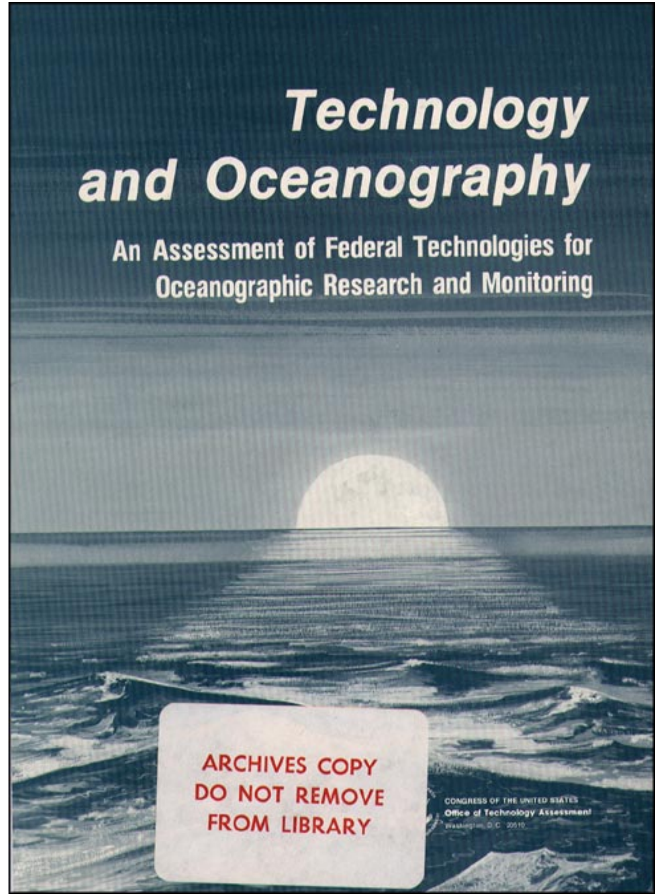
*Technology and Oceanography: An Assessment of Federal Technologies for Oceanographic Research and Monitoring*

June 1981

NTIS order #PB82-101718



Library of Congress Catalog Card Number 81-600086

For sale by the Superintendent of Documents,
U.S. Government Printing Office, Washington, D.C. 20402

# Foreword

This assessment of technologies which are supported by the Federal Government for oceanographic research and monitoring was prepared at the request of the Senate Committee on Commerce, Science, and Transportation. It was requested to provide Congress with a useful structure to evaluate both ongoing ocean programs and new initiatives, especially those that involve costly and complex technologies.

The report describes the status of technologies in use today, such as research ships, submersibles, buoy systems, aircraft, and satellites. It analyzes future problems and opportunities and examines the Federal agencies and programs charged with conducting oceanic studies and providing the necessary management and hardware systems. It analyzes selected national programs directed toward conserving and managing marine fishery resources, developing a new oceanographic satellite system, investigating the geology and possible resource potential of the continental margins beneath the deep ocean, and developing a future climate-prediction capability.

OTA received valuable assistance from contractors, individual consultants, working groups, and many expert advisors in the preparation of this assessment. Each of the Federal ocean agencies also provided valuable descriptive material and useful review comments. An advisory panel of experienced oceanographers and technology specialists from academia and industry reviewed and critiqued the final draft report.

A comprehensive overview and analysis such as this report has not been available in the past because the Federal ocean effort is distributed among so many diverse agencies. A large number of productive and promising oceanographic programs require substantial investments in technology to address critical national concerns. Choices about the future course of these programs and the technologies to support them will undoubtedly require careful congressional review.

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# Acknowledgments

Many individuals and groups have assisted in various aspects of this study, each making a valuable contribution to the information and analyses assembled and presented here. While all contributors have not agreed with **all** aspects of the entire report, all views on major issues are presented. Substantial contributors include:

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**Department of Energy**
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**Environmental Protection Administration**
**National Aeronautics and Space Administration**
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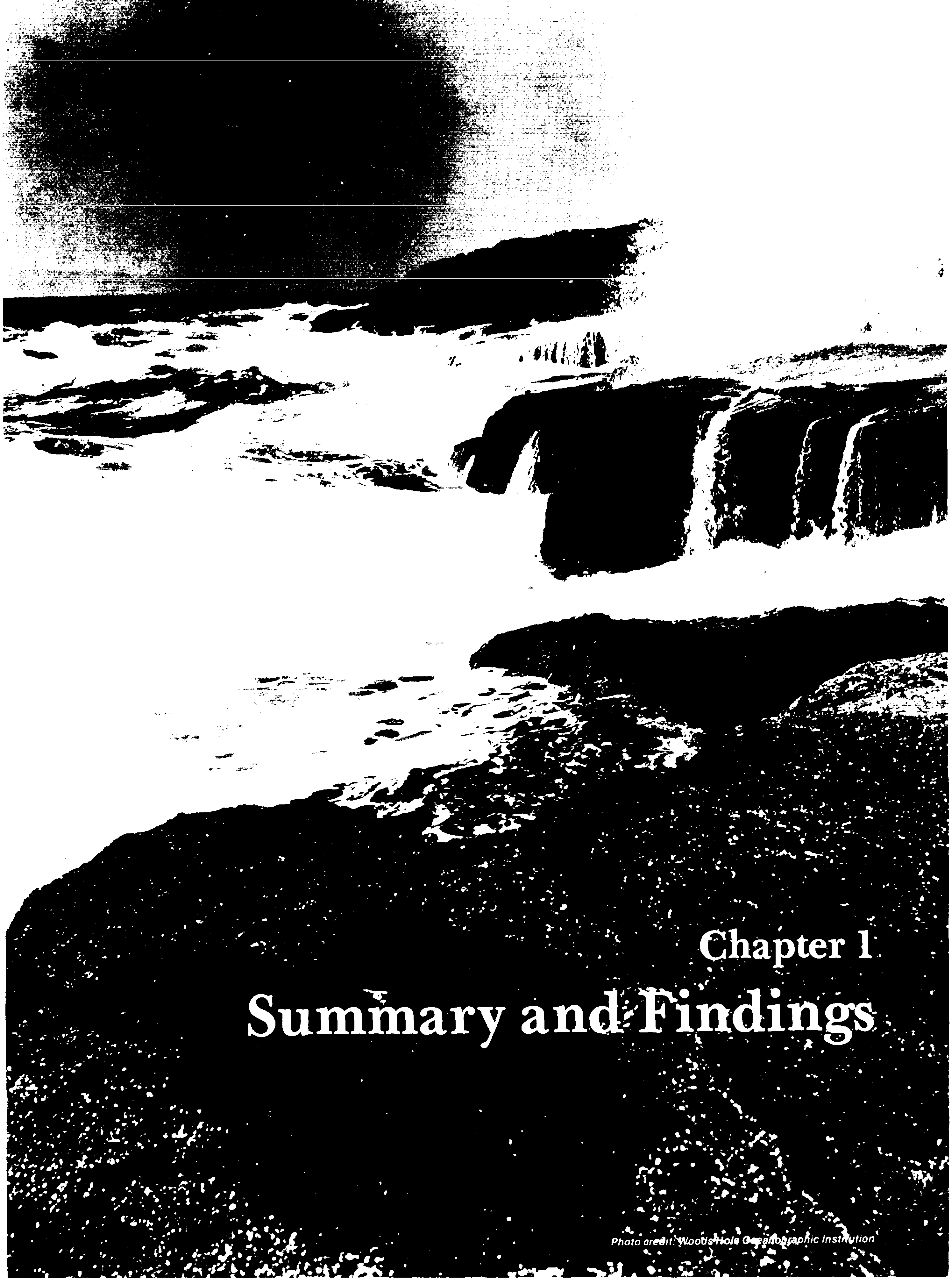

# Chapter 1
# Summary and Findings

*Photo credit: Woods Hole Oceanographic Institution*

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# Chapter 1
# Summary and Findings

## OVERVIEW

In the past two decades oceanography has yielded a treasure of knowledge about the ocean and its resources. Once viewed as relatively static, the ocean is now seen as a dynamic environment actively affecting climate, geology, food and resource supply, and environmental quality. Continued research and monitoring of the ocean to understand further its influence on the Earth has become a vital endeavor.

