowledge base of mesoscale structures, phenomena, and processes. These observational studies will span an imposing range of weather events, from winter cyclones and embedded precipitation processes to tornadic thunderstorms. The initial components of NOAA's mesoscale observing system will be new Doppler radars, automated surface observing systems (ASOS), and an extended-area experimental wind-profiler array. Data from these will support parallel research programs to study organized thunderstorm and precipitation systems on the scale of an individual radar's coverage, and the development and structures of intense winter cyclones, initially over the central United States, and over all sections of the country by the end of the century;
- Substantial improvements to existing numerical forecast models must be effected. Advances in modeling will require efficient four-dimensional data-analysis-and-assimilation techniques. New, higher-resolution operational forecast models will eventually be developed at the national and regional scales. These mesoscale forecast models will employ improved treatments of complex terrain, precipitation processes, surface and boundary conditions, energy fluxes, and specifications of latent heating fields. Efficient use of the data streams from high-rate mesoscale remote sensors will be made possible by NOAA's new-generation supercomputing systems. Advances in computing power will also allow development of nearly continuous update techniques for the mesoscale models; and
- The transfer of knowledge and the development of new techniques for operational forecasting require that testing and transfer mechanisms be strengthened between the research and operational components of NOAA's mesoscale weather programs. It is clear that total automation of NOAA forecast and warning services via highly precise and explicit numerical forecast models remains many decades distant. The professional meteorologist will continue to be a critical component of the forecast system for the foreseeable future. Promising research advances must be translated into forecast procedures such as expert-systems approaches and products within test and development environments that bring together researchers and operationalists.

As our mesoscale knowledge base increases, NOAA scientists will play an increasing role in efforts to keep the training and proficiency level of our forecasters as high as possible.

Why Now?

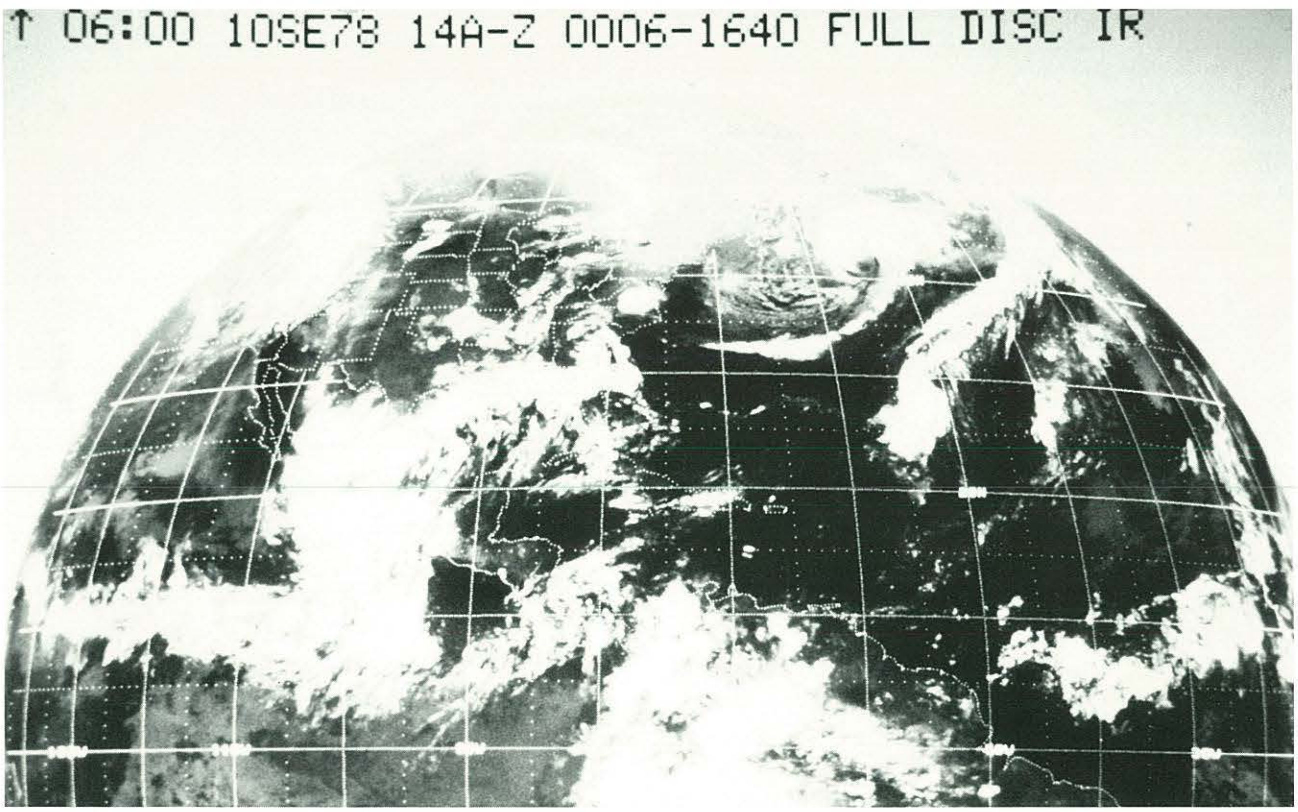
The NWS modernization will be moving toward completion by the middle 1990s. Several of NOAA's new observing systems have progressed sufficiently for the efforts described above to begin immediately. Mesoscale research and forecasting programs are needed to ensure public safety, to minimize economic impacts of hazardous weather, and to optimize the cost-effectiveness of our modernized observing and forecasting systems.

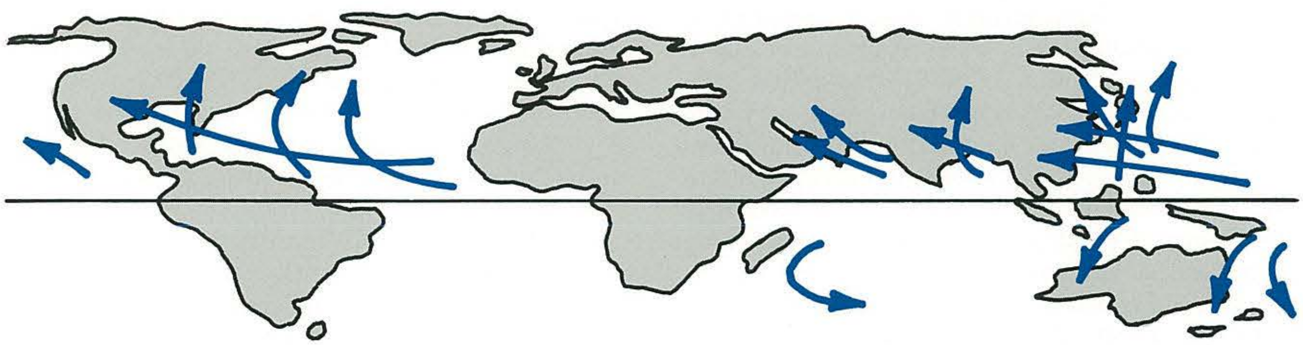
Benefits

Improved mesoscale observations, understanding, modeling, forecasting, and warnings will produce substantial benefits in five areas: reduced private, public, and industrial property damage; reduced loss of life and injuries from weather hazards; improved efficiencies and savings for industry, transportation, and agriculture; improved resource management, particularly of water; and more accurate weather forecasts for the public and for public officials. The potential annual benefit to the nation in these areas can easily be measured in hundreds of millions of dollars.

Interactions

Progress toward improved mesoscale weather services will continue to depend upon collaborative interactions between many different groups. Within NOAA, the principal contributions to OAR's programs are coming from the National Weather Service's National Meteorological Center, Office of Meteorology, Systems Development Office, Hydrology Office, Regional Scientific Support Divisions, and many local offices. The NESDIS research groups in Washington, DC; Madison, Wisconsin; and Fort Collins, Colorado, are working actively in these areas. Direct collaborations with NCAR, UCAR, and individual universities will continue to be essential to our efforts.





Hurricane Prediction

Problem and Opportunity

Hurricanes are a major cause of death and destruction in the United States and elsewhere. In the United States, they affect virtually all of the east coast, the Gulf of Mexico coast, and portions of southern California and the Hawaiian Islands. These storms are born over the warm tropical oceans and can be among the most destructive of all natural disasters. They have winds over 75 mph near their centers, and are associated with tremendous quantities of rainfall. The main causes of damage when tropical cyclones strike coastal areas are strong winds, storm surges, and heavy rainfall. Most damage is caused by the storm surge which is a rapid increase of sea level along the coast produced primarily by winds driving the water ashore. In extreme cases, the rise may be as much as 10 meters.

In 1970, the loss of life resulting from a tropical storm striking Bangladesh exceeded 500,000 people. In 1900, a hurricane striking Galveston, Texas resulted in more than 6,000 deaths, which is the largest loss of life from a natural disaster in the history of the United States.

The distance between a forecasted position and the subsequent observed position of a hurricane storm center is called the 'error' of the forecast. The errors resulting from the forecasts released by the National Weather Service's (NWS) National Hurricane Center (NHC), for the decade 1976-1985, averaged 215, 459, and 687 km for the 24-, 48-, and 72-hour forecasts, respectively. Using a combination of climatology and persistence as a basis of comparison, the 24-hour forecast shows the highest level of skill. Skill decreases with forecast interval and approaches zero at 72 hours. Forecast errors show large spatial variation, averaging up to 30% greater than the mean in the central Atlantic, and up to 30% less than the mean over the Gulf of Mexico and the Caribbean Sea. These differences arise from better data availability in the latter areas, as well as from different characteristics of hurricane motions within these areas.

The NHC's 24-hour forecast errors have declined about 17% over the past 30 years. This decline can be attributed to various factors, such as the ability, beginning in the early 1960s, to monitor and track these storms through satellite imagery. However, the rate of error decline has slowed significantly in recent years. The lack of meaningful improvement in hurricane track forecasts over the last decade has caused concern among the forecast, research, and preparedness communities.

Research Strategy

To achieve smaller forecast errors, the models that are used to provide objective guidance to the forecaster must become more reliable. Dynamical and statistical-dynamical models appear to offer the greatest potential for improved guidance. High-resolution global models have recently shown considerable promise as an ultimate tool for reliable forecasting of hurricane tracks. High-resolution nested-grid regional models, with time-dependent lateral boundary conditions obtained from global models, have the potential to provide accurate forecasts of hurricane tracks and intensity changes. The reliability of models of the future is dependent on improved understanding of tropical storms' physical processes and on improved operational data over the tropical oceans.

Increased understanding of the development and maintenance of tropical cyclones is difficult because of the wide range of horizontal scales and the complicated physical processes that are important. The characteristic scale of the hurricane vortex is several hundred kilometers. However, the destructive inner core consists of mesoscale systems such as rainbands and the eyewall. These mesoscale phenomena interact strongly with the still-smaller convective- and boundary-layer scales, with the larger vortex scale, and with the still-larger synoptic scale. Changes in the synoptic scale that can lead to important changes in the hurricane can be produced by changes on the hemispheric and global scales. The synoptic-scale and larger scales play the major roles in determining the track of the hurricane.

The important role played by instrumented research aircraft in the study of hurricane processes on the vortex-scale, the mesoscale, and the convective scale has been recognized for over 30 years. This results from the relatively small scale of the high-energy core of the system, and from the fact that tropical cyclones are born, and live most of their lives, over tropical oceans, on which we have relatively little data. While meteorological satellites are important for the detection and location of tropical cyclones, and have provided dramatic pictorial descriptions of the hurricane cloud shield, they have provided little in the way of quantitative information concerning the physical processes at work in the storm core. Thus the research aircraft remains a necessary tool.

In recent years, instrumented aircraft have also proven their value in describing the synoptic-scale flow in which hurricanes are embedded, and which mainly determines the tracks of the storms. The skill of the objective models upon which the hurricane forecaster relies to provide guidance for hurricane-track predictions depends, to a large extent, on the quality and quantity of observations of the environmental flow around the tropical cyclone. The database over the tropical and subtropical oceans currently consists of relatively-dense coverage in the lowest 2 km, where surface observations are obtained from ships, and winds are determined from the motion of low clouds viewed by satellite. Coverage is also extensive in the layer from 9 to 12 km, where wind observations are available from jet aircraft and from satellite-observed high cloud motions. Few observations, however, are routinely available at the mid-tropospheric levels with which storm motion is best correlated.

Before the potential of new dynamical and statistical track-prediction models can be fully achieved, mid-tropospheric observations over the tropical and subtropical oceans must be improved. While progress is being made toward reducing the data deficiencies through satellite remote-sensing techniques, major technical problems remain with this approach. Currently, dropwindsondes launched from aircraft are the only proven capability for obtaining reliable mid-tropospheric wind data in remote ocean areas.

Why Now?

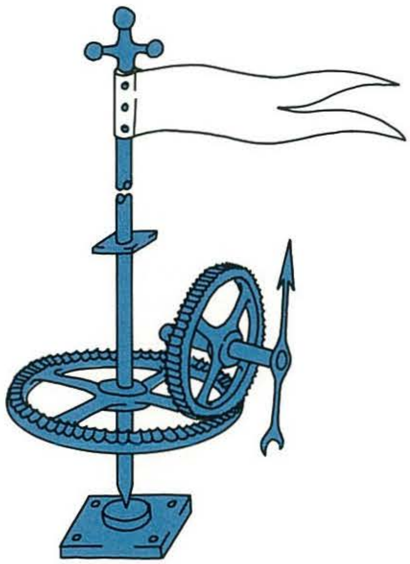
With current forecast accuracy, it is necessary to issue hurricane warnings for rather large coastal areas. Warnings issued 24 hours before hurricane landfall average 550 km in length. Normally, the swath of damage encompasses about one-third of the warned area, so the ratio of affected area to warned area is about one to three. Approximately two-thirds of the area is, in effect, overwarned. Considerable improvement is needed in the understanding and prediction of tropical cyclone intensity changes. Present operational forecasts are only slightly better than forecasts based on persistence and climatology. Mean absolute errors of maximum-wind-speed forecasts are deceptively low, since they are heavily weighted towards the average condition where intensity changes are slow and persistence forecasts work well.

Benefits

The ultimate goal of hurricane research is to minimize loss of life and property from hurricanes. Given the current state of the art of hurricane prediction, and the recent dramatic increase in coastal population, this goal can best be accomplished in the short term through better public awareness, disaster preparedness, and coastal evacuation planning. For the longer term, however, we must turn to new observational techniques, new data-assimilation procedures, and new models to improve the quality of objective guidance supplied to the hurricane forecaster, who, in turn, can translate this guidance into more accurate watches and warnings.

Interactions

The Hurricane Research Division (HRD) interacts with the National Hurricane Center in all phases of its research, and with the National Meteorological Center and the Geophysical Fluid Dynamics Laboratory in research concerning numerical modeling of hurricanes. The HRD cooperates with the National Center for Atmospheric Research on problems related to hurricane rainbands. Cooperative research with other NOAA groups, federal agencies, private-sector groups, and universities is also in progress.



Information Systems and Database Management

Problem and Opportunity

A recurring theme in the history of science has been that technology acts as a stimulus to allow rapid and unanticipated advances in understanding. This was true for Galileo, looking at the moons of Jupiter through his newly invented telescope, and it is true now. In the closing years of the 20th Century, powerful new computers, with advanced graphics and information handling systems, are the technological equivalent to Galileo's telescope—they offer a window on the natural universe previously unavailable to scientists.

The need for new and better ways to view the complex phenomena of the natural world has never been greater. Subtle but profound changes in the global atmosphere, measured in parts per million, and seen on color-coded satellite images (the Antarctic ozone hole, for instance), warn of the new role the human race has assumed. No longer are we passive members of an unchanging natural world; now we have thrust ourselves into the role of active participants in the fate of the planet we inadvertently modify on a grand scale.

NOAA and its research arm, OAR, have much to offer in the detection and understanding of complex phenomena. During the last decade, NOAA has developed new ways to look at atmospheric data. The complex fields of atmospheric variables, as seen by diverse remote sensors (such as radar and satellites) and as output from computer analysis and prediction models, have been ingested, integrated, and presented to humans using the newest of computer graphics techniques. The Program for Regional Observing and Forecasting Services (PROFS) has built and tested data-management and information systems which have become a basis for National Weather Service modernization. The opportunity we now face is to apply these same advances across the broad range of NOAA's mission—including oceans, chemistry, and the solar environment, as well as atmospheric phenomena on all time scales.

Strategy

Our strategy is to place in the hands of all NOAA operational personnel, researchers, and decision makers the most modern tools of information science. These include advanced data archives, the latest in computers (from supers to micros), and the information-processing tools to make a complete system.

Three broad areas must be addressed: weather, climate, and the oceans. Each is similar in its need to have large amounts of data easy to access and use. However, each is different in the approach required:

- *Weather*

  NOAA/OAR is a leader in the advanced use of weather data. In the decade from 1985 to 1995, there will be a 30-fold increase in the number of observations over the US mainland. This increase will not be due to additional weather balloons, but rather to a diverse set of remote sensors, including wind profilers, automated surface-observing systems, Doppler radars, and automated aircraft wind reports. Organizing such a dataset is significantly more complex than the homogeneous sets which characterize the previous 30 years. The outputs of all sensors need to be integrated and analyzed to infer the values of primary variables, such as mass and momentum fields. By use of four-dimensional assimilation, the increased temporal resolution of the new sensors can be converted to higher information density in space. Scientists will need to use the data in many forms, from direct sensor readings (such as radiance detected by a satellite sensor), through inferred point values, to fields which have been created using many sensors, and are presented on evenly-spaced grids. NOAA/OAR has direct responsibility for the implementation of one of the most important new data systems, a network of wind-profiling radars being implemented over the central portion of the country. In addition to making the data from these sensors available, there will be an opportunity to test new sensors (such as RASS, which can accurately measure temperatures in conjunction with a profiler). In summary, NOAA/OAR is the leader in the management of the finest mesoscale dataset available in the world;

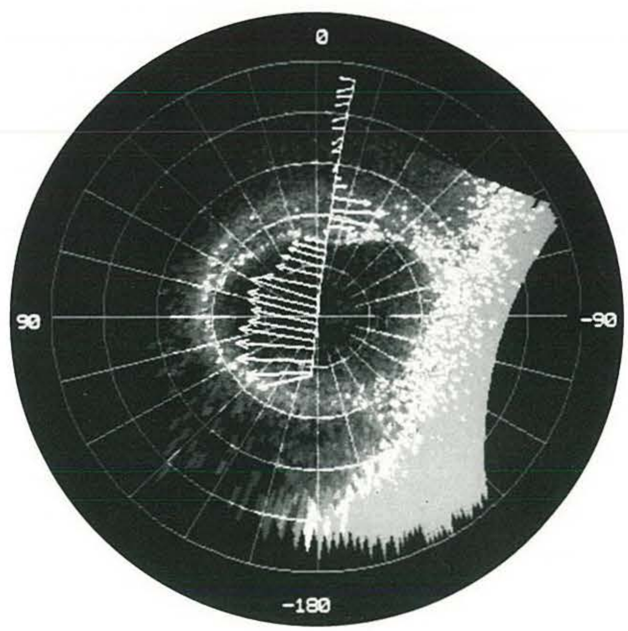
- *Climate*

  NOAA/OAR has been a leader in both the collection and use of climate datasets. To understand Earth's climate, a very difficult job of inferring past climate must be accomplished. This can be done by painstaking collection of weather observation records from the most recent two centuries, and by inference of climate by indirect means such as tree-ring correlation and study of deep-sea sediments. Again, the common necessity of understanding and relating data of many different types to one another, and using them to formulate an understanding of past climates, will be well served by advances in data management, processing, and display; and

- *Oceans*

  As with the atmosphere, the volume of observations from the ocean is increasing rapidly. NOAA's satellites have been used to present detailed and beautiful images of ocean-surface temperature for the last decade. New methods of remote sensing are being used to study the ocean depths. Promising technologies will allow remote sensing of ocean currents and wave spectra over large areas of the ocean. To convert these datasets, first to information, and then to understanding, will require the best technology available.

Within the field of data-management and information science, there are a number of state-of-the-art advances which NOAA/OAR can take advantage of immediately. Fantastic increases in the power of workstations will result in more productivity when they are made available to working scientists. New techniques for archiving will allow each researcher to rapidly and easily access volumes of data from their workstation. Networks will allow scientists separated by tens of feet or thousands of miles to collaborate closely. New methods of display of complex data, such as animation of three-dimensional data fields, will allow understanding not possible from a stack of computer print outs.



Why Now?

It is not surprising that the tools needed to effectively use advanced datasets are proliferating at precisely the same time that so much new data is coming available. Both the data, and the tools for their productive use, are due to the revolution in digital technology. What is surprising and fortuitous is the availability of such powerful new tools precisely when the need for understanding of the planet reaches a critical point. Effective use of data and information by our scientists is the key to understanding geophysical phenomena, which must be the basis for rational actions which will affect the future on all time scales.

Benefits

The benefits of better data-management and information systems are increased productivity. Although many have questioned the meaning of productivity for researchers, those closely associated with the field have observed for years the inordinate amount of time scientists spend in laboriously gathering and checking data. Automation of these activities will result in optimal use of the limited resources the nation can invest in this field. Increased scientific productivity will lead directly to more rapid development of prediction techniques on all scales, which in turn will lead directly to increased application and efficiency in American industry and government.

Interactions

NOAA/OAR efforts have been a crucial part of the National Weather Service plans for modernization. PROFS has been able to develop and test functional prototypes of all the data-management and information systems which will be implemented in the 1990s. These include advanced workstations, and processing of radar-, satellite-, and direct-sensed data. Information systems have been built and are in everyday use by the National Weather Service, National Ocean Service, and National Environmental Satellite and Data Information Service (NESDIS). In summary, NOAA/OAR has taken a new role in recent years as a source of expertise and as a development center to help NOAA in its widely-varied needs for data-management and information systems.

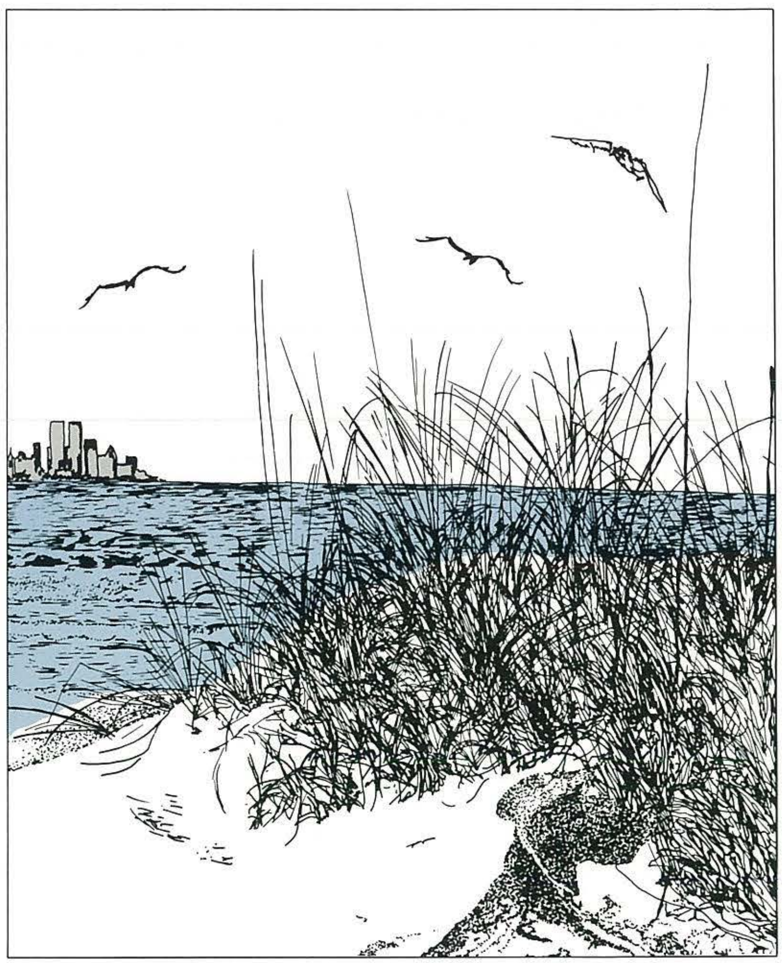
Section III

ENVIRONMENTAL QUALITY

Chapters

The rapid growth of technology throughout the industrialized nations of the world has unfortunately resulted in the degradation of the environment. Environmental concerns such as nuclear waste disposal, acid rain, and polluted waterways have become increasingly prevalent in our daily lives. The social impacts of environmental degradation are many, and include those related to human health as well as to the nation's economy.

In support of NOAA's mission to protect and better understand the total environment, OAR conducts research in a number of areas that are of vital concern to the nation. The research is aimed towards a better understanding of the environmental problems of our nation's estuaries and Great Lakes, coastal shorelines, and regional air quality. This chapter provides a brief overview of OAR's environmental-quality research.



Estuarine Systems: Productivity and Environmental Change

Problem and Opportunity

Estuaries and their associated coastal waters are a valuable and yet vulnerable component of the marine environment. They provide the biological foundation for our productive coastal waters. In the United States, two-thirds of the commercial-fisheries harvest is estuary-dependent. Future economic and population growth is forecast for our coastal and estuarine areas, such that by the year 2000, approximately 50% of the US population is projected to live in coastal counties.

Our estuaries already are suffering the consequences of accelerated heavy use. Evidence shows that the health of our nation's estuaries is declining. Degradation of environmental quality, and subsequent economic costs in the form of fisheries losses and threats to public health and safety, have become widespread. Low oxygen levels in bay waters have resulted in massive fish kills. High levels of toxic contaminants have been reported in sediments and benthic organisms from urban estuaries. There is widespread disappearance of submerged aquatic vegetation; there is continued loss of coastal wetlands; and there are dramatic declines in estuarine-dependent species including oysters, clams, striped bass, and shad.

Recognizing the urgent need for action to maintain and enhance the ecological integrity of the nation's estuaries, the US Congress has urged the development of management plans for these critical areas. OAR research can provide an insight into the functioning of these systems. Such information is essential for developing an ability to predict responses of estuarine environments to human actions and natural events, including climatic change, and for implementing cost-effective strategies to manage these systems.

Research Strategy

Until an understanding of estuarine processes and the effects of human activities on these systems increases substantially, these regional resources cannot be effectively managed. OAR will implement a scientific program focused on estuarine productivity in five target estuarine habitats: Spartina marshes, seagrass beds, mangrove forests, unvegetated flats, and the water column. Unlike many previous estuarine research programs, which emphasized studies of whole estuaries or specific pollutants, this approach will examine and compare the factors controlling productivity in a limited number of estuarine habitat types across the country. Research will focus on these themes:

- The effect of variation in freshwater inflow on physical structure and biological productivity in estuarine habitats;
- The effect of nutrients and nutrient cycling on habitat productivity;
- The relationship of habitat structure to habitat productivity, including the cumulative effects of habitat loss on productivity;
- The relationship between the nature and functioning of estuarine food webs and habitat productivity; and
- The effects of toxic chemicals on estuarine foodwebs.

Why Now?

Recent legislation (such as the 1987 Clean Water Act), and actions by federal administrators, have placed estuaries in the limelight. Legislators, environmental managers, the media, and the general public are being made increasingly aware of estuarine systems, their importance to coastal environments, and the potential harm that may come to these systems as a result of short-sighted or inadequate management. In this regard, President Bush has committed his administration to policies that will reduce loss of wetlands. This heightened environmental awareness coincides with the maturation of many subdisciplines within environmental science, in particular:

- Improved computer technology and techniques, and enhanced modeling capabilities enable, for the first time, description of estuarine dynamics with some realism; and
- New instruments and facilities, and a better understanding of the time frames of estuarine processes, can now be applied by scientists to achieve major new insight into estuarine processes.

NOAA has in place a core program of estuarine efforts, and is positioned to undertake a focused, comprehensive study of estuaries. Additional research funds for NOAA, its researchers, and their academic colleagues will permit the agency to build upon these strengths.

Expenditures of funds on site-specific problems are seen as a poor investment for developing a national approach to estuarine management by a research- rather than a resource-management agency. Needed now are studies on the basic functions of estuarine habitats and their relationships to overall productivity around the country.

NOAA is poised to initiate multidisciplinary and multi-institutional research to address critical estuarine issues. Failure to exploit this opportunity will result in a loss of research momentum, and could deprive society of information needed to wisely manage estuaries into the 21st Century.

Why NOAA?

The federal government has a role in estuarine governance, especially where estuaries and uses of their resources cross state and national boundaries. As the nation's lead civilian ocean-science agency, NOAA is uniquely qualified to assist in this role by conducting a program to increase understanding of estuarine systems, and by providing information necessary to predict and assess changes in these systems. NOAA's diverse capabilities in atmospheric science, ocean systems dynamics, biological processes, resource protection, and coastal zone management provide a pool of expertise capable of addressing major estuarine problems in a comprehensive manner:

- NOAA has a national network of estuarine and coastal facilities that includes 27 NOAA laboratories, 18 Estuarine Research Reserves, 29 Sea Grant Programs, and 7 NOAA/academic cooperative institutes;
- NOAA employs or funds many of the nation's outstanding estuarine scientists, some of whom serve in NOAA's research laboratories, and others associated with NOAA through existing programs;
- NOAA scientists have excellent relationships with scientists in academia. These relationships have formed the bases for partnerships among estuarine interests in NOAA, the academic community, and the states. These partnerships can be used to provide expertise to respond to research and assessment needs;
- Partnerships between NOAA and academia can be used efficiently and effectively through the National Sea Grant College Program to respond to complementary needs for long-term estuarine research and monitoring, as well as for short-term process-oriented studies;
- NOAA is sensitive to resource management needs. In partnership with the states, NOAA is responsible for managing living marine resources and the coastal zone. Additionally, NOAA advises other agencies (such as the US Army Corps of Engineers and the Environmental

Protection Agency) on living marine resources, under numerous legislative directives; and
- NOAA has a great deal of experience in predicting and forecasting that should be directed to estuaries.

NOAA's role and experience in environmental prediction and forecasting will form the basis for tying these resources and responsibilities together.