Oceanography itself is a large, diversified field of investigation, encompassing many disciplines. In this report, the term *oceanography* includes all of the federally supported activities (except classified military work) that involve collecting data about the oceans and conducting experiments in the oceans. These activities range from standard surveys needed for producing maps and charts, to data collection on the sea surface or above for weather predictions, to basic research or experiments conducted by universities and Federal agencies on marine biology, chemistry, geology, geophysics, meteorology, and physical oceanography.

Determining how to manage such oceanographic activities, however, involves considerations not present 20 years ago. For, in addition to new information, the thrust in oceanography has generated new programs and technologies, dramatically changing the practice of ocean science and data collection. Scientists no longer work in isolated groups, using simple equipment. Instead, research teams from Government, industry, and academia share information gathered from technologies ranging broadly in complexity from sample bottles to satellites. Oceanographic programs now require long-range planning, considerable funding, sophisticated data management and analysis, specialized personnel, and coordination of effort among agencies whose program functions and needs frequently overlap. Increasingly, oceanographic research involves international cooperation particularly in global monitoring efforts such as those needed for climate studies.

Federally funded ocean research is conducted by private research institutions, universities, and Federal agencies — all with varying goals and functions. These organizations use a variety of oceanographic technology, defined for this assessment as stations, vehicles, instruments, and equipment used in oceanography. This includes completely engineered systems, innovative technologies, and new inventions as well as adaptations of equipment originally developed for other fields.

This report details the OTA assessment of present capabilities and future needs for federally funded ocean research, surveying, and monitoring. The assessment focuses primarily on the programs of the eight Federal agencies most actively engaged in oceanography, and it addresses the problems of effectively and economically using and maintaining appropriate oceanographic technology.

To complete the assessment, OTA requested that each Federal agency engaged in oceanographic research provide a description of its present programs, budgets, and plans, particularly as they related to providing technology for oceanographic research and data collection. The responses from these agencies provided the necessary information base for this assessment. Subsequent analyses of technologies and selected national programs provided the assessment findings and identification of issues.

Some agencies were not included in the assessment—in particular, the U.S. Army Corps of Engineers and the Maritime Administration in the Department of Commerce. The missions of these two agencies were considered of only marginal relevance to the principal subjects addressed. Although the Corps of Engineers was not covered in the program discussions, some of its work is noted in this report where appropriate. Military systems and classified information were not covered at all. The following sections are summaries of and findings from each of the major chapters in this report. The summaries highlight important topics discussed later in detail, and the findings are from the analyses performed during this assessment. References and other documentation appear in the subsequent chapters.

# AGENCIES, PROGRAMS, AND BUDGETS

## *Summary*

To conduct systematic and reliable oceanographic studies, the Federal Government has a sizable investment in programs and supporting technology. At present, the Federal ocean effort consists of approximately 90 programs conducted primarily by the following eight Federal agencies:

- U.S. Coast Guard (Department of Transportation),
- Department of Energy (DOE),
- Department of the Interior (DOI),
- Environmental Protection Agency (EPA),
- National Aeronautics and Space Administration (NASA),
- National Oceanic and Atmospheric Administration (NOAA) (Department of Commerce),
- National Science Foundation (NSF), and
- U.S. Navy (Department of Defense).

The oceanographic programs conducted by these agencies receive varying levels of emphasis. To simplify a review of the large number of ocean programs, OTA has classified them into nine broad categories according to their primary emphases:

- ***Technology Development*** programs created specifically to provide technological support to Federal programs in oceanography, including the design, construction, testing, and deployment of hardware and other equipment.
- ***Ocean science*** programs to advance scientific knowledge.
- ***Weather and climate*** programs dealing with the collection and analysis of oceanic and atmospheric data.
- ***Energy and mineral resources*** programs to explore and develop nonliving natural resources for the ocean.
- ***Environmental quallity*** programs to improve or enhance the quality of the oceans, Great Lakes, and coastal regions.
- ***Fisheries resources*** programs to develop food resources from the oceans and the Great Lakes.
- ***Public service*** programs organized especially to communicate with the public and to assist the public in the solution of ocean-related problems, including marine safety.
- ***Managemen t and enforcementt*** programs to manage or assist in managing marine resources or to enforce laws and regulations pertaining to the coastal and ocean environments.
- Agency ***support*** programs to support either the efforts and missions of the agency in which they are located or the efforts of other Federal agencies,

Since many programs perform tasks outside their primary missions, a single classification does not always adequately represent a total program. For example, some agencies support general technology development efforts, while others, like the U.S. Navy and U.S. Coast Guard, have strong technology development programs which are directed only toward their own mission needs.

The interdependence of programing and technology creates problems for Federal agencies when programs identify needed technologies that require many years of development to become operational. Such long leadtimes mean that agencies need to engage in long-range planning for research and to demand close cooperation among prospective technology users.

Estimated **Expenditures of Federal Marine Programs: by Agency–by Category-Fiscal Year 1980**
**(in millions of dollars)**

| | *Agency* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Category | Coast Guard | DOE | DOI | EPA | NASA | NOAA | NSF | Navy | Total |
| Agency support | — | $ 2 | $ 70 | $ 4 | – | $ 68 | – | $139 | $283 |
| Energy and mineral resources | | 43 | 44 | — | — | — | — | — | 87 |
| Environmental quality | $ 1= | 18 | 4 | 28 | – | 20 | – | – | 206 |
| Fishery resources | — | — | 12 | — | — | 45 | — | — | |
| Management and enforcement | 477 | — | 41 | — | — | 130 | | | 648 |
| Ocean science | — | — | — | — | — | 4 | $106 | 88 | 198 |
| Public service | 686 | – | 19 | — | | 214 | — | — | 919 |
| Technology development | 59 | – | – | – | $24 | 13 | – | 10 | 106 |
| Weather and climate | — | — | — | — | — | 20 | – | – | 20 |
| Total | $1,358 | $ 63 | $190 | $ 32 | $ 24 | $514 | $106 | $237 | $2,524 |

SOURCE: Office of Technology Assessment

Through the review and budget process, Congress exercises its authority to continue support of ongoing programs, to redirect Federal efforts, to initiate new programs, and to discontinue existing programs. In fiscal year 1980 the total Federal expenditure for ocean programs studied by OTA was $2.5 billion. Three agencies–Coast Guard, NOAA, and Navy– accounted for over 80 percent of that total. Based on funding, the principal program areas of emphasis for each agency appear to be as follows:

- Coast Guard — public service, management and enforcement;
- DOE — energy and mineral resources, environmental quality;
- EPA —environmental quality;
- DOI — agency support, energy and mineral resources, management and enforcement;
- NASA — technology development;
- Navy —ocean science, agency support;
- NOAA — public service, management and enforcement, weather and climate, fisheries resources, agency support;
- NSF— ocean science.

## *Findings-Agencies, Program, and Budgets*

- The 90 programs in the total Federal ocean effort are often scattered among different agencies whose missions or goals appear very similar. Overlap and duplication of effort does occur in some areas OTA has studied and is very difficult to identify.
- Of the total Federal expenditure of $2.5 billion for the ocean programs studied by OTA, 30 percent was spent for the technology, science, and applied research programs that this report addresses.
- With the exception of technology in the military sector and of satellites in NASA, development of new technology that can be used by a wide range of users in different programs and agencies is not focused in any one agency.
- There is no consistency among agencies in their plans for future program or capital expenditures. Some agency plans include an inflation factor, and some do not. Some agencies plan for possible future technology needs, while others do not include any new expenditures in their plans until a new item is firm. Some program plans include substantial contingencies and related activities, while others do not.
- From the information on future plans for technology and oceanography, provided to OTA by the eight agencies surveyed, OTA identified only two new initiatives — the Ocean Margin Drilling Program and the National Oceanic Satellite System–which include plans for substantial technology and funding requirements. Other proposed programs, like the climate program, have yet to establish such requirements, but must nevertheless be considered when planning future budgets.