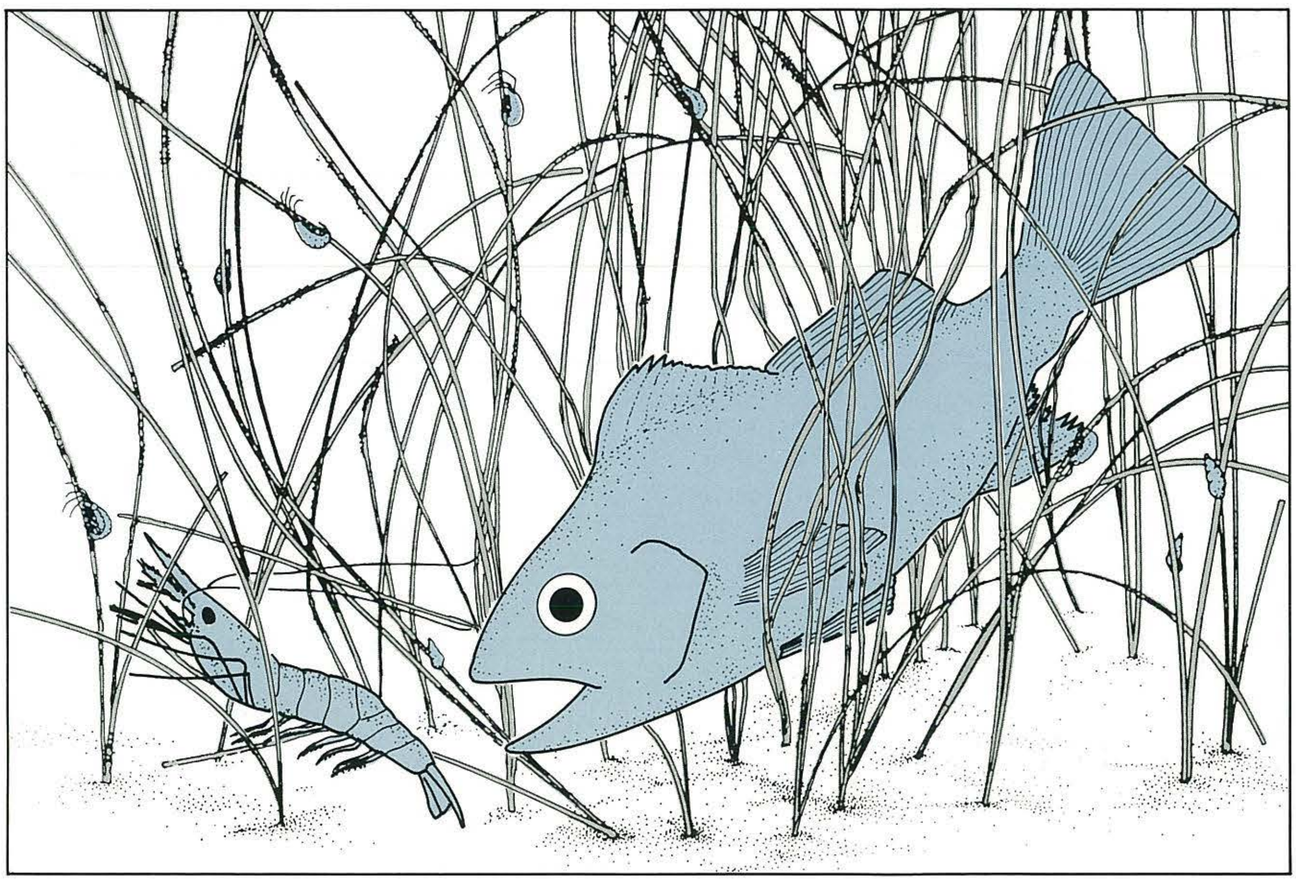
Benefits

Scientific findings from this program will improve our understanding of factors affecting estuarine productivity, and thereby provide the critical knowledge needed to:
- Develop appropriate land-use strategies;
- Develop water-management strategies, including pollution control and water supply;
- Maintain and restore critical estuarine habitats;
- Restore and enhance estuarine-dependent fisheries; and
- Improve our ability to sustain and increase long-term economic returns from estuaries through recreation, resource extraction, transportation, and waste disposal.

This new knowledge can be used by resource-management agencies to develop cost-effective regulations, improve permitting, and reduce litigation. The ultimate benefit will be enhanced economic development through the wise use and management of estuaries.

Interactions

The proposed investigations complement research and assessments being undertaken by a variety of federal agencies including the US Fish and Wildlife Service, the Environmental Protection Agency, the National Park Service, the Soil Conservation Service, the Minerals Management Service, and the US Army Corps of Engineers. Potential links also exist with the National Aeronautics and Space Administration for



the application of satellite- and aircraft-mounted remote-sensing technology to issues relating to coastal-environment quality. Findings are likely to have wide application, both within this country and on an international scale, where the rapid loss of estuarine habitats, such as tropical and subtropical mangrove forests, may have significant effects on the viability of economically-important living marine resources. Resulting information should also improve our understanding of the transfer of nutrients and carbon from terrestrial and riverine environments to coastal seas and, ultimately, to the oceans. This is also a major goal of components of the National Science Foundation.

Great Lakes Ecosystems

Problem and Opportunity

The Laurentian Great Lakes contain 20% of the world's surface fresh water and 90% of the surface fresh water in the United States. They provide a water transportation route to the nation's heartland for over 200 million tons of goods per year and 45 billion gallons of freshwater per day for use by the basin's residents and industry. The basin supports 15% of the nation's population and 50% of its heavy industry. The total benefit of the Great Lakes, in all its various forms, to the nation's economy is measured in hundreds of billions of dollars, and it is relatively of much greater benefit to Canada. Yet the long-term health and well-being of the Great Lakes ecosystem continues to be problematical.

Large lakefront populations and heavy industrial concentrations continue to perturb the system. Over 30,000 chemicals are produced or used in the basin, and 33% of the nation's hazardous wastes are generated here. The majority of the chemicals are untested for toxic effects, but at least 300 constitute a potential problem (International Joint Commission, 1980). Long water-residence times in the Lakes enhance the concentration of these contaminants in the system. Increasing demand for water and vagaries of climatic variation promise increasing fluctuations in water quantity in the Lakes, with inevitable effects on the ecology and economy of the system. In particular, global climate warming may have significant impacts on the Great Lakes system.

The Lakes have historically functioned as a 'miner's canary' to predict important ecological problems in our marine and other large lake systems. PCB contamination was first found in the Great Lakes, resulting in a world-wide awareness. The effect of DDT on wildlife was discovered in the Great Lakes ecosystem, and public outcry resulted in a ban. Now the potential carcinogenic effects of PAH contamination on wildlife discovered in the Great Lakes may have major national importance. We must detect subtle changes in the ecosystem as early as possible, for once problems have become obvious, solutions may take decades. If the problems become irreversible, recovery may be impossible.

The renegotiated Water Quality Agreement with Canada, the 1987 Clean Water Act, and the infrastructure provided by the International Joint Commission (IJC) provide an opportunity to focus on these problems from an interdisciplinary and predictive standpoint. Understanding the ecosystem and its responses to the multitude of perturbations inflicted upon it will provide managers the tools and information necessary to maintain the Lakes for all their potential uses and long-term benefits to the national economy.

It should be noted that the Lakes are shared with Canada, and water-management-and-regulation responsibilities are shared through the IJC and, to some extent, the Great Lakes Fishery Commission. The research community is also very international, and while there is general agreement among scientists from both countries concerning priority of research needs, implementation of any plan must include Canada as a full partner.

Many problems which affect the Great Lakes ecosystem are common to other coastal environments. Consequently, the expertise gained from the Lakes is applicable to coastal environments. For instance, research on eutrophication, sediment contamination by toxic substances, anthropogenic impacts on food webs, hydrology, and marine hazards are all appropriate to the NOAA/OAR mission.

Research Strategy

Our goal is to improve prediction tools supported by an improved scientific understanding to allow informed decisions pertinent to Great Lakes resources, pollution, and activities. These decisions affect ecosystem structure, stability, and the nation's economy. Systems analysis based on a strong field program provides for informed, rational management decisions. Three classes of simulation or prediction models are required: to describe the structure and function of the Great Lakes ecosystem; to quantify the effects of stresses and remedial options on the Great Lakes ecosystem; and to assess alternate management options for a given set of economic and environmental objectives. We must sufficiently understand the cause-and-effect relationships, both anthropogenic and natural, in the Great Lakes ecosystem to simulate the ecosystem and to assist in decision making. Thus process-oriented research, coupled with experimental and theoretical problem-oriented research, is essential.

NOAA's Great Lakes research program is designed to improve our basic understanding of ecological processes and to support management decisions by providing modeling capability using a total-ecosystem approach. We must address five important issues and their cumulative effects:

- Toxic Substances
  - Source and environmental fate of toxics,
  - Loading and concentration estimates and predictions,
  - Chronic effects,
  - Relationship to productivity,
  - Synergistic effects, and
  - Economic-impact assessment;
- Nutrient Over-enrichment
  - Predictive models for determining the effects of altered nutrient loadings,
  - Limiting factors for production and composition of the phytoplankton community,
  - Effect on trophic dynamics, and
  - Importance and fate of non-point-source nutrient enrichment;
- Habitat Modification
  - Measurements, and models to predict measureable fish losses at the population level,
  - Models to estimate cumulative impacts on biological production, and
  - Mitigation of anthropogenic impacts and economic assessment;
- Water Quantity/Quality
  - Biological and economic effects of changing water levels,
  - Hydrologic models to predict changes in lake levels and inter-lake flows, and
  - Economic and biological assessments of water quality and quantity changes;
- Physical Processes and Marine Hazards
  - Improved understanding of processes contributing to mass, momentum, and heat transfers,
  - Effect of physical processes on the fate of toxics and modified habitats under different water-level regimes,
  - Economic impact, and
  - Improvement of Great Lakes marine forecasting capabilities to mitigate physical hazards.

Why Now?

Critical resource problems are accelerating in the Great Lakes:

- Over 300 chemicals and compounds have been found in the system. They pose potential threats to biological resources and human health. At least some of these materials enter from outside the system through atmospheric transport, a situation which greatly exacerbates their control;
- Tumorous lesions in fish and abnormalities in wildlife are increasing;
- Human health may be at risk. Recent research has identified correlations between lower developmental rates in infants and high maternal consumption of Great Lakes fish. Other human-health concerns are currently under investigation;

- Recent extreme fluctuations in water levels in the Lakes have caused dramatic economic hardships and shoreline and wetland erosion;
- Water shortages in the Midwest and West have heightened demand for Great Lakes water diversion; these shortages may be exacerbated under 'global warming' scenarios;
- Degraded water quality and spawning habitat have frustrated efforts to rehabilitate native lake-trout stocks after successful control of the invading parasitic sea lamprey;
- The economic potential of the Great Lakes is jeopardized by their declining ecological condition;
- The Great Lakes, as a closed and relatively stable system, are a natural laboratory in which to study these problems with an eye toward much wider application in our coastal bays and estuaries;
- The predicted advent of climate change may cause severe biological stress to the system and economies of the region; and
- Increased recreational use of the Lakes expose many more people to potentially hazardous weather conditions.

Why NOAA?

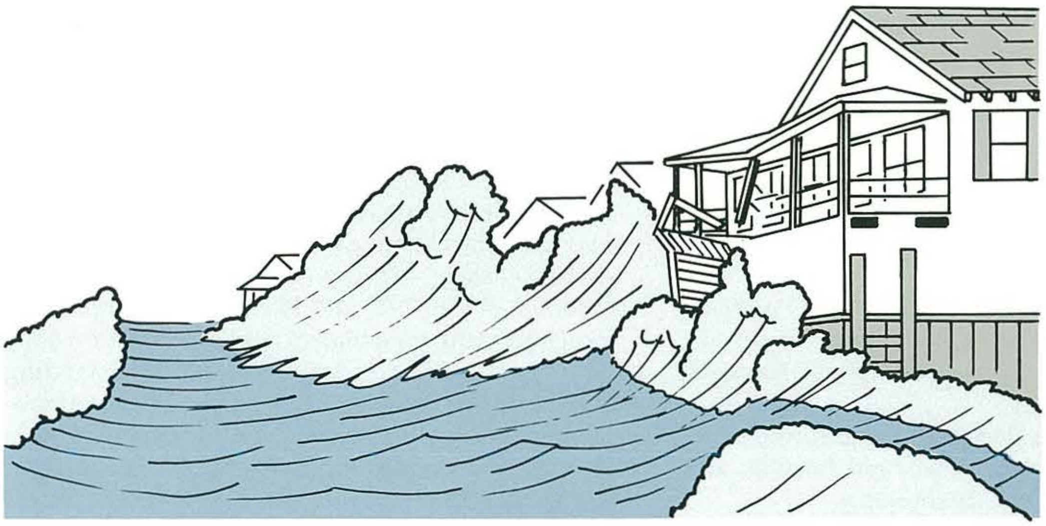
The complexity and diversity of the Great Lakes' ecological problems require an interdisciplinary approach to research involving a number of natural-resource agencies and academic institutions on an international scale. NOAA, with its capabilities in remote sensing and biological, chemical, and physical research, and with its mission to provide scientific knowledge and tools to support resource management and environmental services, is in a unique position to provide crucial support to this massive effort. This is especially true since this work will have ramifications for the similar environmental situations which are evolving in many other marine and estuarine communities along our coasts.

Benefits

Most management decisions affecting the Great Lakes are being made on the basis of insufficient knowledge and information. A NOAA workshop on Great Lakes water quality emphasized this point in the following recommendation: "There exists the need to develop an increased understanding of how the Great Lakes ecosystems function in order to evaluate their response to various stresses and corrective measures" (NOAA, 1980). A similar need to understand causality in complex estuarine systems was cited by the National Research Council Geophysics Research Board (NRC, 1983) as a necessary precursor for the development of accurate predictive models. When decisions regarding the use of our nation's freshwater and marine systems must be made, the store of reliable knowledge and predictive capability of our models must be considered the primary source of useful guidance. The benefit of this program will be to help provide this base of information and thus improve our predictive capabilities to properly manage the Great Lakes and estuarine resources.

Interactions

Great Lakes water-quality and habitat issues are extremely complex and diverse. Since the Lakes are shared with Canada, there are international considerations as well. Each US federal and state agency with a specific mission (often competitive in nature) regarding the Lakes is generally mirrored by a corresponding Canadian national and provincial agency. Coordination within this community is extremely important, not only to prevent duplication, but more important, to ensure maximum mutual benefit. Primary mutually-supportive programs are maintained with the US Environmental Protection Agency, US Fish and Wildlife Service, US Army Corps of Engineers, and the Department of State (through the International Joint Commission and Great Lakes Fishery Commission) as well as numerous state fisheries, environmental, and public-health agencies.



Coastal Sediment Transport and Shoreline Stability

Problem and Opportunity

Each year in the US, millions of dollars worth of waterfront real estate is lost through coastal erosion, and millions more in property damage is caused by coastal storms. In spite of the millions of dollars committed each year to coastal protection and restoration, day-to-day meteorological and oceanographic forces—possibly accelerated by rising sea level—are threatening most of the US shoreline. This is not a new phenomenon, for continental erosion occurs as a natural consequence of local weathering processes and climatic changes. However, the problem is exacerbated today by an increasing demand for coastal resources and rapid development of coastal areas. By the year 2000, approximately 50% of the US population is projected to live in coastal counties.

The sediments released by these erosional processes further affect our economy. Each year, this country's commerce fails to realize its full potential because, in spite of the hundreds of millions of dollars spent on channel and harbor dredging, shifting sediments create navigational hazards which impede coastal shipping.

Solutions to these problems depend upon knowledgeable decisions by managers, engineers, and scientists at local, state, and national levels. Good decisions not only require quantitative understanding of the processes, but also rely upon accurate models for predicting the impacts of both natural and man-made changes. Yet our ability to provide meaningful information and accurate predictions is falling behind management requirements for at least two reasons: first, the processes controlling sediment transport and deposition in coastal environments are extremely complex; and second, although advances in coastal science have resulted from recent large-scale field studies, knowledge of the fundamental physics involved in wave, current, and sediment interactions in the coastal zone remains rudimentary, due in large part to a continuing inability to make accurate measurements. Consequently, the numerical models upon which informed management decisions rely are relatively crude. A coordinated, science-driven national program is needed to gain insight into the complex physical and geological processes controlling coastal sediment transport and shoreline stability.

Research Strategy

The ultimate goal is to develop dynamic models of nearshore fluid and sediment motions over varying time and space scales. However, sediment transport in nearshore waters is the result of complex interactions at the sea bed between waves, currents, sediments, and bed roughness. These multiphase interactions span a wide range of time scales (seconds to days) and occur in a complex hydrodynamic region. An effective research program on contemporary sediment transport must be based on a coordinated set of long-term field measurements, to develop statistically-valid inputs for regional sediment-transport models. It must include an ordered sequence of process-oriented field experiments to investigate forcing and response mechanisms over a wide range of time and space scales, each level using results from preceding levels. Finally, numerical modeling and laboratory experiments are required to quantify the effects of a number of distinct influences. Major research priorities include:

- Local Fluid- and Sediment-Transport Processes
  - Initiation of sediment motion and suspension,
  - Bedload and suspended-sediment transport rates,
  - Wave breaking, dissipation, and turbulence,
  - Boundary layers for waves and currents, and
  - Bedform types and dimensions;
- Large-Scale and Regional Processes
  - Nearshore bar development and migration,
  - Shallow-water wave energy transfer,
  - Meteorological effects on nearshore sediment transport,
  - Tidal-inlet sedimentation, and
  - Sea level rise.

Why Now?

Increasing development of the coastal zone is driving property values dramatically upward and placing extreme demands on finite coastal resources. Each year, natural processes destroy or damage millions of dollars worth of resources and property. With the advent of deeper-draft vessels, our full economic potential is restricted by an inability to control and mitigate wave- and current-induced shoaling in navigable waterways. Accordingly, this is an opportune time for research progress:

- Advancements in acoustic and optical instrumentation for measuring sediment and fluid motion, combined with new computer systems, allow more rapid collection and syntheses of large, complex datasets;
- Numerical techniques have only recently begun to provide some initial capability to predict dynamic situations within the ocean and atmosphere useful in testing hypotheses; and
- The intellectual and technological resources capable of making significant advances in both understanding and predictability are at a critical point—leadership and direction are needed to fulfill this potential.

Why NOAA?

NOAA, as the nation's lead agency in coastal ocean and atmospheric data collection, coastal zone management, and Exclusive Economic Zone (EEZ) activities, is intimately familiar with the important scientific and managerial questions related to coastal sediment transport and shoreline stability. The Nearshore Sediment Transport Study, which NOAA funded between 1978 and 1982, was the largest and most successful quantitative field investigation of its time, and significantly advanced our understanding of coastal hydrodynamics. The NOAA Sea Grant program continues this involvement by providing over $3,000,000 annually for coastal-process research. NOAA also develops forecasts to predict the effects of oceanic and atmospheric processes on natural and developed areas. Investigators at NOAA's Great Lakes Environmental Research Laboratory have also made significant contributions to coastal processes research, particularly concerning wind-induced flows in the Great Lakes.

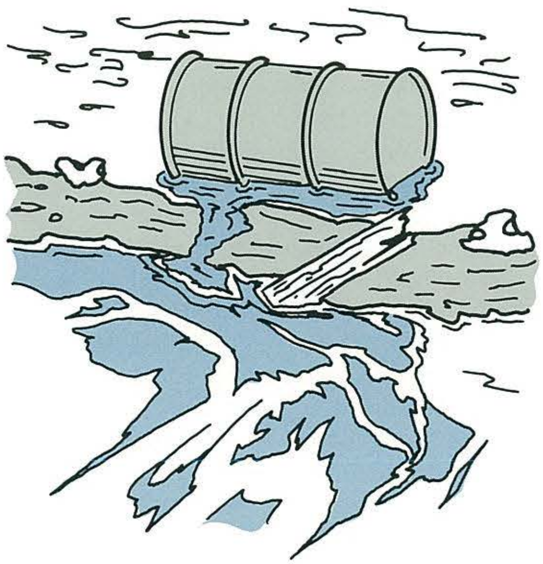
Benefits

Benefits resulting from improved understanding of fundamental sediment-transport processes and from development of predictive techniques include:

- Enhanced commerce at US ports through design of more efficient dredging techniques, and from cost savings in dredging operations. For example, knowledge of spatial and temporal distributions of fine-grained sediment transport could reduce dredging costs in Gulf channels by as much as 15% (annual cost savings of $3,000,000 in Louisiana alone). Similar benefits would accrue for Great Lakes locations, where water levels and sedimentation also affect large-scale commercial activities;
- Reduced property damage from coastal flooding and shoreline erosion through improved design of protective structures; and
- Reduced costs of beach nourishment projects through effective selection and placement of nourishment material.

Interactions

Within NOAA, OAR's program will interact closely with the Coastal Ocean Program Office in planning and management. University scientists of the Sea-Grant network will be important for the successful implementation of the program. The program will also interact heavily with ongoing research initiatives being developed by NSF Ocean Sciences Division (Coastal Physical Oceanography and Coastal Margin Sedimentation) and the USGS Office of Marine Geology (Coastal Erosion). In addition, through a joint office with the USGS, NOAA is responsible for research and mapping of the EEZ, and the need for coordinated studies of nearshore processes has been formally recognized in an EEZ symposium report. The program will benefit other agencies having related missions, including FEMA, DOE, Navy, EPA, and the Army Corps of Engineers.



Toxic Organics in the Marine Environment

Problem and Opportunity

US coastal and Great Lakes waters provide essential spawning and nursery habitat for many important living marine resources. Human activities have contributed many different contaminants to these waters, including synthetic organics and petroleum hydrocarbons. Contaminants degrade essential habitats for important living marine resources, and may affect entire ecosystems, including human consumers and other apex predators. Toxic organic compounds are widespread in the coastal and estuarine environment.

Declines in important commercial fisheries have been attributed to pollution of coastal and Great Lakes waters but cause-and-effect linkages have not been demonstrated. Chronic sublethal effects, such as lesions and tumors, are found in fish in all our coastal and Great Lakes waters; however, no effect on fish populations as a whole has been demonstrated. Effects of toxic organics on reproduction and larval survival have been demonstrated, but the effects on populations are, again, unclear. The effect of toxic organics on marine and Great Lakes ecosystems are not well understood and cannot be predicted reliably. The most serious consequences to date have been restrictions on both commercial and recreational fisheries. There is little knowledge of the effects of the complex mixtures of toxic compounds that actually exist in the marine environment.

Research Strategy

The Federal Plan for Ocean Pollution Research, Development, and Monitoring: Fiscal Years 1988-1992 (NOPPO, 1988) specifies six major research goals of the national marine pollution program. The goal for toxic materials is to understand the sources, fates, and effects of toxic materials entering the marine environment as a result of human activities.

The plan identifies a series of questions necessary for achieving this goal. Two of the questions directly address NOAA's interests and responsibilities as steward of our nation's living marine resources, and are in keeping with its mandated responsibilities for research to support the health and welfare of the Great Lakes. These management questions, along with their companion research questions, are:

(1) What are the mechanisms that influence exposure patterns and bioavailability of toxic contaminants in the marine environment?

- What factors influence the transport, physical fate, and chemical transformations of toxic contaminants in the marine environment?
- How do physico-chemical forms of toxicants affect bioavailability?
- How do metabolic processes affect uptake and toxicity of contaminants?

(2) What are the effects of toxic contaminants on marine organisms and populations?

- What are the sublethal effects of toxic materials on marine organisms?
- What are the implications of toxic effects on populations of marine organisms?
- How do synergism, antagonism, and additivity among chemical species affect toxic response?

The Federal Plan identifies the toxic compounds of major concern in the marine environment. Organic compounds on the list include halogenated compounds such as dioxins and polychlorinated biphenyls; polycyclic compounds such as the aromatic hydrocarbons; a variety of pesticides; and some other compounds. NOAA's research program in toxic organic compounds addresses the two management questions presented above. A research program in simulation and prediction modeling, coupled with a research program in ecosystem processes, is focused on the issues of transport, physical fate, transformations, and uptake of toxic organics. Additional programs are concerned with developing an understanding of the effects of mixtures of toxic organics on key marine species, and on developing an understanding of the sublethal effects of toxic organics with emphasis on the relationship between the effects on individuals and the integrity of populations.

The NOAA program will use systems analysis to address the concerns about toxic organic compounds in the marine and Great Lakes environment. Systems analysis provides an approach for informed, rational management decisions. Fundamental to a generic systems-analysis approach is the definition of objectives for the system, identifying the problem to be assessed, and criteria such as allowable cost and risks that help guide managers to feasible choices of remedial options. Three classes of simulation or prediction models are required: (1) those which describe the structure and function of the marine ecosystem being affected, (2) those which quantify the effects of stresses and remedial options in the ecosystem, and (3) those which identify optimum management solutions for a given set of economic and environmental objectives. The cause-and-effect relationships in the ecosystem must be understood sufficiently to use models for marine assessment. Thus process-oriented research that focuses on those ecosystem compartments relevant to present and perceived future aquatic problems is essential. In addition, coupled experimental and theoretical problem-oriented research is needed to develop improved engineering prediction tools and to support assessments necessary for informed decision making.

Why Now?

Long-lead-time, comprehensive multidisciplinary research is needed to address marine environmental-quality issues and management questions. The time allowed for policy and marine-resource-management decision making in most cultures is characteristically shorter than the time inherently required for the careful and comprehensive analyses required in a marine assessment. Answers are usually needed very quickly by decision makers after the questions are identified. This can result in a superficial response unless questions can be anticipated with sufficient lead-time to enable research to develop understanding and thoughtful analysis before answers are needed. There is a clear need, then, for long-lead-time research on fundamental questions, improved predictive capability for ecosystem responses, and frameworks for assessing chronic and acute risks to ecosystem health and to the productivity of our commercial fisheries. If our marine and Great Lakes ecosystems are to remain healthy, and our fisheries managed wisely and productively into the next century, we need to begin our research program now.

Benefits

With over 60,000 compounds currently in the toxic-control register, and thousands added annually, there are neither the scientific nor fiscal resources available to assess the impact on the environment of each chemical. It is essential to develop predictive techniques, including numerical models that use fundamental chemical structure, physical properties, and observed biological effects to predict the effects of toxic compounds on marine ecosystems and fishery populations. Only when this occurs will the natural resource agencies be able to accurately understand and assess the impact of toxic organic chemicals, and the regulatory agencies be able to evaluate the potential environmental impact of new compounds before their production and release to the environment. The research strategy described here will result in major advances in these predictive capabilities.

Interactions

Within NOAA, OAR's program will interact most closely with the National Marine Fisheries Service's Environmental Conservation Laboratory and with the Coastal Ocean Program Office. University scientists will be an integral part of the research effort through NOAA's Sea Grant College Program. The Environmental Protection Agency and the Fish and Wildlife Service will be the primary beneficiaries of the research program outside of NOAA. As the issue of toxic organics and their effects in the Great Lakes is one of great concern to both Canada and the United States, the program will work closely with Canadian Federal Laboratories and the International Joint Commission.

Regional Air Quality

Problem and Opportunity

There is ample evidence that mankind is seriously altering the atmospheric environment and in the process sacrificing an invaluable resource, air quality. In considering this resource, it is useful to bear in mind that the distance across any small city in the United States is equivalent to the height of the atmosphere and the ozone layer above it. Yet this limited volume contains all life and all that maintains life.

Unfortunately, harmful changes are readily apparent at all scales in the atmosphere. The local enviroment may be threatened by the release of toxic chemicals, substances that are sufficiently dangerous that their presence in trace amounts can endanger human welfare. On the regional scale, anthropogenic emissions form acid rain and lead to increased surface-ozone levels. In this case, emissions from another state or even another country produce compounds through atmospheric chemistry that pose a threat to lakes, crops, and forests. Finally, declining air quality can trigger environmental changes of global dimension. Industrial emissions in the northern hemisphere generate thick haze during the winter in the Arctic, producing chemistry-altering particles that alter the Earth's albedo by darkening the snow-covered surface.

These alterations of air quality are cause for serious concern. All of the above changes in air quality, plus others, are due to mankind's stress on our atmospheric resources. Over the past one hundred years, the human population has doubled. More significant, the world's industrial productivity has increased fifty-fold. Demographers estimate that the world's population will double again before the year 2050. In the future, with more people needing more food and goods, the potential for degradation in air quality will increase.

If we are to avert problems, rather than be overtaken by them, we must:

- Issue warnings when toxic substances are released into the atmosphere that indicate when and where risk exists and elicit appropriate emergency responses;
- Provide accurate forecasts of impending changes in regional air quality to allow ample opportunity for intelligently-considered risk assessment and abatement; and
- Predict the consequences of man-made and natural emissions into the atmosphere and the implication of the emission trends for regional and extra-regional air quality.

Research Strategy

The goal of air-quality research is to understand the chemical and meteorological processes that shape the composition of the atmosphere, and to incorporate this understanding into reliable air-quality-forecast models. Specifically, the research addresses two questions: (1) what are the relevant chemical species, and (2) what are the characteristics of the chemical and meteorological processes that form, redistribute, and remove them?

Earth's atmosphere is an oxidizing medium. Through atmospheric chemical processes, compounds containing carbon, hydrogen, nitrogen, sulfur, and other elements emitted by natural and anthropogenic sources are oxidized, yielding either nonreactive long-lived species (such as carbon dioxide) or short-lived acidic species that are removed by wet and dry deposition (such as nitric acid and sulfuric acid). The atmospheric oxidation of any particular compound is accomplished by a complex and poorly understood sequence of gas-phase, aerosol, cloud, and precipitation processes. When generated, the products of these reactions reside in the atmosphere for periods sufficient for them to be transported great distances (especially particles and relatively unreactive gases) before being removed by contact with the surface or through scavenging by precipitation.

Understanding the oxidation processes is necessary if we are to predict air quality during a time of increasing stress on the atmosphere. The oxidation process is fundamental for cleansing the atmosphere. Within days, most oxidizable substances that enter the atmosphere are transformed to products that are often, but not always, more benign, or that are more readily removed from the atmosphere. From a human perspective, the results of atmospheric oxidation can be either beneficial or harmful. Oxidation can lead to the decomposition of toxic chemicals released into the atmosphere; however, the same processes can also lead to elevated ozone levels that are believed to be responsible for significant losses to health and industry. In either case, a demonstrated capability to predict the fate of the chemicals released into the atmosphere, as well as the by-products of these emissions, is needed.

Obtaining such a predictive capability involves the following prerequisites:

- Detailed understanding of the oxidation process;
- Identification and formulation of processes that cause toxic chemicals and the products of atmospheric reactions to be removed from the atmosphere;
- Incorporation of this understanding into mathematical models that simulate the fate of compounds emitted into the atmosphere;
- Measurement of atmospheric chemical composition to test the validity of the model predictions; and
- Monitoring of chemical constituents that control oxidation to determine long-term trends.

Why Now?

The importance of maintaining air quality is recognized by the public. The nation has demonstrated a willingness to pay for, and make sacrifices for, clean air; for example, by accepting costly emission controls for automobile and industrial emissions. The public asks in return that these costs are justifiable and the results properly documented. This justification and documentation can be provided by a demonstrated predictive understanding of the atmospheric environment.

Why NOAA?

NOAA has long had the responsibility to forecast atmospheric changes involving weather. NOAA is the leader in new research aimed at predicting the chemical and physical alteration of the atmosphere that can lead to global climate change. It is reasonable that NOAA assume its obvious responsibility with regard to forecasting air quality and, thereby, to provide the scientific basis for regulation, enforcement, and protection.

Through the National Acid Precipitation Assessment Program, the research infrastructure has been developed within NOAA to assume this role in forecasting air quality. The nation has a heavy stake in this development and, as a consequence, NOAA can now act at once to use this capability to develop the needed air-quality analysis, to protect a large national investment, and to safeguard the national interest.

Benefits

Adequate air-quality forecasts will benefit all elements of our society. They will provide government and business the means for determining the fates of toxic substances released into the atmospheric environment, allowing maximum time to avert danger or damage. Forecasts of potentially harmful changes in regional air quality will provide the opportunity for development of a sound abatement policy. Finally, forecasts will allow development of realistic emission scenarios for estimating the stresses being placed on the atmosphere's most important defense, its oxidative cleansing mechanism.