# TECHNOLOGY

## *Summary*

Oceanographic research is complex, and no single technology system is best suited for its tasks. Thus, a combination of types of systems and techniques is usually the best approach for collecting ocean data and for conducting research experiments.

Federally supported technology systems used in oceanography include:

- ships
- submersibles
- remotely operated vehicles
- buoys and moored systems
- equipment and instrumentation
- satellites
- aircraft
- oceanic data systems

Ocean research covers such a broad spectrum of activities that no logical generalizations can be applied when comparing the suitability or cost effectiveness of different technologies. Therefore, various ships, other vehicles, and instrument systems can only be evaluated in the context of specific research tasks to be accomplished.

A few concepts regarding various technologies can be explored, however, when comparing scales of space and time, when comparing research experiments to routine data collection, and when comparing basic research to applied research.

Ships are the only general-purpose vehicles for carrying oceanographers to sea to conduct experiments. They are both transport vehicles and floating laboratories, with living accommodations for scientists and crew. They are necessary for taking physical and chemical samples of the ocean, the sea floor, and the biota; for deploying instruments in the ocean environment; and for collecting data over a large ocean area, as in making subbottom profiles of the geology beneath the sea floor. In addition, ships are used to implant and support other vehicles, submersibles, data buoys, remotely operated stations (fixed or floating), and diving systems.

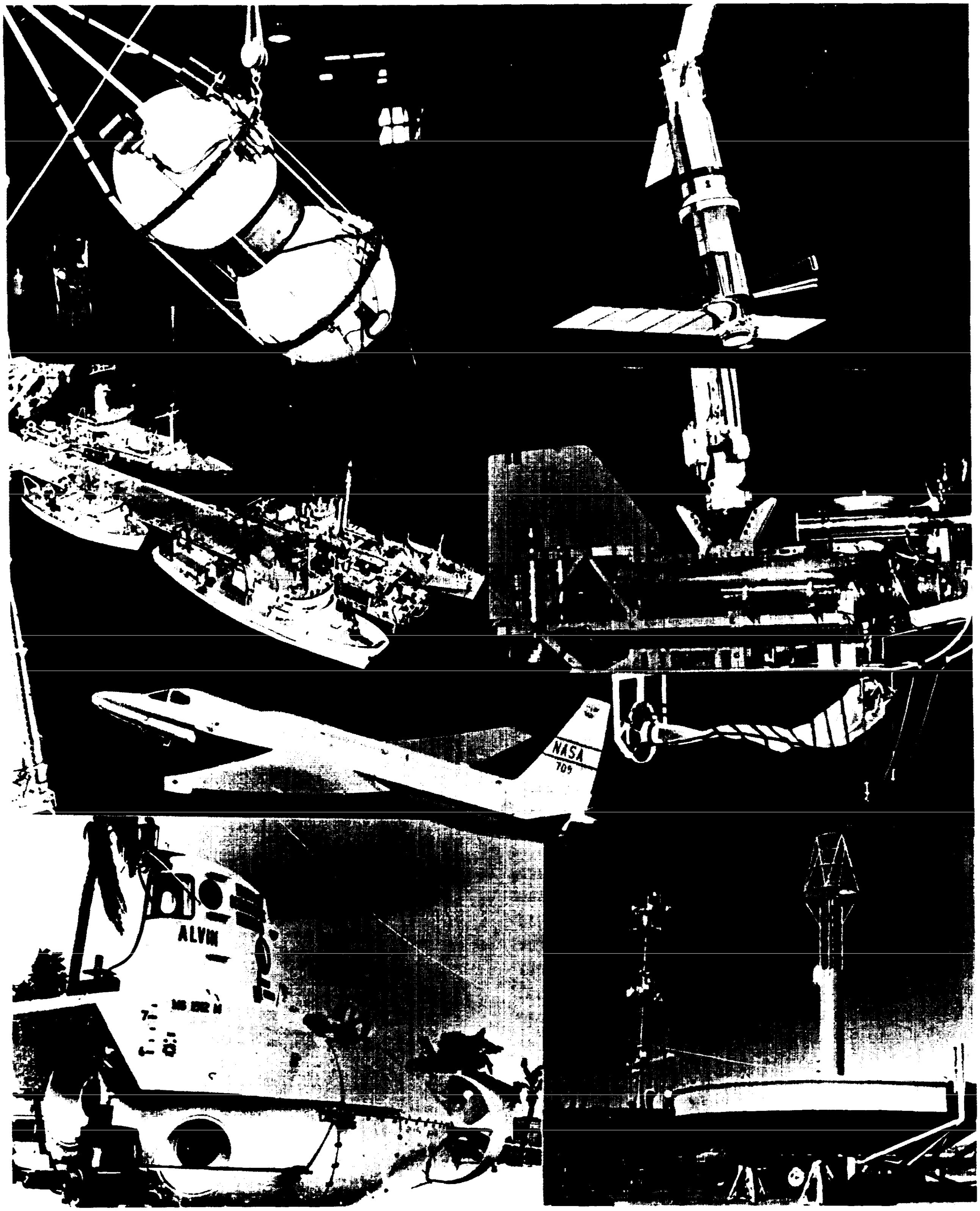
The federally supported oceanographic fleet of about 80 ships is comprised of a variety of types and capabilities and is supported by many agencies and programs. It is a fleet in name only because the ships have a variety of operating systems and their categories of use are usually not interchangeable.

Submersibles are vehicles that can carry a few scientists and instruments to the ocean bottom. They are invaluable for conducting experiments where human observers "on the spot" in the ocean are most important. In the past decade, submersibles were considered the most promising research tool of the future and much successful research was done with them. Today, only one manned, deep-diving submersible, the *Alvin*, *is* federally supported for nonmilitary research but studies of future submersible needs are underway.

Remotely operated vehicles (ROVs) cover a variety of unmanned, underwater vehicles controlled from the surface. They are used for many specialized tasks and are recently becoming of increasing value for oceanographic research and monitoring.

Buoys and moored systems capable of unmanned data collection are used most often when instruments must be placed in the ocean to collect data at and below the surface over a long period of time. They are thus invaluable for certain kinds of meteorological and oceanographic observations. Self-sustained, special-purpose buoys and moored systems have at times been developed as the principal technology for a research program, while in other cases they are part of the more standard oceanographic equipment and instrumentation carried aboard research ships.

Oceanographic equipment and instrumentation include many kinds of items, from shipboard-installed equipment and portable instruments handled from ships to permanently mounted sensors aboard buoys and other stations. Shipboard equipment includes winches, cables, cranes, and laboratory facilities. Multipurpose research ships, contain a combination of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fixed equipment, permanent instrumentation, and special instruments for each experiment. Single-purpose data buoys have built-in permanent instruments and data-handling systems.

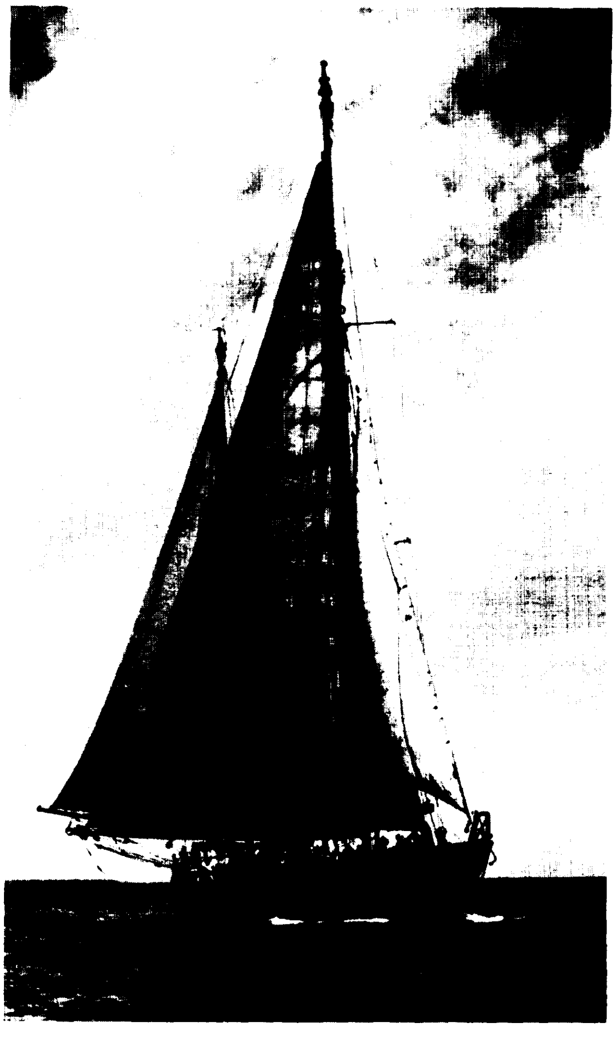
Thousands of separate oceanographic instruments are in use today. Standard shipboard instrumentation includes navigation equipment and some meteorological and standard ocean parameter sensors. Because many ships, such as those of the academic fleet, are now used by scientists for a large variety of research projects, it has become prudent to provide guidelines for standardization of some equipment and onboard data systems.

Satellites provide worldwide coverage of ocean surfaces and can provide data on a timely basis. Limited at present to covering sea-surface phenomena, new satellite instruments will give more comprehensive and accurate information. Certain surface phenomena related to large-scale ocean processes, sea-surface data on a global grid, and other large-scale ocean research can only be accomplished at reasonable cost by satellite. As valuable ancillary tools, satellites are routinely used for navigation and data-transmission purposes.

Aircraft are used less in ocean research, but their coverage and speed of data taking are valuable for laying a line of air-droppable instruments, detecting ocean pollutants, measuring gravitational and magnetic fields, measuring sea-surface conditions with high resolution, investigating hurricanes, and conducting research on marine mammals.

Oceanic data systems include the data handling, archiving, processing, and disseminating networks that now provide services to Federal agencies and other users. Most oceanographic data from satellites, ships, buoys, and other sources are archived by NOAA's Environmental Data and Information Services. The recent large flow of satellite data into the existing system has called attention to the growing problem of providing modern technology and adequate management systems for the handling of oceanic data.

This report does not cover certain categories of ocean technology that either are not a significant part of existing Federal programs or are ancillary to this study's focus on major systems used in the field. Some examples of such ocean technology which may be significant to many future programs are sail-powered ships, satellite data telemetry and communication systems, satellite navigation systems, and computers. Studies within the agencies and the National Academy of Sciences/National Research Council address future needs for these technologies.



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## *Findings-Technology*

- Ships are the vehicles from which most research on the ocean has been conducted. The addition of new ways to examine the ocean has not replaced the need for ships, but has instead identified new and more productive ways to use these vessels.
- The Federal research and survey fleet is facing a shortage of ship operating funds. Fuel, maintenance, and overhaul costs are all escalating rapidly. NSF may be forced to reprogram capital funds to operating accounts and/or to lay-up more ships now in the academic fleet.
- There is a general erosion of capabilities in the Federal fleet which will probably continue in the future. The number of ships in the fleet is decreasing, and ships are not being adequately maintained or upgraded. The erosion of capability is most apparent in deepwater academic ships but extends to all vessels and affects their general condition and the instrumentation and equipment on board.
- Over the next 20 years, the Federal fleet of about 80 ships will require replacement or major rehabilitation. The replacement cost for these ships is about $1.5 billion in 1980 dollars. The two largest fleet groups are the NOAA fleet and the academic fleet, which is operated by various oceanographic institutions. The NOAA fleet is generally older and may require earlier attention to replacement or rehabilitation.
- Many ocean research programs require cooperative efforts between countries and thus coordination of capabilities. The total number of oceanographic ships operated by other countries is difficult to determine precisely because many are used for several other purposes. However, OTA has determined that together the U.S.S.R. and the United States operate about 60 percent of the total oceanographic research and survey ships in the world. Only the Russian fleet equals that of the United States in number of ships, and in fact, exceeds it in number of large ships.
- It appears that, in the future, increased attention will be given to remotely operated and other unmanned vehicles, buoy systems and moored systems, as appropriate, for many specialized ocean data collection and monitoring tasks. New data links with satellites are making buoys and moored systems more useful. Advanced buoy- and moored-system technology, developed within several research programs, could be even more widely used by the mission agencies.
- Instrumentation for oceanography and data collection is generally good especially for those programs that have supported its development and use over long periods of time. Increasing sophistication and reliability of microelectronic technology holds promise for improved instrument systems.
- There are no dedicated oceanographic satellites in orbit today that provide coverage of the world's oceans with modern sensors. *Seasat*, an oceanographic research satellite launched in 1978, lasted only 3 months. The *Nimbus* series of research satellites that provides coastal zone ocean data is being phased out. If the new NOSS program is supported as planned, only part of the *Nimbus* and *Seasat* capabilities will be reinstated.
- Aircraft continue to be used for specialized ocean data collection and surveying in certain programs. Some remote sensors, when used in local areas, are more effectively employed by aircraft than by satellite.
- Existing oceanic data systems are not meeting the research needs of many oceanographers. New satellites and other remote-sensing systems with large data volume potential will make this problem more critical in the future.

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# CRITICAL REVIEW OF SELECTED NATIONAL PROGRAMS

This assessment has identified for special analysis the following four national programs that are representative of the institutional and technological opportunities and problems facing Federal efforts in oceanography.

- Ocean Margin Drilling Program (OMDP)
- National Oceanic Satellite System (NOSS)
- Federal Program in Fisheries and Marine Mammals
- National Climate Program

Two of these – OMDP and NOSS – are major new ocean program initiatives for fiscal year 1981. The drilling program is principally a scientific endeavor with unique private industry participation. NOSS combines the operational needs of military and civilian satellite mission agencies with related scientific investigations. Both programs involve large, new technology systems.

The other two programs exist by congressional mandate. The first, the Federal Program in Fisheries and Marine Mammals, has been in place for a long time, but new legislation has forced its research to be directed more toward resource management problems. The second, the National Climate Program, has been recently directed by legislation to address national needs for delivery of a climate prediction capability and public services that result from that capability. The technology required for each program is a mixture of conventional systems in use for a long time and new developments. The latter could significantly advance future research.

Many other national programs, such as those in marine pollution, offshore energy development, or ocean minerals, could be addressed in a similar manner, and it is hoped that this review will help identify a useful structure for future analyses.

## *Ocean Margin Drilling Program*

### Summary

To gain more knowledge of the nature and origin of the Earth, NSF has begun an important new $700 million, 10-year scientific program of marine geologic investigations. This effort, known as the Ocean Margin Drilling Program (OMDP), resulted from years of planning and evaluation by academic and Government-sponsored committees. It is both a continuation of deep-ocean drilling under NSF's Division of Earth Sciences and a new thrust to investigate the geology of continental margins and ocean crust where very deep drilling is necessary to penetrate unknown regions. Some of the margin regions that are the borders between Continental Shelves and the deep ocean might contain substantial oil and gas resources, but sufficient evidence has not yet been collected to confirm this.

The success of OMDP is contingent on major development of advanced ocean technology, such as deep-drilling, coring, and well-control techniques and hardware. It will be necessary to focus a considerable effort on technology development in the early stages of this program in order to assure that its science goals can be accomplished.