Interactions

The development of a predictive capability to assess and forecast local and regional air quality immediately supports another major NOAA mission in global climate change. Atmospheric oxidation and associated removal mechanisms play important roles in the distributions of radiatively-important trace species, such as ozone and methane. The development of analytical models to predict the fate of chemicals released into the atmosphere will draw upon the knowledge and services of the meteorological and dynamical science divisions of NOAA. Understanding the transport of substances through the atmosphere will use meteorological tools such as profilers and boundary-layer radars. On the other hand, understanding chemical processes in the atmosphere provides useful chemical tracers to help map meteorological processes. The development of a predictive capability for atmospheric chemistry can provide the ocean sciences with the information needed to ascertain the deposition of environmentally-important substances, such as nitrates, into lakes and coastal and estuarine waters. Finally, a predictive capability will alert the nation to potential atmospheric changes resulting from industrial or commercial activity.

There is strong coupling with other agencies. The availability of adequate air-quality warnings and forecasts will aid the regulatory and enforcement arms of the Environmental Protection Agency, the licensing activities of the Department of Energy, and the crop and forest hazard assessment elements of the Department of Agriculture.

Section IV

RESOURCES: OAR AND THE NATION'S COMMERCE

Chapters

NOAA's Office of Oceanic and Atmospheric Research (OAR)—through its programs of research, technology transfer, and global environmental information processing and distribution—contributes enormously to the functioning of the nation's commerce. Many of OAR's scientific programs—such as severe weather forecast improvement, advanced atmospheric weather observation, climate-change prediction, and the National Sea Grant College Program—directly benefit the national economic well-being. For other OAR programs, the links to the economy might be less familiar to us, but are nonetheless significant.

Advances in weather forecasting depend on understanding the physics of the atmosphere on all scales from the synoptic (large) to the mesoscale (middle) and microscale (small). Our growing knowledge of Earth's highly complex, dynamic atmospheric condition has led to improved forecasts and earlier warnings. These provide a substantial economic benefit to the agriculture, fishing, transportation, construction, utilities, manufacturing, and recreation industries in the United States.

The annual cost-avoidance benefit from OAR's weather research and forecasting advances resulting from reduced property damage and productivity losses inflicted by high winds, flooding, hail, lightning, tornadoes, and blizzards, are estimated at $3 billion dollars.[1] The annual national loss from severe weather, irrespective of whether protective measures could be taken, is estimated at $35 billion dollars.[2] The human toll in lives is daunting; an annual average of 9,000 people die in weather-related incidents, with most (8,000) occurring in traffic fatalities related to bad weather.[3]

Even our fledgling ability to analyze and predict interannual oceanic and atmospheric climates has such profound economic impact that the major commodities and securities dealers now have climatologists on their staffs. The ultimate fountainhead of our economy and well-being is the global climate. To the extent that we can predict natural global variation and mitigate unnatural perturbations, we will be able to adjust our civil pursuits, or possibly even preserve human civilization.

The annualized dollar impact of the National Sea Grant College Program in 1987 was nearly $842 million dollars, over 20 times the federal investment in the program. This does not include the non-monetary contributions to environmental quality, human health, and safety.

Accordingly, OAR's scientific programs are essential to the nation's commerce and economic well-being. This section of the NOAA/OAR Research Strategy Overview focuses on both the development of resources and the processing of global environmental information. Resource development programs, carried out through the Sea Grant Program, include research that will improve the predictability and management of fishery resources, supplement the natural sources of marine food and fiber through aqua-

[1] Thompson, J. C., 1972. **The Potential Economic Benefits of Improvements in Weather Forecasting.** Department of Meteorology, California State University, San Jose. NOTE: An inflation factor of three was used to update figures for 1989.

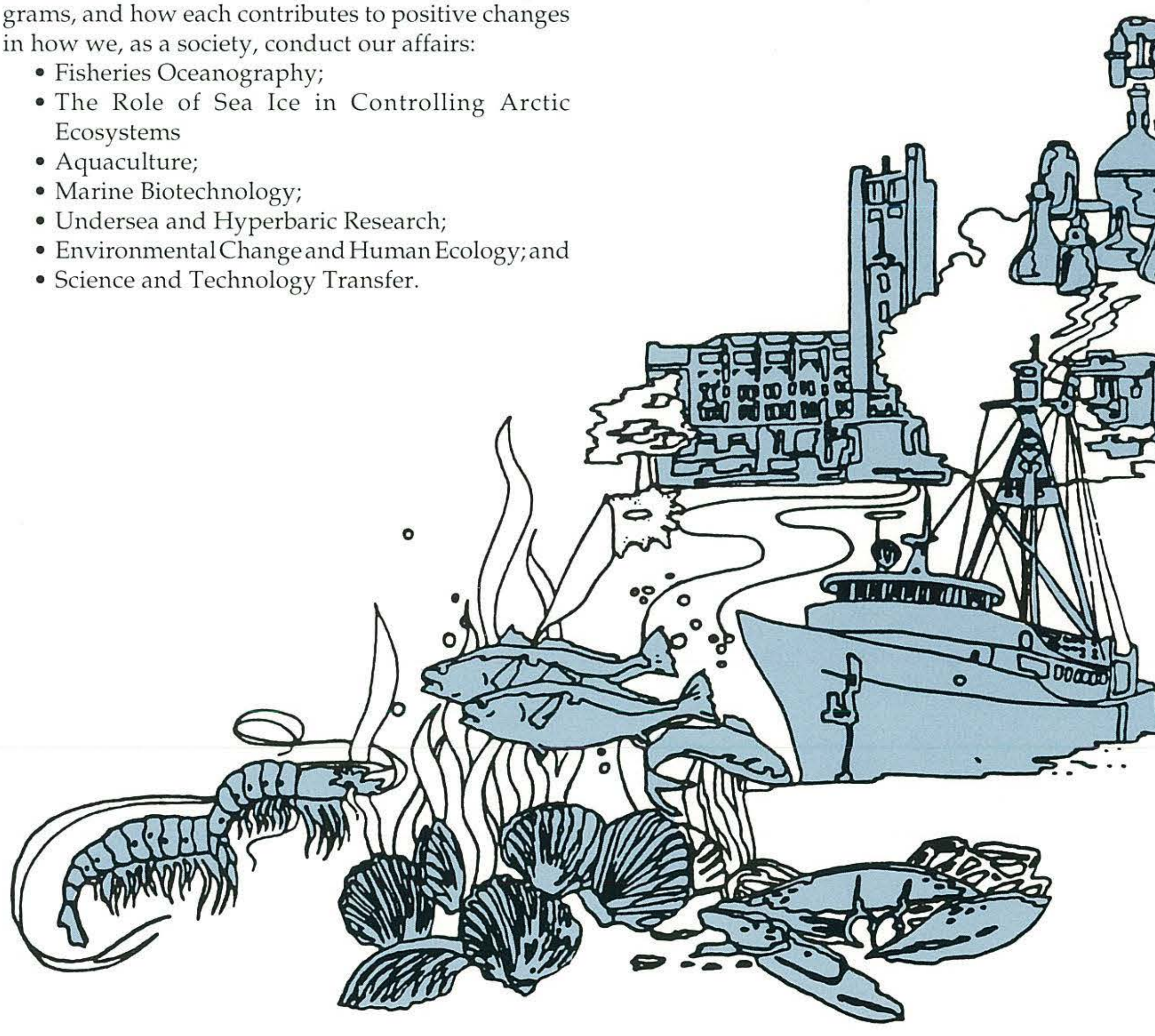
[2] Ibid.

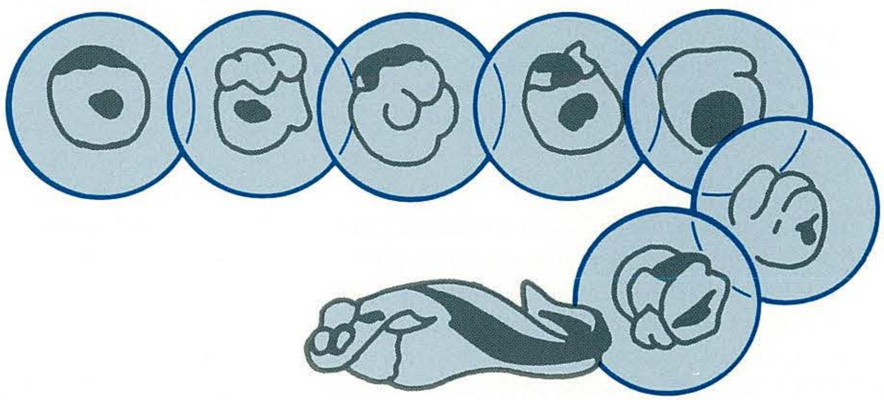
[3] Statistics from the National Weather Service.

culture, and develop modern biotechnology to produce new and improved products. Of equal interest is the capability of OAR's Environmental Research Laboratories to gather data, whether from the surface of the sun or the depths of the abyss, and then to transform it into useful information.

This section describes the following OAR programs, and how each contributes to positive changes in how we, as a society, conduct our affairs:

- Fisheries Oceanography;
- The Role of Sea Ice in Controlling Arctic Ecosystems
- Aquaculture;
- Marine Biotechnology;
- Undersea and Hyperbaric Research;
- Environmental Change and Human Ecology; and
- Science and Technology Transfer.





Fisheries Oceanography

Problem and Opportunity

The fisheries resources of the United States are, with a few notable exceptions, products of coastal ocean waters and adjacent estuaries. These resources support the nation's major commercial and marine recreational fishing industries. However, fish populations and communities fluctuate, sometimes substantially, from year to year, and to even greater extents on longer intervals (interdecadally). This variability, and our lack of knowledge of its causes, reduce the effectiveness of resource management, resulting in the economic dislocations so characteristic of fisheries.

Research Strategy

A major goal of fisheries science is the accurate prediction of the status of species for both short-term (inter- and intra-annual) and long-term (interdecadal) time periods. Most of the existing forecasting methods are known to be inadequate, particularly in regard to long time scales and radical population change. Short-term predictions are needed to better set harvesting levels and conditions (timing, place, etc.). Long-term predictions are essential in identifying the booms, collapses, and changes in community structure that cause the major dislocations in fisheries. Recruitment is the process by which young fish (or shellfish) are added to the adult or fished stock, and is, therefore, the essential process on which the continuity of a fishery depends. Evidence suggests that recruitment variability is intimately linked to the physical dynamics of the oceans and large-scale climatic fluctuations. Fisheries scientists throughout the world have identified recruitment fisheries oceanography as the most important topic in fisheries science, and the key to accurate predictions.

A research program on fisheries recruitment has not only the potential for improving fisheries management, but also for improving man's understanding of the linkages between the physical environment and the ocean's productivity.

Recruitment fisheries oceanography needs to address the following questions:

- What is the role of abiotic environmental variation in controlling survival of eggs, larvae, and juveniles?
- What is the role of food availability in controlling survival of larvae and juveniles?
- What is the role of invertebrate and vertebrate predation in controlling survival of eggs, larvae, and juveniles?
- What is the role of physical factors in transporting eggs or larvae to appropriate juvenile habitats, and in controlling predator-prey interactions?
- How do the above factors interact to affect total survival-to-recruitment?
- Does the relative importance of various survival mechanisms change within or among years?

There is general agreement among researchers that the program should focus equally on short- and long-term time scales, seek to determine factors promoting survival rather than accounting for various sources of mortality, and focus on comparing recruitment processes in a limited number of target coastal ocean environments (upwelling, fronts, continental shelves and banks, and large lakes).

Why Now?

Since the initiation of the Exclusive Economic Zone and its concomitant fisheries management responsibilities, fisheries oceanography has become a high priority. The first requisite of effective fisheries management, a way to accurately forecast stock size, is not available. Existing forecasting methods have been criticized for being inaccurate, unrealistic, oversimplified, and biased towards over-representing the effects of fishing.

Benefits

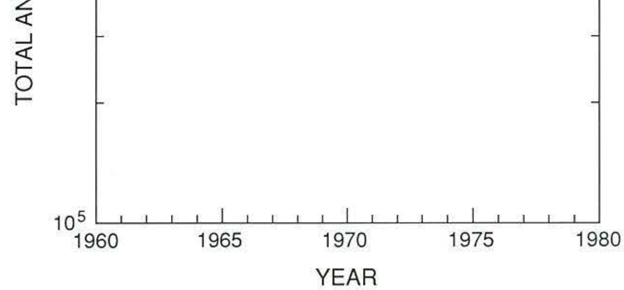
As a result of these activities, it should be possible to identify and efficiently monitor the environmental factors that are the best predictors of stock abundances. Improved understanding of the causes of population size and variation will enable the consequences of man's activities in coastal and marine environments to be evaluated. Such research should also lead to the prediction of major climate and oceanographic events, since it has recently been demonstrated that movement, distribution, and variation in recruitment of marine organisms are early indicators of such events. When we gain an understanding of the factors that control the size of fish and shellfish populations, it will be possible to determine how the actions of man affect these populations.

Interactions

The Fisheries Oceanography Program is the product of a joint planning effort of the Office of Oceanic and Atmospheric Research (OAR) and the National Marine Fisheries Service (NMFS). The program was developed by scientists representing the Environmental Research Laboratories (ERL), NMFS laboratories, and the academic community. As an essential component of NOAA's Coastal Ocean Program, recruitment fisheries oceanography will provide the bases upon which meaningful impact analyses can be made and monitoring schemes can be designed. Information on early life history of estuarine-dependent species is critical to understanding the relationship of estuarine habitat to fish productivity, a major element of the Estuarine Ecosystems Program.

To pursue this effort effectively, we need to employ satellite remote sensing and data buoys capable of providing oceanographic and weather information in real time. These tools will provide the temporal and spatial coverage required to conduct large-scale ocean experiments.

This program has been coordinated with the National Science Foundation's (NSF) developing Global Ecosystem Dynamics Program (GLOBEC) and could be pursued as a joint effort. Similar efforts at coordination have been initiated with the Office of Naval Research (ONR) program offices of Coastal Science and Biological Oceanography.



The Role of Sea Ice in Controlling Arctic Ecosystems

Problem and Opportunity

Sea ice exerts an influential control over the Arctic marine ecosystem. Its extent, formation, and melt are critical factors for the annual primary production cycle of the Bering Sea Shelf. Sea ice acts as a platform and habitat for mammals, and a substrate for the tiny plants that form the base of the food chain, supporting birds, shellfish, fish, and mammals. The ice-melt water stabilizes the sea and allows a strong spring pulse of food production, making the American Arctic one of the richest commercial fisheries in the world. The retreat of the ice edge through the Bering and Chukchi Seas is equal to fertilizing an area from Texas to the Canadian border and the Rocky Mountains to the Mississippi River. The Northern Bering Sea has recently been shown to have the world's highest primary production rates. Yet the critical pathways of energy flow from plankton to bottom organisms and then to commercial fisheries and mammals are not well understood.

Research Strategy

The proposed research will test the hypothesis that interannual variation of maximum ice extent and seasonal ice retreat account for the major year-to-year variation in the biological productivity of the Bering and Chukchi Seas. Elements of this study include:

- Reevaluation of existing biological and physical datasets, and initiation of a historical study using satellite and other remote-sensing data;
- Biological and physical oceanographic sampling along the ice edge over an eight-year period;
- Examination of the dynamics of primary production, and nutrient recycling and fluxes at the ice edge;
- Examination of benthic populations with respect to the vertical flux of particulate material;
- Examination of the relation of ice-edge primary production to the occurrence and timing of zooplankton and larval fishes and crustaceans;
- Research on the variation of high-latitude weather and its effect on ice extent, location, and timing;
- Study of sea-ice and oceanographic processes in coastal areas by *in situ* and remote-sensing techniques;
- Synthesis of field studies into models, and examination of fish and mammal population dynamics in the light of the expanded database on weather, sea ice, and oceanography;
- Reactivation of the Bering Sea ice model developed earlier, its extension to the Chukchi Sea, and its use to design sampling strategies; and
- Measurements of currents, nutrient dynamics, biological productivity, and particulate flux in the vicinity of Bering Strait during the ice melt-back.