Early planning for an ocean margin drilling program began in 1973 and continued with the Conference on the Future of Scientific Ocean Drilling held in Woods Hole, Mass., in 1977. In 1978 an NSF advisory group reviewed the scientific merit of an ocean margin drilling program, and in 1979 an NSF blue-ribbon committee addressed the national interest in such an effort. More recently, at an NSF-sponsored meeting in March 1980, an initial ocean margin drilling model program plan was developed. That plan is the basis of NSF's OMDP. Scientific objectives stated in the plan are to investigate: 1 ) passive and active continental margins, 2) the Earth's crust beneath the deep ocean, and 3) the deep-sea sediments.

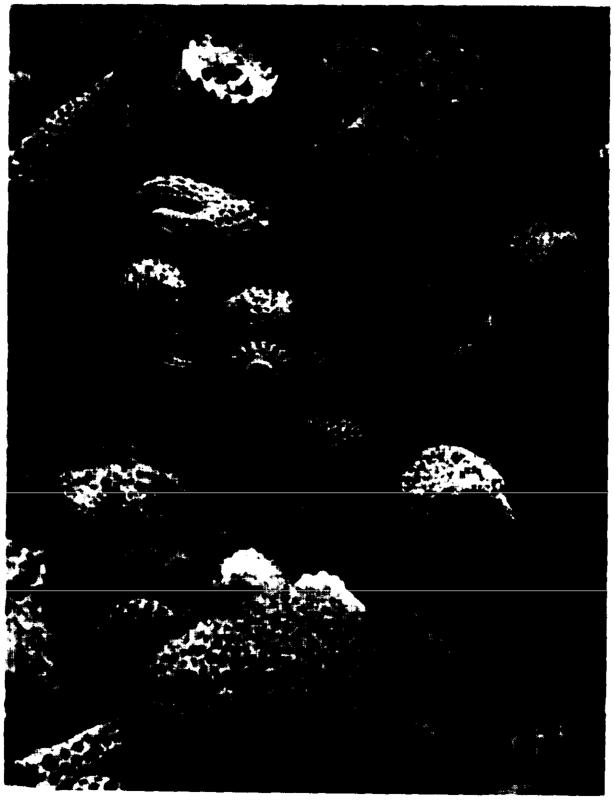
The model program allots 4 years for preparation and 6 years for drilling. It also presents an estimate of program costs. The program includes 10 sites and 15 holes, the deepest of which (Southeastern Gulf of Mexico) is about 21,000-ft below the sea floor in about 11,000 ft of water. Two model sites are in the Pacific Ocean, one is in Antarctica's Weddell Sea, and others are in the Atlantic Ocean and the Gulf of Mexico.

As planned, the program will be jointly funded by the Federal Government and the petroleum industry, each sharing 50 percent of the costs over the 10-year period. Several major petroleum companies expressed interest in participating and, by October 1980, eight had agreed to fund the first year's planning effort. The technology plans include both the conversion of the Government-owned *Glomar Explorer* to a deep-drilling ship as well as the development of a riser system* for controlled drilling in maximum water depths of 13,000 ft and in maximum depths below the sea floor of 20,000 ft.

## Findings

- NSF and other Federal agencies have stressed the unique nature of OMDP as a basic science effort with industry support and cooperation. Many oceanographic institutions are also participating in the planning and future management of science work.
- Technology is not yet developed for controlled drilling 20,000-ft beneath the ocean bottom in 13,000 ft of water, and engineering studies predict many technological difficulties. The technological uncertainty of such deep-ocean drilling may preclude completion of some of the planned deep holes. Engineers and scientists will likely have to make compromises as the program proceeds, resulting either in lowering of the scientific objectives or in significant cost escalations.
- By July 1980, cost estimates for ship conversion and riser development had already increased substantially from those proposed earlier in the year. The OTA analysis highlights concerns that funds to cover the future additional costs to develop deep-drilling technology might be diverted from OMDP science or from other NSF ocean science programs.
- NSF has successfully directed the deep-sea drilling project over the past 12 years, using an established oceanographic institution to carry out the day-to-day management. However, OMDP involves a major funding increase and a new thrust in technology development from previous efforts in deep-sea drilling. Thus, OTA questions the capability and appropriateness of NSF to directly manage the more complex OMDP. The questions include whether NSF is the most appropriate organization to manage the considerable technology development work, whether aspects of the oil and gas resources should dictate more direct involvement by DOE or U.S. Geological Survey (USGS), and whether the science benefits are overshadowed by the technology development benefits.
- A more sharply focused science program with fewer options than the present plan is advocated by several industry and academic scientists contacted by OTA during its preparation of a technical memorandum on this subject in May 1980. These scientists suggested alternatives that might result in lower initial costs and a postponement of the decision to fund major technology developments. Many of these alternatives include an approach to identify first those drilling targets that are within pres-

*A riser is a large-diameter pipe, extending from the sea floor to the drilling ship on the surface, through which the drill pipe is inserted. The riser acts as a conduit for drilling fluid, which is pumped down the pipe and flows back up to the ship between the pipe and riser. The riser is essential for controlling pressure in the well and for supporting blowout prevention.



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ent technical capabilities. Other alternatives involved a greater emphasis on hydrocarbon resources (thus increasing industry involvement), but would probably require considerable changes in Government practices in leasing offshore lands for oil and gas exploration.

## *National Oceanic Satellite System*

### Summary

A major new 10-year effort, the National Oceanic Satellite System (NOSS), was scheduled to commence in fiscal year 1981 but the new administration has recommended a substantial budget cut and delay. Funded jointly by NASA (25 percent), NOAA (25 percent), and Navy (50 percent), this program is designed to collect and deliver synoptic* global measurements of the ocean to Navy and NOAA centers using an orbiting spacecraft, ground control, and data communication and processing systems.

NOSS is designed to demonstrate an operational capability for global, all-weather ocean coverage with real-time data processing and distribution that may presage a series of oceanographic satellites in the future. Synoptic ocean-surface data from NOSS could have significant value in future programs of worldwide weather and climate forecasting, measurement of ice cover, measurement of surface waves and currents, forecasting of sea conditions, observations of surface pollutants or chlorophyll, and other oceanic observations.

NOSS has a planned 5-year demonstration period. Launch of the first NOSS spacecraft from the space shuttle was scheduled for the third quarter, fiscal year 1986. Once the spacecraft and ground systems are operational, a second satellite will be launched (within approximately 6 to 12 months).

NOSS's satellite will carry four basic sensors. The technology for each of these has been developed and tested in previous research satellites, *Seasat* and *Nimbus*. They are: a radar altimeter to measure sea-surface height accurately and thus provide observations of waves and sea state; a radar scatterometer to observe windspeed and direction at the sea surface; a microwave radiometer to measure sea-surface temperature; and a color scanner, which can observe different pigmentation at the sea surface and, in turn, distinguish optically between concentrations of certain substances such as chlorophyll. These sensors, plus the data handling and processing network, will produce pictures, charts, and other forms of information to be used by Navy and NOAA to analyze and forecast weather, sea, and other environmental conditions globally. Researchers outside of Government and industry will also have access to the observations and data. The systems for providing these data products, however, are in the process of being detailed by

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* **A comprehensive and broad view of the whole.**

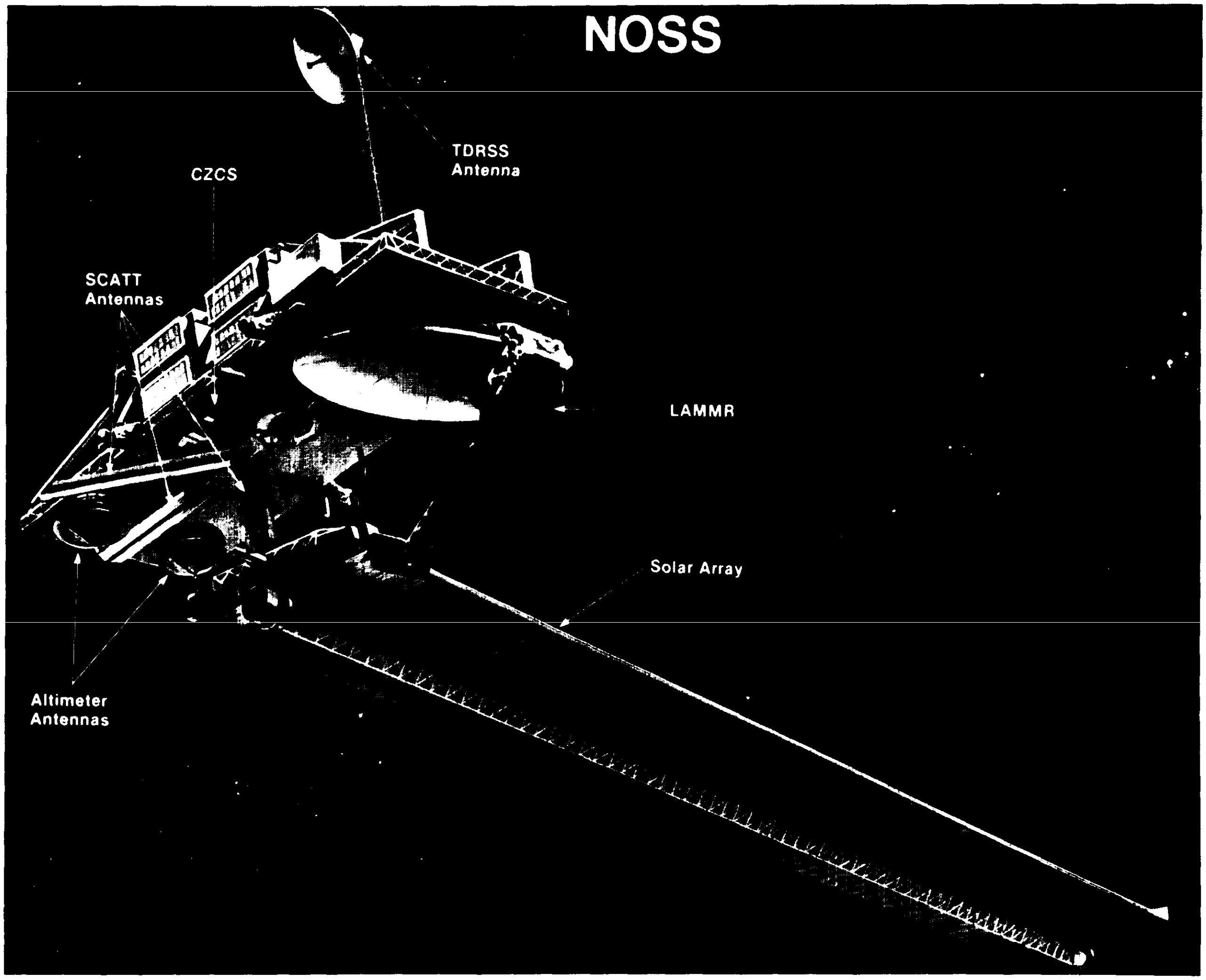



Photo credit National Aeronaut/es and Space Administration

An artist's drawing of the proposed National Oceanic Satellite System. The sensors will provide observations of waves, sea-surface temperature, surface winds, and particles in surface water over the global oceans

the agencies and are only partially included in the program cost.

The total cost of the NOSS program from fiscal years 1981 to 1991 is estimated to be $700 million to $900 million and includes the cost of a planned demonstration period. Since some additional agency costs are not included, such as that for end-user data distribution, the total system costs may approach or exceed $1 billion. These estimates, in fiscal year 1981 dollars, contain no allowance for inflation.

Findings

- NOSS is a major new program in satellite oceanography. If successful as a "limited operational demonstration, " it may be the first generation in a series of satellites for collecting global ocean data in the 1990's and beyond.
- NOSS differs from other satellite programs in that it has all-weather capabilities and uses sensors not used by operational meteorological satellite programs,

- The cost of the NOSS 10-year program, jointly funded by NASA (25 percent), Navy (50 percent), and NOAA (25 percent), is estimated at about $800 million. However, NOSS alone will not provide all the satellite oceanic data required for research and operational purposes, A complete program of satellite oceanography will cost much more.
- The primary operational use of NOSS will be to improve global weather and sea condition prediction for Navy and NOAA weather service. If successful it will provide global, all-weather, synoptic ocean measurements of winds, surface waves, and sea-surface temperatures.
- Three basic NOSS sensors will provide the required operational data on winds, waveheights, and sea-surface temperature. They are the scatterometer, the altimeter, and the large antenna multichannel microwave radiometer (LAMMR). The scatterometer and altimeter are proven technology while the LAMMR requires development.
- The coastal zone color scanner is one NOSS sensor without a clear, direct use in Navy or NOAA operational programs. Instead, for these two agencies, the scanner's chlorophyll and water-clarity measurements will be more important for research programs. These research programs will include evaluation of whether this sensor can obtain adequate measurements through clouds (prevalent in coastal areas), how chlorophyll data can be used to indicate biological productivity, and how water-clarity measurements can aid other research.
- NOSS's program office has conducted studies to determine an optimum orbit for the satellite, given NOAA's and Navy's stated data needs and given the four sensors selected. However, no detailed mission analysis has been prepared that compares the value of other research needs to NOAA and Navy requirements or that considers alternative orbits, sensors, and data systems. The ongoing contracted studies of alternatives to NOSS will not consider these major options to the planned system.
- The research mission of NOSS is limited, and secondary to the stated agency operational missions. Only part of the past research satellite (Seasat and *Nimbus)* capabilities of several years ago will be reinstated with NOSS.

## Fisheries and Marine Mammals Research

Summary

The large and diversified Federal Program in Fisheries and Marine Mammals is directed principally by the National Marine Fisheries Service under NOAA at an annual cost of $50 million; selected aspects of the program are directed by the Fish and Wildlife Service of the Department of Interior at an annual cost of over $10 million.

Fisheries. — The Federal fisheries program is directed toward conserving and managing U.S. fisheries stocks, as mandated by the Fishery Conservation and Management Act of 1976. The Act, in an attempt to alleviate overfishing of certain stocks, extended U.S. jurisdiction over fisheries to 200 miles from the coastline and specified the establishment of Regional Fishery Management Councils to allocate and conserve fish resources for future use. The councils prepare management plans based on scientific information principally furnished by the Federal Government about species that are or may be harvested. The process of supplying this information focuses and directs much of the present and future fishery research in the United States.

The National Marine Fisheries Service within NOAA conducts fishery research through observation and monitoring of stocks, monitoring of commercial and recreational harvesting, investigation of fish behavior, and of environmental and other influences. The work is carried out at fisheries research laboratories using the 10 NOAA fisheries survey vessels and other ships that are chartered when needed. The work at sea involves sampling of stocks and analysis of results by technologies that are basically adaptations of fishing gear or biological oceanography. New technologies are periodically tested by the fishery researchers, and some development work is supported at individual laboratories.

***Marine Mammals.*** –The Federal program in marine mammals focuses on conserving marine mammal populations by limiting harvest and by researching and ensuring conditions that will provide maximum productivity of various species. Research expeditions using various technologies and methods are necessary to count species whose behavior and habitat are more variable than those of fish. Present marine mammal research and technology are adapted from experimental programs or from other fields.

The following findings are based on analyses of the status and trends found mainly in NOAA's program in fishery and marine mammals research and on analyses of the possible future programs related to krill resources in Antarctica.