Why Now?

Dramatic, largely unexplained changes are occurring in the Arctic system:

- The king crab and Tanner crab harvests have plunged since 1979 with serious economic impact. Other commercial species such as pollock are being heavily exploited;
- The northern fur seal population is declining rapidly (4 to 8% per year). All large baleen whale populations have been severely reduced and may not be recovering. The walrus population has become very large and is in danger of crashing. Sea-otter populations are increasing and competing with fishermen for shellfish; and
- Dramatic increases in marine growth and survival have been documented for salmon populations of the Bering Sea. Recent indications of an end to the boom in production of the past ten years have very serious economic implications for both commercial and subsistence fisheries.

Why NOAA?

NOAA, with its research capabilities, satellite imagery, environmental-data archives, and fisheries mandates, is well configured to address this important problem.

Understanding the role and dynamics of this process then will enable NOAA to provide resource managers the tools to perform closer management and to make more prudent fisheries-allocation decisions. The lead time that this approach yields will also enable commercial fishermen, seafood processors, and the relevant markets to make smoother adjustments to resource variation and consequently to better allocate human and capital investments.

Benefits

The ocean's productivity defines the limits on all marine biological systems. The work here will provide Arctic marine-ecosystem researchers with the basic information to estimate parameters of biomass, recruitment, exploitation, and competition. The answers to the important questions of production of groundfish, crabs, and salmon, and of the timing of salmon harvests, lie in understanding the dynamics of the Alaskan continental shelves.

In his April 1983 statement on United States Arctic policy, President Reagan emphasized that the United States has unique and critical interests in the Arctic region. In light of the region's strategic importance, the administration feels that the Arctic warrants priority attention by this country. A review of national issues and priorities for the Arctic Research and Policy Act has been completed by the Polar Research Board of the National Research Council and the US Arctic Research Commission. Based on these reports, the Interagency Arctic Research Policy Committee (IARPC) and the State of Alaska established an implementation plan to address the structure of ecosystems of the major Arctic shelves (Bering Sea, Beaufort Sea, and Chukchi Sea) through integrated programs with strong physical oceanographic and weather and climate components. They specifically identified the biological production and food-web dependencies in relation to physical features such as ice edges, polynyas, and hydrographic structures (such as fronts) as priority areas for research. The Arctic and Antarctic are less well known than any other area of comparable size. Most Arctic-rim countries, particularly the Soviet Union, possess Arctic technologies far more advanced than those currently available in the United States. Sponsorship of currently-neglected research in basic science is a necessary and proper function of the federal government, to fulfill national objectives in Arctic research.

Interactions

Research in the Arctic is by nature a cooperative effort. For the previous ten years, NOAA investigators have conducted joint research in the western Arctic with the Office of Naval Research, and NASA and National Science Foundation investigators. The Marginal Ice Zone Experiment, MIZEX-WEST, represented a large effort in the Bering Sea during 1983. In response to research priorities established by the Arctic Research Commission, the Interagency Arctic Research Policy Committee has established a plan and budget cross-cut for completing a joint program in lead and polynya dynamics, marginal ice-zone processes, ecosystem dynamics, Arctic-basin circulation, and shelf dynamics. The core programs are ONR's Leads program, use of the NASA synthetic-apperature radar (SAR) facility, NOAA's Ice-Edge Ecosystems Study, and related projects in NSF. Field efforts will scale up in 1991, coinciding with availability of SAR data for sea-ice studies.

Aquaculture: Seafood for the Future

Problem and Opportunity

Most traditional fisheries in the United States are being harvested at or near maximum sustainable yield, and commercial harvest of wild species has not increased significantly over the last ten years. At the same time, our demand for fish products is so great that we import much more than we export. In 1990, US fishery imports amounted to over 2.9 billion pounds of edible fishery products valued at $5.2 billion; exports totaled only $1.9 billion pounds valued at $2.8 billion, leaving us with a $2.4 billion trade deficit in edible fishery products (NMFS, 1990).

Aquaculture of high-demand aquatic species such as shrimp, lobster, and salmon offers a mechanism for reducing our dependence on foreign imports, while at the same time providing new industries, jobs, and products for US citizens. A doubling of US aquaculture production is expected over the next 15 years. Estimates of aquaculture production for the year 2000 are about 1,000 million pounds. Greater increases than these can be obtained if additional support is provided for technology development.

Research Strategy

For aquaculture to meet its potential contribution to our economy, the following research issues need to be addressed:

- *Physiology and Endocrinology*
  - Hormone control of reproduction,
  - Hormone control of growth, and
  - Blood chemistry as a diagnostic tool;
- *Genetics*
  - Selective breeding,
  - Gene transfer through biotechnology, and
  - Gene manipulation with chemical and mechanical means;
- *Disease Diagnosis and Control*
  - New vaccines for viral diseases,
  - Development of disease resistant strains, and
  - Evaluation and clearance of new drugs;
- *Aquaculture Engineering*
  - Improved water-reuse and recirculating systems,
  - Economical water-heating systems,
  - Better harvesting and processing equipment, and
  - Improved growout systems; and
- *Nutrition*
  - Clarification of nutrient requirements by species,
  - Improved broodstock diets, and
  - Artificial diets for larvae.

Successful US aquaculture will probably take the form of a highly intensive, high-technology industry that would take into consideration the special needs of culture under North American climatic conditions. Research topics such as those listed above require a long-term commitment and risk that discourage investment by industry. The OAR research strategy would keep these factors in mind when determining support for research.

Why Now?

Past research has shown the technical feasibility of culturing aquatic organisms, and several aquaculture-based industries are already successful. Significant advances in biotechnology and in engineering design have made possible more-reliable production of faster-growing species. Other countries are forging ahead of the US in the production of shrimp, mollusks, and finfish, and imports are increasing because of declining domestic fisheries production. The increasing demand for seafood by the American public ensures that imports will increase even more unless we increase support to the development of a US aquaculture industry. The next few decades will see a shift from wild domestic fisheries to aquaculture in the US, but the US must move quickly to be able to compete in the global market.

Why NOAA?

Within NOAA, the National Sea Grant College Program and the National Marine Fisheries Service (NMFS) have sponsored the bulk of aquacultural research in the past. Sea Grant has access to over 200 marine-science institutions and the top scientific talent in the field of aquaculture, especially in the area of marine and estuarine species. Many Sea Grant- and NMFS-sponsored aquaculture programs are already in place and simply require additional support to obtain the necessary information for the advancement of aquaculture in the US.

Benefits

Further development of aquaculture in the United States can lead to the following benefits:

- Reduce, if not reverse, the fishery-products foreign-trade deficit;
- Increase the supply of domestically-produced, top-quality seafoods;
- Provide a stable supply of seafood to the US seafood industry, particularly processors;
- Create new jobs and related industries;
- Improve the recreational and commercial potential of our marine waters;
- Augment our understanding of the life cycles of commercially and recreationally important species; and
- Develop protein-production technology for export to third-world countries.

With proper support, aquaculture could become a major economic opportunity employing tens of thousands of people and revitalizing farm and coastal economies. Norway, for example, expects to produce 80,000 tons of salmon and trout per year in the early 1990s, and to employ 100,000 people in its aquaculture industry. Aquaculture is a strategic area of the economy where investment will generate not only incremental gains, but will also foster changes in production several times larger than what exists today.

Interactions

Both Sea Grant and the National Marine Fisheries Service maintain close working relationships with the US Department of Agriculture (USDA) and the US Fish and Wildlife Service (FWS). Aquaculture extension agents are often co-sponsored by Sea Grant and USDA. The Marine Advisory Services of Sea Grant already have many aquaculture specialists that are working with industry, and as further technology is developed, this will be the mechanism used to reach the industry. With the USDA taking a stronger role in aquaculture, it will become increasingly more important for Sea Grant to coordinate its research effort with the new Regional Aquaculture Centers administered by the USDA, even though they are less research-oriented. This is already being done at the Washington level and more effort will be placed on coordination at the regional level in the future.

Sea Grant and the National Marine Fisheries Service have also played an important leadership role on the Joint Subcommittee on Aquaculture, which consists of representatives of all government agencies having an interest in aquaculture, and on aquaculture panels convened by the National Academy of Sciences. In addition, both organizations interact regularly with the National Science Foundation and AID on their aquaculture programs.

On an international level, Sea Grant has taken a lead role in technical exchange with Japan through the UJNR (United States-Japan Natural Resource Panel on Aquaculture). Technical-exchange agreements for aquaculture also exist between NOAA and France and Israel. There has also been interaction with China. Many Sea Grant Colleges also have strong international programs with many different countries and foreign universities.

Marine Biotechnology

Problem and Opportunity

Biotechnology is an important and growing sector of the nation's economy. It produces breakthroughs in science and technology almost monthly. Indeed, a recent poll for the US Office of Technology Assessment shows that 66% of all Americans believe that genetic engineering will improve life for everyone. Some analysts argue that the competitive position of the United States depends on developments in commercial biotechnology. Much of the basic research supporting the growth of this industry is long-term, fundamental, and of uncertain commercial value, and is, therefore, usually conducted by universities.

Heretofore, research in biotechnology has concentrated on use of terrestrial organisms and their biochemical components. Relatively little attention has been turned to the rich array of marine micro- and macro-organisms that are in great diversity and have been largely unexplored for biotechnological potential.

Nonetheless, marine organisms already have yielded a variety of useful bioactive substances of unique structure and function. Marine polymers are now important in commerce, and certain signal molecules from marine sources are providing clues for the design of future classes of therapeutic and diagnostic agents. Estuarine microorganisms are being used to treat industrial effluents and to decontaminate solid wastes. This is just the beginning: opportunities for research with broad ramifications for the national and international economy lie in the areas of natural chemicals such as polymers and pharmaceuticals, genetically-engineered plants, animals, and microorganisms, and services such as sensitive measurement with biosensors and control of biofouling and corrosion.

Research Opportunities

Here are several opportunities for marine research to advance science and provide the basis for new developments in biotechnology:

- ***Biochemistry and Pharmacology***
  Fundamental research on the biochemistry of marine organisms can identify useful new substances, particularly bioactive metabolites potentially useful in medicine and agriculture. Study of the structure, function, and mechanism of action of these compounds is especially important. Why do they work as pharmacological or medicinal agents? What is their role in nature? What insight can they provide to such issues as allelopathy, ecological relationships, biosynthesis, chemical communication, and biochemical aspects of symbiosis?
- ***Molecular Biology***
  Manipulation of the genetic complement of plants, animals, and microorganisms to produce chemical products and diagnostic reagents, to control diseases of marine organisms, to detoxify

wastes, and to enhance the growth and competence of aquacultural species. Of particular interest is the enhancement of species vigor and productivity through transgenic procedures, but few procedures for manipulating the genetic complement of marine species or for expressing new genetic information have been attempted. Other opportunities include applying DNA and antibody technology to developing simple, sensitive, and specific assays for human pathogens in seafood, especially mollusks, and in their surrounding waters.

- *Biochemical Engineering*
To benefit from useful substances identified in marine organisms, industrial production on a large scale must follow. For many products, biochemical engineering information will be needed to develop biosynthetic methods, and to determine the yield potential of individual products. As examples, the feasibility of photobioreaction as an alternative in producing chemical feedstocks, and the use of marine biota as sources of fine chemicals and industrial chemicals such as polymers, should be investigated. The biochemical competence of marine microorganisms or cells of higher organisms such as algae, sponges, and coelenterates might be exploited in bioreactors, yet the science and technology for culturing such cells and controlling their primary and secondary metabolism are lacking.
- *Microbiology and Phycology*
There are huge gaps in marine microbiological knowledge. Basic studies in microbial physiology (the relationship between metabolic capability and the environment) and taxonomics are essential in this neglected area. What little is known is intriguing. For example, through mediation of non-photosynthetic sulfur bacteria, sulfur compounds can be oxidized and chemical energy reclaimed for conversion of carbon dioxide to organic matter of value. Nitrogen-fixing bacteria and the anaerobic bacteria near hydrothermal vents also have unique biochemical properties. There is evidence that marine microorganisms, like their terrestrial counterparts, will prove to be rich sources of antibiotics. Biofouling and marine corrosion, causing serious economic losses to marine industries, are dependent in part on microbial mediation of chemical and electrochemical processes. Research is needed in these areas, and there is a range of unexplored possibilities for further exploiting marine macroalgae as sources of polymers, fatty acids, and fermentation products.

Why Now?

Enhanced investment in marine biotechnological research is critical because:

- The low level of investment in such research has so far yielded promising results;
- Greater phylogenetic and species diversity of marine organisms as compared to terrestrial organisms, and their relatively unexplored chemical and biological capabilities, indicate potential for industrial applications;
- Recent progress in gene splicing and recombining DNA into new sequences allows us to exploit the biochemical capabilities of organisms more quickly and efficiently; and
- Increasing our international economic competitiveness is a national priority.

The US needs to stay abreast of similar developments in other countries. Japan's Ministry of International Trade and Industry, through a consortium of government, industrial, and academic interests, is establishing a marine-biotechnology institute whose objective is to create the first full-scale marine biotechnology research and development base in the world. The gross costs for the initial 10 years of the project are estimated at 35 billion yen (more than $200 million). This is a clear challenge for the US to maintain its global competitive position.

Japanese researchers at the Tokyo University of Agriculture and Technology recently developed methods that induce marine algae to produce large amounts of the enzyme superoxide dismutase (SOD). SOD is a natural antioxidant that converts oxygen radicals into ordinary oxygen molecules. It can be used in a range of medical, cosmetic, and food applications. Market analysts have reported a potential annual market for SOD in the United States of $700 million.

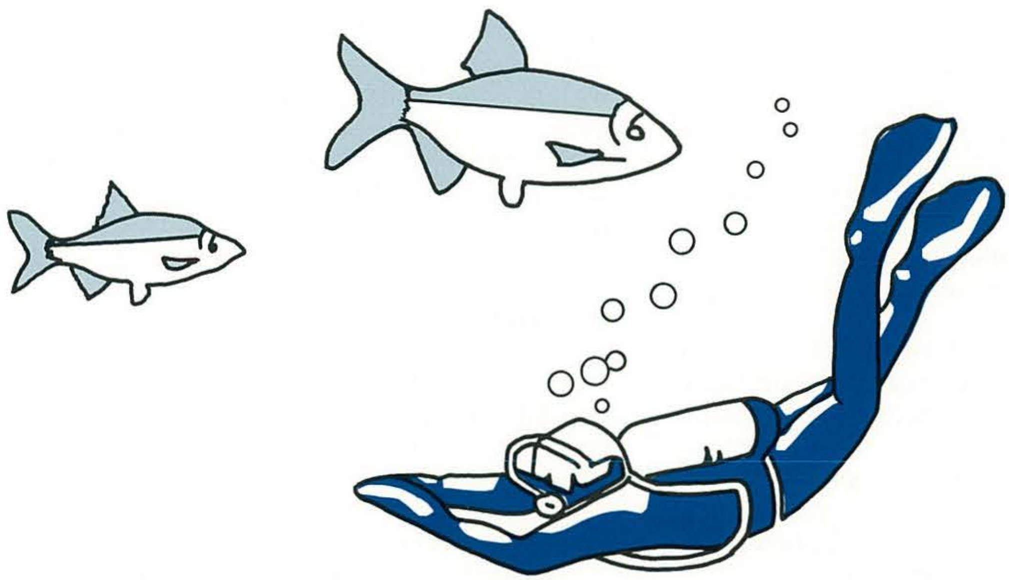
Benefits

The ramifications of a fully-developed research effort in biotechnology are broad. The development of new marine products and services, and development of domestic substitutes for foreign products, have the potential for decreasing the US trade deficit. The use of marine organisms in industrial processes and in producing fine chemicals and chemical feedstocks can provide employment, decrease production of toxicants, and reduce dependence on petroleum. Increased availability of high-quality seafood through aquaculture, and greater food safety for seafood products, are achievable goals through techniques of biotechnology. Control of marine pollution and new methods of waste disposal through the use of marine organisms also are within our grasp. Biotechnological developments from marine resources will require purposeful and fundamental research over a long period in several scientific disciplines. Much of the required research is appropriate for the academic setting; however, transfer of knowledge between universities and industry, and greater use of interdisciplinary collaboration and planning are essential.