### Findings

- The 1976 legislation has shifted attention to management problems and socioeconomic factors at the expense of fishery sciences and research. Future research and technology needs are thus being shaped by the more immediate needs of the fishery managers.
- Present technology for gathering stock assessment data on fisheries is adequate for most current, high-priority monitoring programs, More data on actual fish harvesting (catch-data) are needed by fishery managers, but the limitations on getting these data are institutional, not technological. The possible future need for more research-ship time to cover assessment of new stocks could be met by additional chartering and by upgrading existing ship capabilities.
- The one new technology with the potential to improve future stock assessment capabilities is acoustic measurement. While similar technology is used for military purposes, considerable development and applications testing is required to transfer the best techniques to the stock assessment problem. NOAA has not yet bridged the gap between experimental acoustics and engineering development of an operational system.
- Satellite remote sensing of ocean-surface conditions has not proven useful for stock assessment. Some satellite measurements of surface chlorophyll or temperature may provide indirect evidence of biological productivity and be useful for more basic research.
- New technology for efficient harvesting, reduced waste of catches, better safety, improved processing, and other factors of fish utilization could aid the development of new fisheries by U.S. fishermen. Some of these technologies are now being used by foreign fishermen in the U.S. zone. Some are necessary to make products acceptable to the U.S. market. The Federal Government has paid little attention to this research in the past.
- *Krill.* – Research on Antarctic krill is now basic and exploratory. Much more basic research is needed on krill lifecycle, growth, and behavior. Comprehensive survey techniques for data collection, evaluation, and reporting must be developed and standardized to better understand the role of krill in its ecosystem. It is probably premature to establish a major stock assessment program for krill until more harvesting tests are monitored and more basic research is done.
- *Marine Mammals.* – The Federal Government must invest major funds if it is to comply with many of the specifications of the Marine Mammal Protection Act of 1972. Past funding limitations have constrained methodological research and technological development; slowed data acquisition, analysis, and distribution; and created shortages of necessary equipment and manpower. A major technological difficulty is the current lack of suitable, well-designed survey ships and aircraft for large-scale surveys.

## *National Climate Program*

### Summary

The ability to forecast climate on a seasonal, annual, or longer-range basis requires not only an understanding of the effects of the ocean on climate, but also information from global monitoring of selected oceanic parameters over many years.

Precisely how the oceans affect future atmospheric conditions is not known. It is known that the oceans are a major heat-energy source for the atmosphere, that the oceans absorb and release carbon dioxide ($CO_2$), and that air-sea interactions play an important role in climate dynamics.

Scientists around the world have been studying aspects of the ocean's role in climate and can predict some climatic fluctuations over land based on variations in conditions in the oceans. During the 1980's scientists will begin a global effort to understand climate dynamics. The National Climate Program plan and the World Climate Research Program are parts of this effort.

In compliance with the National Climate Act of 1978, Federal agency scientists have proposed a variety of planning and feasibility studies and field experiments to determine what factors control climate and to determine how best to study the ocean's role. These studies are generally not adequately funded for technology development. Moreover, since the National Climate Program is in its initial stages, there is no well-defined, broad statement of its technology requirements, although present programs are doing the scientific planning necessary for the establishment of such requirements. Substantial increases in technology funding for climate studies will probably be required by the mid- to late 1980's if the research plans gain agency and congressional support.

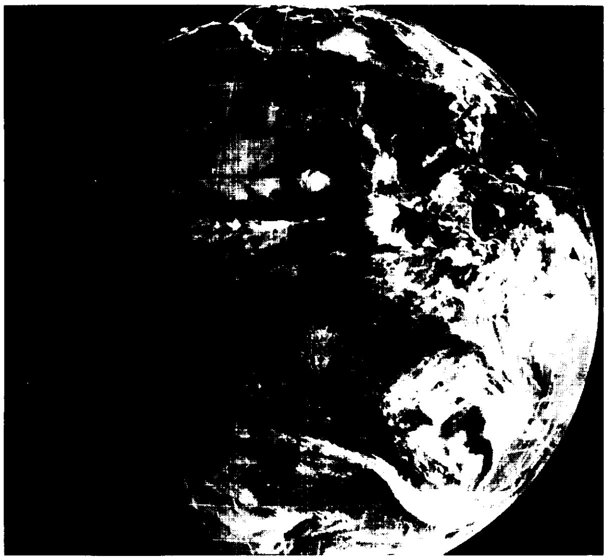


*Photo credit: National Oceanic and Atmospheric Administration*

The full Earth disk, with the Western Hemisphere artificially outlined for reference, shows global weather patterns from a geostationary satellite

The National Climate Program is managed by the individual agencies that have climate research activities. While the National Climate Program Office was established to coordinate these interagency activities, it does not presently have sufficient resources to effect this coordination and to initiate action to fill the inevitable gaps between the diverse agency programs. It also lacks overall authority to direct a coordinated research program.

On an international level, the World Climate Research Program is expected to provide the required degree of coordination among countries. The U.S. interest in an international research effort was expressed in the National Climate Program Act of 1978. As the needed research is more specifically defined, both costs and benefits of these efforts can be evaluated.

### Findings

- Because climate research is still in the planning stage, there is no comprehensive statement of its technology needs. However, there are ocean technology needs in communication and data processing that, if met, could play a major, immediate role in understanding climate dynamics.
- One or more dedicated centers and a dedicated computer for the collection, processing, and distribution of future climate-related data would lead to a much improved capability to analyze climate dynamics.
- A mix of sensors and vessels, such as ships-of-opportunity, * drifting buoys, and arrays of moorings, will be needed to measure oceanic heat storage. This mix will necessitate an expanded and improved data collection and coordination system.

*Commercial ships or other vessels not normally engaged in oceanography but which can be used to make routine measurements or launch automated sensors.

- Four general areas of technology needs for future climate research are listed below, along with examples of specific technology development or use that appear to be of highest priority based on OTA's analysis of program needs.

  1. *Stations:*
     - Organization of a worldwide ships-of-opportunity data collection program, including a satellite data network and centralized data-processing center.
     - Substantial improvements and cost reductions in expendable buoys and probes.
     - A commitment to long-term, moored stations. (Many of the existing long-term stations, on which much of our current knowledge of ocean climate is based, are being closed for economic considerations. )
  2. *In situ sensors:*
     - *New* types of upper-ocean-current sensors that would be used to collect data to evaluate the manner in which the ocean moves heat from the tropics to the high latitudes.
     - Improved, cost-effective sensors for measuring temperature, salinity, and velocity from fixed moorings.
     - Improved, cost-effective sensors for measuring profiles of ocean temperature, salinity, and velocity as part of the worldwide ships-of-opportunity program.
     - New technology for measuring the humidity content in the atmospheric boundary layer near the ocean surface.
     - Sensors that measure various trace gas constituents such as $C0_2$.
  3. *Satellite sensors:*
     - Technology for measuring the global windfields, useful for describing and predicting the oceanic variations that can affect atmospheric changes. (It may be possible to make the necessary measurements using satellite instrumentation such as that proposed for NOSS. )
     - Satellite capability to determine surface currents and precipitation on the time and space scales appropriate to climate.
     - Satellite systems that transmit in situ measurements using the same data stream as measurements from satellites themselves.
  4. *Data management:*
     - The anticipated flood of data from satellite sensors will require major efforts to upgrade data management and handling capabilities to retain existing satellite data, to merge historical data of various types with satellite data, and to provide easy and economical access to data bases.

# ISSUES

Whether new oceanographic research programs can gain adequate support for needed technology depends not only on the program needs, but also on whether the technology itself has adequate support. For many oceanographic programs adequate mechanisms have not been developed to satisfy technology needs through either the adaption of existing technology or the development of new technology. It is very difficult to provide technological support for science programs when the science has broad or diffuse goals and objectives.

Four important issues concerning Federal activities in technology and oceanography have been identified through this assessment. These issues cover subjects of significant controversy about how technology is provided now or how it may be supported in the future to meet diverse Federal goals and missions in oceanography. They cover overall institutional considerations and technological subjects. The issue discussions provide a basis for congressional actions such as oversight, budget review, or new legislative initiatives.

The issues are, briefly:

1. ***Ocean Technology Development. –*** Whether a larger and more centralized ocean engineering effort within one or more Federal agencies would significantly

improve future ocean technology development.