Interactions

NOAA's program of research in support of marine biotechnology is the product of planning in the Office of Oceanic and Atmospheric Research (OAR). The research is conducted in the National Sea Grant College Program, and is coordinated with related programs at the National Science Foundation (NSF), the National Cancer Institute (NCI), and the Office of Naval Research (ONR). For example, the National Sea Grant Office, NSF, and ONR sponsored a workshop to examine opportunities for applying biotechnology in elucidating ocean processes.

OAR also has pursued informal interactions with academic and industrial scientists in Japan, who are engaged in or planning for marine biotechnology, as a result of a NOAA/NSF sponsored assessment of marine biotechnology in Japan. Other international interactions are anticipated as a result of the Second International Conference on Marine Biotechnology held in Baltimore, MD, in October 1991.



Undersea and Hyperbaric Research

Problem and Opportunity

During the past two decades, major advances have been made in our knowledge of the oceans and the marine environment. The foundation for these advances, and the assurance of future progress, is the availability of advanced technology which permits researchers to better understand the three-dimensional structure of the global ocean and its benthic boundary layer. Ultimately, the most significant way to investigate marine processes is to place the investigators under the sea at the site of these interactions.

Our nation must continue to develop research programs and the technological capability to understand more fully the processes governing variability over the entire depth of the world's oceans. Our ability to predict and respond to global ocean changes will be based on our ability to understand, develop, and protect the oceans on a global scale. Prediction requires that observation of natural patterns be integrated with knowledge of the processes governing system dynamics. Undersea research and technology, complemented by traditional surface-based oceanographic sampling techniques, will enable us to sample, measure, and ultimately understand the marine environment and the processes governing stability and change in this global system. Of particular importance are those processes governing interannual variation in the recruitment of marine organisms, transport and fate of nutrients and contaminants, and the global-ocean chemical budget. Cross-cutting all these areas is the need to improve safe access to the marine environment for investigators as well as commercial and sport divers.

Research Strategy

During the next ten years, undersea research must focus on several areas to improve our understanding of the global ocean and to enable us to predict and respond to its change. Research priorities include:

- *Productivity and Habitat Characteristics*
  - Processes governing variation in biological productivity;
  - Structure and function of marine and lacustrine food chains; and
  - Factors controlling interannual variation in recruitment.
- *Coastal Ocean Processes*
  - Processes governing the behavior and fate of fine-grained particulate matter;
  - Factors affecting nutrient cycling and enrichment; and
  - Conditions responsible for the development of anoxia or hypoxia.
- *Pathways and Fate of Materials in the Ocean*
  - Role of particulates in transporting pollutants;
  - Biological and chemical transformation of material in the water column, at the sediment-water interface, and in sediments; and
  - Effect of material on organisms of economic value or of importance in the food chain.

- *Global Ocean Processes*
  - Processes governing global ocean chemistry, biology, and geology;
  - Paleo-oceanographic history of ocean and climate processes;
  - Ocean lithosphere and mineral resources;
  - Evolution and structural framework of continental margins;
  - Tectonics and structure of mid-ocean ridges and basins;
  - Chemical and physical evolution of ocean crust;
  - Transport and fate of marine sediments; and
  - Geologic and environmental history of the oceans.
- *Submersible Platform Technology*
  - Develop and deploy technology to increase productivity of undersea investigations; and
  - Enhance access to the deep sea.
- *Diving Safety and Physiology*
  - Enhance diving safety and capability;
  - Evaluate new diving technology;
  - Improve management of, and emergency medical response to, diving accidents; and
  - Determine the physiological effects which limit diving.

Why Now?

Conventional technology has facilitated many advances in marine science. However, we are now at a point at which our knowledge of processes governing ocean and climate dynamics requires fine-scale measurement and observation. This can only be obtained with precise control over sampling and with the ability to conduct manipulative experiments over time and space in a generally hostile environment. *In situ* research is the only method available to achieve this requirement for fine-scale measurements and experimentation.

Why NOAA?

In 1980, an agreement was reached between the Department of Commerce Office of Management and Budget (OMB) and Congress that created one focal point for the support and conduct of undersea research for the entire US civilian scientific community. This agreement established the National Undersea Research Program at NOAA, the federal agency with comprehensive ocean-research responsibilities guided by civilian scientific and economic interests and needs. To fulfill NOAA's ocean mandate requires the capability to explore, sample, and sense the full range of the global ocean. This capability includes *in situ* access to the ocean environment, and is only available to the civilian scientific community through NOAA's National Undersea Research Program (NURP).

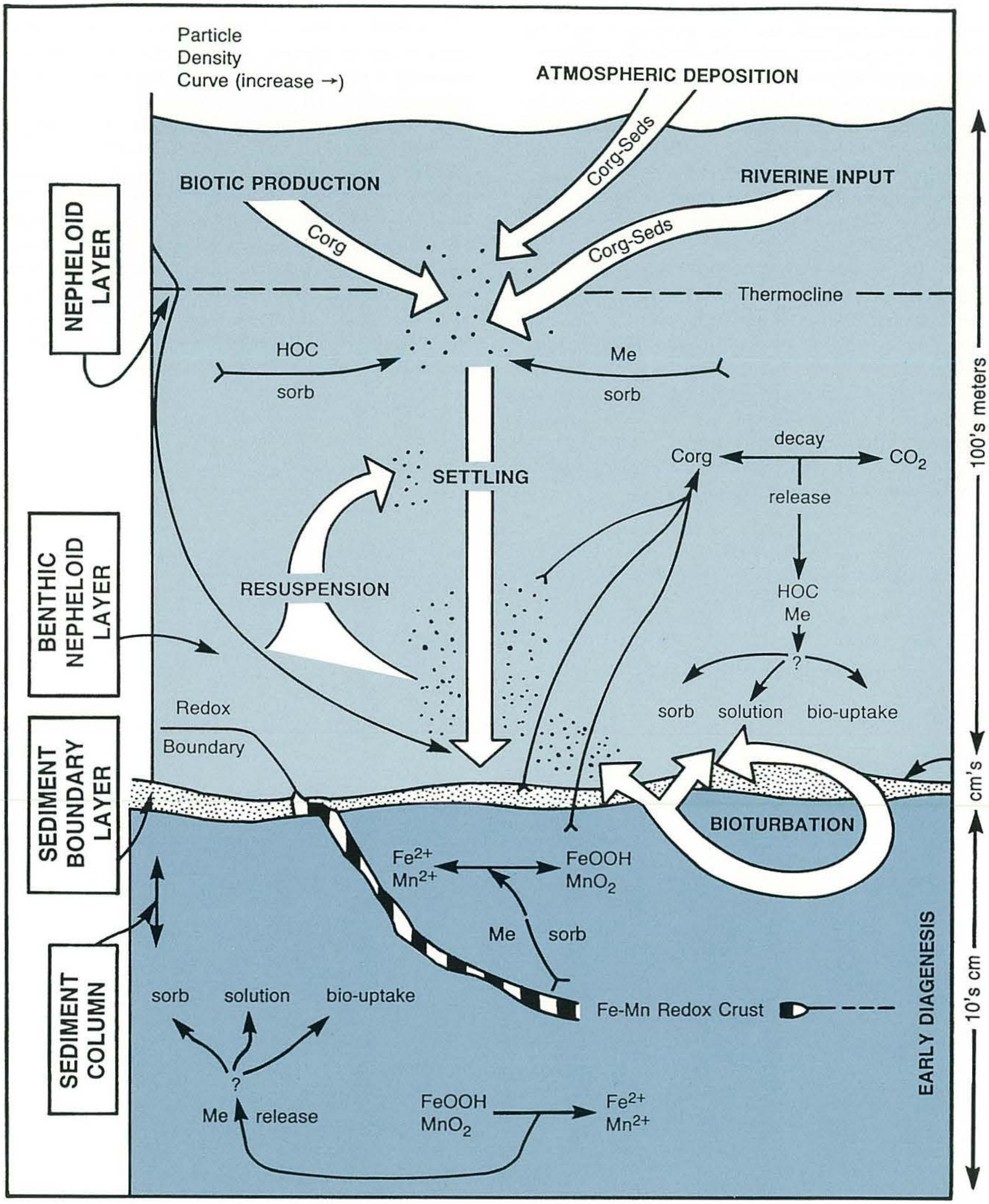
Benefits

Undersea and hyperbaric research will improve our ability to understand the basic processes which govern marine ecosystems and to develop a predictive capability to enhance management of the global ocean. Specific benefits are:

- Development of a predictive capability to improve management of marine resources through a better understanding of the causes of natural variation in biological productivity, composition and function of marine food chains, and the factors controlling recruitment;
- Ability to predict the carrying capacity of marine ecosystems and their ability to absorb waste and pollution safely;
- Prediction of ocean and climate changes caused by human production of compounds such as carbon dioxide, and improved procedures for managing other anthropogenic, environmentally-harmful materials;
- Prediction of global climate variation with the possibility of avoiding the often-tragic human consequences of natural disasters;
- Improved ability to forecast tectonic activity as well as the source and location of mineral resources;
- Improved access to remote or hostile areas of the ocean in a timely manner, with enhanced capability to collect samples *in situ*; and
- Improved diving capability and safety.

Interactions

Interaction between NURP and the marine community occurs in a variety of ways, in intersecting spheres representing international, national, and regional foci for programs. The single point of contact for international and national activities is the national office of NURP. For domestic projects with a regional focus, the principal point of contact is the appropriate undersea research center. In each sphere, activities involve joint planning, funding, and execution of



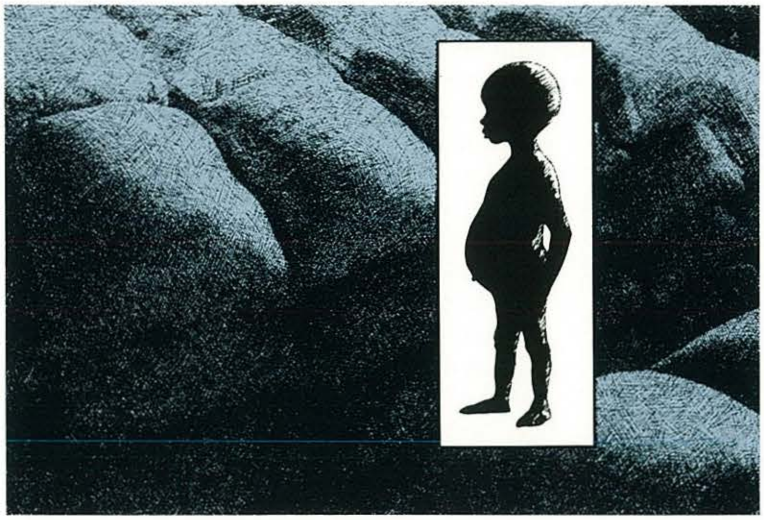
NURP-sponsored research in Lake Superior investigated the fate and transport of organic pollutants. The lake bottom was found to be highly enriched in certain organic contaminants, such as PCBs. The adsorption of contaminants onto particles in the water column, followed by rapid settling of the particles to the lake bottom is a major control on pollutant behavior in Lake Superior. (Diagram courtesy of Dave Long, Michigan State University.)

the approved project. Scientists participating in approved projects come from the academic, corporate, and government communities.

In the international sphere, NURP operates under formal agreements for cooperative research with agencies of the governments of France, Germany, Israel, and Japan. Agreements between other nations are being negotiated. To date, scientists from 12 countries have, in one way or another, taken part in approved research projects.

On the national level, NURP's longest-standing formal cooperative agreement is the one with NOAA, the National Science Foundation, and the Office of Naval Research. It provides for joint funding of the DSV ALVIN. Other cooperative activities with agencies occur on a project-specific basis for a definite time span. Examples include the US Naval Medical Research Institute and the National Aeronautics and Space Administration. In addition, NURP occupies a position on several national committees.

The bulk of research and supported field operations occur at specific selected sites. Because this research is process-oriented, the field site is usually representative of a geologic, oceanographic, or ecologic region. Research in those regions is managed by the National Undersea Research Centers, which provide access to the research community, especially that in the nation's university systems. While the largest number of investigators over time are from US academic institutions (approximately 100), a significant number come from local, state, and federal government agencies (about 30) and non-academic institutes (about 40). More than 3,000 persons from this community have brought their skills and talents to research in the sea and on the sea floor.



Environmental Change and Human Ecology: Social Sciences

Problem and Opportunity

Americans are increasingly aware of environmental issues and place them high on the public agenda. The environmental effects of our technology-driven standard of living are clearly visible. On a global scale, we see climate changes possibly associated with the greenhouse effect, the potential for sea level rise, and problems associated with acid rain. On the microscale, humans have to deal with diminished fish stocks, closures of shellfish beds, declining wildlife habitat, and increasing toxics in the water column. Americans are demanding that the causes of degradation and the resultant health and ecological impacts be addressed vigorously.

However, we know little more than pieces of the answers to many of the looming environmental issues. And too often, we are inclined to treat environmental issues as though they were isolated from our economic, legal, social, political, and cultural institutions. Fortunately, we can turn to the social sciences to help understand humans and their institutions, value systems, and behavior.

Social scientists—economists, anthropologists, legal and policy scholars, historians, geographers, and sociologists—provide the human-ecology perspective from which to view environmental change. Their analytical constructs, such as economic efficiency, distribution effects, social adjustment, legal liability, community values, and common-property theory, add a different viewpoint to environmental management to that brought by the natural-science disciplines such as biology, geology or chemistry. These insights about how social values and institutions influence human behavior can be integrated with natural-science paradigms to understand better how anthropogenic activities alter ecological systems and how these changes will affect human populations.

Research Strategy

The inevitability of resource scarcity, and humankind's capacity to affect its environment globally, compel vigilance over our marine resources. The call for intervention will intensify. It appears that the United States, and other post-industrial nations, will deal with this challenge through design and clarification of property rights and other innovative means of governmental control over the resource base. The necessary question for social scientists is, "What lessons have been learned from our perspectives that will shed light upon the directions we are headed?" In the face of resource scarcity and degradation, the issue of how we are going to allocate and use our environmental assets is the principal issue of the future—perhaps replacing military security or economic development as the most pressing issue facing the global community.

The forcing mechanisms described above will drive a set of theoretical and applied-social-science issues to the forefront. We need to understand the processes that influence the following topics:

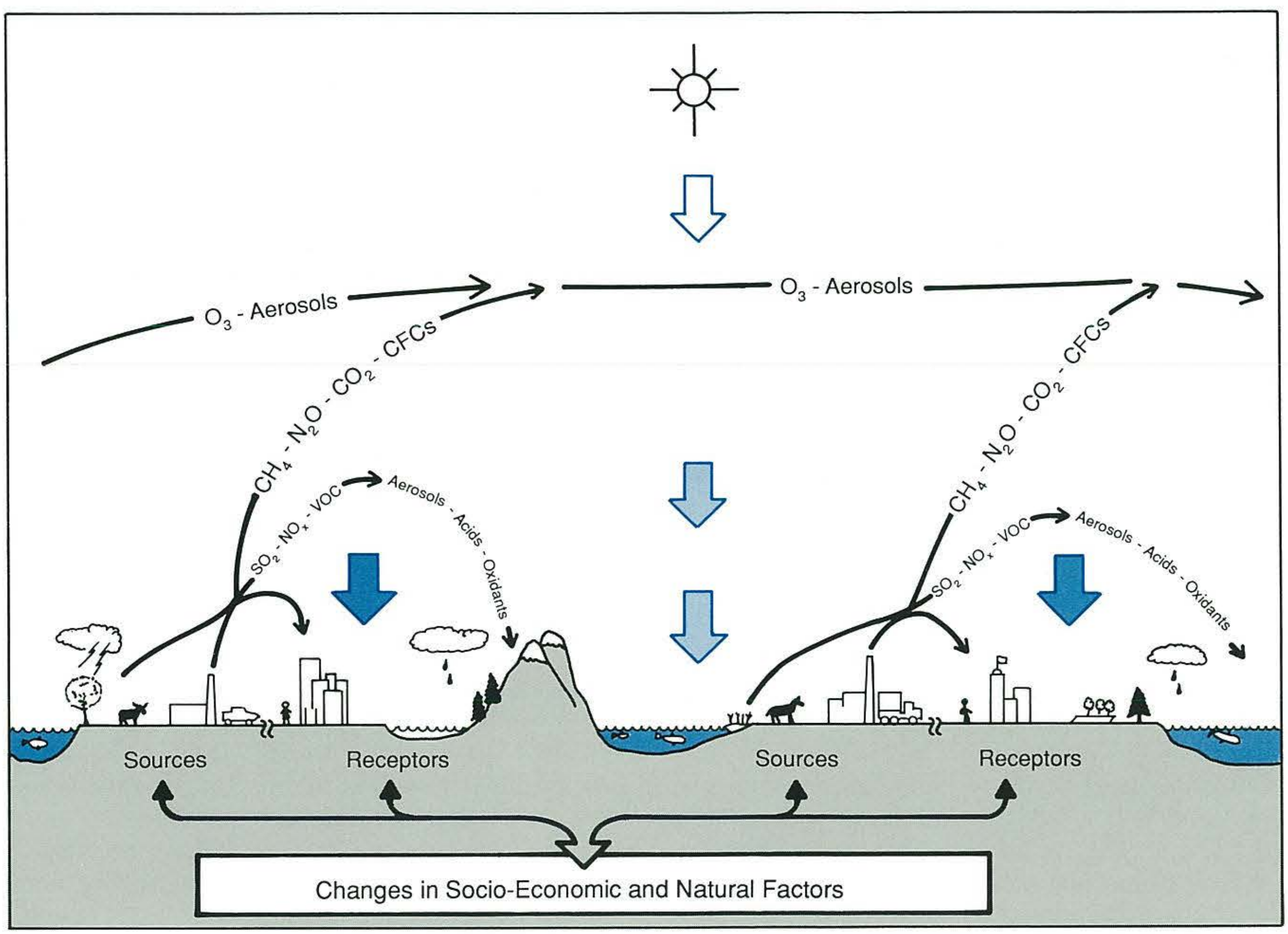
Productivity of Marine Industries

- The long-term outlook for economic and social development of marine-resource-dependent industries, including:
  - Aquaculture;
  - Commercial fisheries and seafood processing;
  - Seabed mining;
  - Offshore energy;
  - Water-borne transportation;
  - Marine biotechnology; and
  - Coastal recreation and tourism.
- The political economy and social consequences of scientific and technological innovation; determinants of productivity and competitiveness of marine industries.
- Impacts of national economic and international trade policy on marine industry performance.

Dynamics of Property Rights in Ocean and Coastal Space

- Effectiveness and effects of legal property rights, such as limited-entry and privatization regimes, across the whole spectrum of ocean and marine resources, including:
  - Over-fishing;
  - Coastal waterfront development and displacement;
  - Beach and water access;
  - Estuarine and coastal pollution discharge;
  - Ocean dumping;
  - Aquaculture leasing;
  - Sea level rise; and
  - Seabed mining claims.
- Conditions under which communally-managed resources are viable.

The Complex Web of Atmospheric Chemistry



Resources of the Exclusive Economic Zone (EEZ)
- Economic significance to the United States of the resources located within the vast 200-mile offshore EEZ; and
- Impact of regulatory regimes and economic-development strategies on the investment climate and resource-use efficiency.

Resource Allocation and Interest-Group Conflict
- Efficient and socially appropriate mechanisms to allocate marine resources such as fisheries, coastal lands, and seabed minerals; and differential effects on occupation or interest groups;
- Benefits from the management of marine resources and the regulation of environmental risks;
- Regulatory costs, including public outlays and the distributional effects of individual and industry compliance costs; and
- Interest-group dynamics, coalition building, and responses to public policy.

Water and Coastal Land Management
- Land-use issues related to water-quality and waste-management problems in coastal areas; and
- Socioeconomics of ocean disposal of wastes and hazardous materials, and the design of market incentives for pollution abatement and environmental improvements.

Non-Market Benefits From Marine Resources
- Economic, social, and cultural value derived from the use of marine resources which are not traded in markets—marine recreation resources, wetlands, habitat preservation, and aesthetic environmental quality.

Why Now?

Since environmental problems are inherently rooted in the economic, legal, political, and sociocultural structures we build, a look at social trends portends important consequences and changes in marine and environmental resource use:
- Increasing resource scarcity—the trend of diminished fisheries, wetlands habitat, clean water, areas for waste disposal, and recreation assets;
- Growing conflicts over resource allocations—heated disputes between recreational and commercial fishermen, seafood and oil interests, environmentalists and coastal developers;
- Greater demographic pressure on coastal areas—changing the nature of coastal communities, increasing property values, displacing water-dependent industry, tourism development;
- Rising concern over health risks and safety issues—clean water, safe seafood, water recreational safety; and
- Technological change and its effects on socioeconomic institutions—development of aquaculture or husbandry, the introduction of marine biotechnology.

These are opportunities for the social sciences. Fundamental questions of resource management involve people, and we need to understand the relationships of social, cultural and economic factors to resource management and other scientific issues.

Why NOAA?

NOAA has both a de jure and a de facto interest in the social sciences. NOAA has management and trustee responsibilities for marine fisheries and mammals, seafood quality, marine and estuarine sanctuaries, coastal-zone management, and deep-seabed mining. For example, the Magnuson Act, the enabling legislation for fisheries management, requires NOAA to consider the socioeconomic impacts of fishery regulations. The National Sea Grant College Act calls for a multidisciplinary NOAA program with universities to develop marine resources, specifically mandating social-science research and technology transfer with as much insight into social groups and social process as possible. NOAA must also handle sensitive issues like marine mammal protection, the regulation of fishery and seabed-mining industries, coastal land management, and designation of marine and estuarine sanctuaries. Each of these is essentially a human activity and has socioeconomic implications and impacts. NOAA's mission is to provide the knowledge base needed to act responsibly in these areas.

Benefits

Collectively, human activities cause important alterations in the global environment, and we now know that the assimilative capacity of the oceans and atmosphere is limited. There are likely to be increasing mandates for conservation and restrictions on resource use, all of which involve social groups and human behavior. If we do our homework now, we may be able to mitigate potential adverse socioeconomic distributional effects which threaten the nation's will to face up to its environmental problems.

Interactions

The research strategy described above is carried out by university investigators largely through the National Sea Grant College Program. Sea Grant is the only federal program specifically mandated to support social-science research with respect to marine and coastal issues. Within NOAA, Sea Grant coordinates with the National Marine Fisheries Service and the Office of Coastal and Resources Management, who support mission-oriented social-science research such as planning and coastal management, and the economics and sociocultural aspects of fisheries management. NOAA also coordinates with other federal agencies such as the Department of the Interior and the National Science Foundation.

Science and Technology Transfer

Problem and Opportunity

One of the greatest challenges to a federal research organization is the transfer of new information, technology, and research results to the operational components of the agency; to the universities for inclusion in course work or extension activities; and to the private sector for providing better products and services to the public. In OAR, this challenge is met through performing cooperative research and development with the operational agency components, state and local groups, and university researchers; through publishing in scientific, technical, and trade journals; through participating in consortia, workshops, and roundtable meetings on national, state, and local levels; by preparing written, verbal, and visual documentation on state-of-the-science of various environmental issues for decision makers; by holding lectures and training classes; and, in some circumstances, through working one-on-one with potential users.

The Congress demonstrated the importance of technology and information transfer by enacting the National Sea Grant College and Program Act of 1966 and the Stevenson-Wydler Innovation Act of 1980. The National Sea Grant College and Program Act set up the Marine Advisory Service to transfer scientific and technical information developed at Sea Grant institutions to the user community. The Stevenson-Wydler Innovation Act of 1980 was modified by Public Law 99-502 in 1986; this change concentrated on federal and private-sector cooperative research agreements and on federal patents, two central mechanisms for technology transfer. In OAR, technology and information transfer is practiced at many levels through formal mechanisms such as the Marine Advisory Service, Joint Institutes, NOAA management teams, other-agency contracts, publications in scientific and popular press; and through informal arrangements between individuals.

Every coastal and Great Lakes state except Pennsylvania has a Sea Grant College Program associated with its university system and each Sea Grant Program has an outreach component (Marine Advisory Services and Communications) that deals with information and technology transfer. The focus of the Sea Grant outreach is at least three-fold: (1) to enhance public safety in regard to marine hazards, (2) to promote development of the marine economic sector, and (3) to contribute to wise use of marine and Great Lakes resources. As an example, the presence of advisory service personnel in local marine communities has enabled an immediate community response to oil spills, and facilitated hurricane protection. They provide information on development of new seafood and aquaculture products and on the marketing of these products, often stimulating foreign trade. They are providing leadership to the Great Lakes community in developing coordinated strategies for controlling the impact of recently-discovered and potentially-devastating exotic species that have entered the lakes and are thriving there.

Seven Joint Institutes have been established between NOAA laboratories and nearby universities. These Institutes are the sites for accomplishment of research on NOAA-mission-related problems by NOAA scientists and university researchers and instructors. The technology and science output of these collaborative programs are immediately available for inclusion in university classrooms, and the technology developed in NOAA is made available to university faculty and students for training purposes. Examples of this technology transfer are the access of university students to the PROFS workstations (the prototype of the NWS Automated Weather Information Processing Systems), to Doppler radar displays (prototype of the NEXRAD radars), to wind-profiler datasets, to ocean workstations, and to the data and models being developed in various scientific programs such as VENTS, Climate and Global Change, and Fisheries Oceanography.

OAR has implemented several high-level management teams to ensure that technology and science development programs are related to the needs of the operational arms of NOAA. Examples of such guidance teams are the 'troika' that provides input to the management of the PROFS program, the Profiler Advisory Committee that provides direction for the wind-profiler program, the Sea Grant Review Panel which oversees the overall direction and scope of the Sea Grant Program, and the Climate and Global Change Advisory Program. These advisory groups provide critical input into the direction of OAR research and development to ensure that technology developed in the research laboratories and cooperating academic institutions can and will respond to the needs of the larger scientific community and of the decision makers and user groups in the private and public sectors.

In an average year, OAR publishes or funds research that results in hundreds of articles in the scientific and popular press. Subjects vary from the forecasts of global climate change by complex numerical models to the calibration process used to measure atmospheric increase in greenhouse gases; from the ecology of wetlands to forecasts of pollack stock in the Gulf of Alaska; and from hazards confronting the public safety provided by localized catastrophic weather phenomena to developing international markets in biotechnology.

Research Strategy

The OAR strategy is to foster technology and information transfer at every level of management, by:

- Funding offices whose primary responsibility is technical transfer;
- Use of multi-line organization-management teams and external advisory committees to plan and implement new technology development and scientific programs;
- Increasing cooperative programs with universities, companies, and other agencies;
- Expanding use of formal agency-private sector arrangements and legal mechanisms to transfer science and technology to universities, small business, and individuals; and
- Increasing the capability and efficiency of the Marine Advisory Service through the use of the best available communication technology systems, to handle increasingly large amounts of technical information, and maximize their audience.

High-level management teams, including outside experts, should be established to provide guidance for the development of the next-generation upper-air sounding system, for the implementation of the Climate and Global Change Program, for guidance in the Coastal Ocean Program, and for the development of an improved NOAA Data-Management System to ensure that these programs meet the needs of the agency and of outside users.

Cooperative programs should be expanded in the Great Lakes, and steps taken to ensure that research conducted in the Lakes is relevant to, and used by, decision makers responsible for maintaining the quality and quantity of water in the Lakes system. Cooperative programs in the coastal areas should be expanded and steps taken to ensure that NOAA, universities, and the local decision makers receive the highest priority and quality information for maintaining the quality of the nation's estuarine systems.

Formal NOAA-private sector arrangements, such as joint development programs, should be encouraged to reduce the cost of developing technology and to move technology rapidly into the marketplace. Technologies such as remote sensing, satellite sensors, and advanced measurement systems are potential areas of opportunity. Mechanisms such as patents, cooperative agreements, and the Small Business Innovative Research Program (SBIR) are vehicles for such development.

The Marine Advisory Service is small (approximately 300 professional agents and specialists) and the potential audience for the huge quantity of new and exponentially-increasing information is extremely large. State-of-the-art information-management and communication and education systems such as CD-ROM technology and satellite teleconferencing must be used.

Why Now?

NOAA is entering an era when economic and environmental issues are at the forefront of government and public attention. Climate and global change, coastal and estuarine pollution, the ozone hole, drought and severe storms, and increasing multiple use of limited marine resources are the economic, political, and social issues of the day. Recognition of NOAA as an integral player in the resolution of these issues is increasing. The time to address the transfer of new technologies, products, and management strategies is when the products and services are being developed; which is now and during the next few years.

Why NOAA?

The demand for NOAA products and services is increasing rapidly as environmental issues gain more attention in the US and around the world. Congress and the Executive Branch are both interested in technology transfer, competitiveness, and intellectual property. Technology transfer requires both a viable product, a transfer mechanism, and a market. An open technology-transfer system provides a mechanism for setting priorities for these products and services, and ensures that when these products and services are developed they will meet the requirements of the users and of the marketplace. NOAA possesses such mechanisms and has used them successfully in the past. Recognition of its accomplishments by its many clientele groups is widespread, and evidence for future contributions.

Benefits

The benefits of technology transfer can be measured by the number and cost of products that reach the market place, the number of common scientific problems solved, the quality and relevance of the scientific information that is published and used by decision makers, and the performance of NOAA in meeting its mission.

Interactions

OAR has several formal arrangements with many state and federal agencies that permit NOAA experts to work directly on their agency programs; and with private-sector companies that permit the cooperative development of technology that can be used by either side. NOAA scientists work on the EPA Acid Rain Program, on the DOE transport and deposition programs, and on DOD remote-sensing programs. These efforts allow the transfer of technology and scientific information between NOAA and their partner agencies. Instrument-development programs between ERL and private companies have resulted in commercial wind-profiling systems, meteorological sensing buoys, wave-prediction models, acoustic echosounders, gas-response thermometers, digital ionsosondes, water-chemistry filters, sensors on NOAA satellites, and other products. By transmitting scientific biological information to the various Fishery Management Councils, NOAA and Sea Grant scientists contribute to development of appropriate resource-management strategies.

Marine Advisory Service interactions are particularly diverse, and include community leaders and decision makers; most resource-management agencies, councils, and commissions in the country dealing with coastal and Great Lakes issues; individual businessmen and entrepreneurs, educators at all levels; and a wide array of marine industries including ports, seafood processors, and marine trades.