2. ***Oceanic Data Systems. –*** Whether the growing need to handle and distribute increasingly large volumes of oceanic data to a variety of users can be met effectively within existing agencies or will merit some new institutional arrangement.
3. Ships. –Whether the unique capabilities of the Federal fleet of research and survey ships will be adequately maintained or improved in the future.
4. ***Satellite Oceanography.*** –Whether the benefits of a major new thrust in satellite oceanography warrant the substantial funding and long-range planning entailed in establishing and maintaining such programs.

## *Ocean Technology Development*

### Issue

There is no effective and comprehensive nonmilitary effort to plan and coordinate the development of new technologies that would advance many major Federal ocean programs. A strong, centralized ocean technology organization has been proposed by several past studies, but many researchers and administrators strongly oppose such a concept. However, most agree that ocean engineering capabilities are inadequate and that important technology development work is not receiving needed attention in some key Federal agencies.

### Discussion

The extent to which ocean engineering capabilities within nonmilitary Federal agencies can be improved and to which ocean technology development can be made responsive to Federal ocean program needs will depend on future institutional changes. At present, Navy and Coast Guard have substantial ocean engineering efforts directed toward their own operational missions and related research. NASA conducts significant technology development programs, but its mission is basically to transfer space-related technologies, when developed, to other agencies. NOAA and other agencies develop some technologies, but their engineering development efforts do not often even meet their own program needs.

Numerous studies have proposed establishing a more capable ocean technology organization within the Federal Government. Proposals have ranged from "centralizing the technological development programs and projects of all civil agencies in a single organization" to simply establishing "an interagency coordinating unit" to aid in the transfer of technology among agencies. Two reports that are often cited for recommending a central technological organization are the "Panel Reports of the Commission on Marine Science, Engineering, and Resources" of 1969 and the 1974 National Advisory Committee on Oceans and Atmosphere report, "Engineering in the Ocean. " Another, the September 1980 report, "Federal Ocean Engineering, " by the Committee on Atmosphere and Oceans, recoin - mended establishing a Federal ocean engineering strategy group to foster communications and to focus Federal technology development work on some key neglected areas, such as polar and deepwater research.

Centralization of technology development within each agency or among agencies, is supported by some who claim that focusing more authority and funding in one office could alleviate the frustrating experiences of trying to initiate promising new techniques amid a bureaucratic maze of unclear authority, funding inflexibility, and a shortage of specific technical experts. Such centralization could theoretically:

1. Provide a technically superior organization that can direct the solutions to a wide range of problems associated with carrying out agency missions.
2, Provide the mechanisms and focal point for advancing ocean technology through grants and contracts and by use of the most qualified Government technical organizations.
3. Provide central budgeting and funding with major program line items for:
   –defined mission and program-oriented technological projects;

– projects that are needed to advance the state of the art; and
– projects that would help bring promising experimental equipment into routine use through engineering development.

Ocean technology developments must be tested at unique sea and shore facilities. Since these facilities are used intermittently, some savings could be made through use of more efficient and more centralized facilities or by combining organizations that need the facilities. Moreover, centralization of technology development may induce a more economic use of staffs that have specific and sufficient technology experience and of project management that has the expertise necessary to raise critical questions and to avoid large and expensive omissions.

Centralization of technology development can also have serious drawbacks. The user of the technology is generally concerned that the centralized organization will not give his problem the attention that it deserves. Also, with the funds not under his control, he cannot control project expenditures in the development and testing processes. If the technology development problem is removed from the organization that needs the equipment, there is a risk of not meeting the real needs of the scientist. Small engineering tasks may have high priority within a specific research project, but low priority within a central technology organization. Finally, there are concerns that a large organization cannot meet the needs of the various smaller organizations; that adequate funding will not be provided for each project when budget priorities are set; and that one office cannot provide for both direct mission support, and the development of more basic technology.

There are many ways that technology centralization can be accomplished. One would be to establish a central interagency organization. Many believe that this option would be worse than the existing system because no agency has developed the required expertise to be so designated. Another approach, intra-agency centralization, would be a scaling down of the central concept in that it would consider only an individual agency's technological needs. To a limited degree, many such offices now exist, although they do not all have the required staff capabilities. In NOAA, a new Ocean Technology and Engineering Service (OTES) has been established to centralize technology development, however, it appears that some of NOAA's technology needs, such as fishery technology, are not considered in OTES. In Navy, ocean technology is important — and often of differing character — in almost every segment of Navy's research, development, and test programs. Thus, each of these programs has an ocean engineering component. In many other agencies, centralization of ocean technology development is done generally by discipline or by specific mission.

Centralization of technology development by discipline occurs within several Federal organizations by grouping both personnel and facilities. For example, Navy's towing basin has served other Federal agencies. Similarly, the Sandia Corp. Laboratory conducts measurements of seismicity for DOE and other agencies. The submarine and manned-diving technologies of Navy have been shared with many agencies. NOAA has become a focal point for scuba and saturation diving for scientific purposes. In addition, all agencies have some technology development offices that serve the principal missions. In certain cases a technology development project is passed to another agency, certain ocean technology development activities of EPA are passed to NOAA for execution. But these established practices fall short of an effective technology development effort to meet important ocean science and monitoring needs in the future.

Short of a Presidential mandate, congressional initiatives may be necessary to make the needed institutional changes and improvements because interagency coordination on budgets and mission authority is difficult to achieve otherwise. For example, Congress could establish a central office to support future ocean technology development in one or more agencies with authority to provide the expertise and project management capabilities for specific missions or program needs, Through oversight, Congress could call for an evaluation of specific technology development needs that are not being met within the major ocean agencies by those ocean engineering offices now established. This evaluation would lead to the identification of neglected areas and priorities of programs for technology development. As another option, Congress could establish an interagency ocean engineering strategy group (as recommended by the Committee on the Atmosphere and Oceans) with authority for technology transfer and other productive coordinating functions.

There is no way to centralize technology development adequately to meet the individual needs of every program and agency. Direct communications between the programs needing technology and the developers of technology is most important. Flexibility in funding is also necessary for accelerating the innovation and bridging process of converting experimental equipment to operational systems. And of utmost concern is assuring the availability of highly qualified personnel in each department or agency for critical program assessment and for focusing on promising directions in technology development.

## *Oceanic Data Systems*

### Issue

Federal programs have not given adequate attention to the handling and distribution of oceanographic data, collected at great expense to the public. Large amounts of data are stored unused because their nonstandardized formats are incompatible with user needs and because they are difficult to retrieve from the archives. These difficulties hamper much oceanographic research. Accordingly, many researchers and private groups recommend that funds and plans for data management and distribution beyond the primary agency users be included in major data collection programs. At present, however, only primary data networks are included within specific programs.

### Discussion

Although several Federal agencies are involved in the collection of oceanographic data, NOAA's Environmental Data and Information Service (EDIS) is the agency specifically created to maintain data and information for use by Federal, State, and local agencies and the general public, Most oceanographic data is archived in either the National Oceanographic Data Center or the Satellite Data Services Division, part of EDIS.

OTA has identified a growing need for more current, near real-time environmental data in almost all major ocean research programs. NOAA representatives have stated, however, that EDIS has the responsibility for supplying only retrospective data to users; it does not have responsibility for the distribution of real-time data. In essence, then, EDIS manages only the archiving of the data stream. The other agencies and contractors that originate the data have the responsibility for data documentation and quality control. As NOAA indicated:

> . . . problems are far greater in obtaining documented, quality-assured data from data originators than . . . in processing it into and out of archives.

Because planning and budgeting for both archiving and distributing retrospective data is not closely tied to similar planning for data acquisition, projects of major significance and cost have been funded without adequate resources for handling and distributing the resultant data. Then, the major question is: Who really should have the Federal responsibility for comprehensive oceanographic data management? At present, the NOAA archives seem to be unable to handle the present digital data stream from existing collection systems in a near real-time environment. New programs like NOSS that generate new data streams will only exacerbate this problem. In fact, NOAA is planning to implement a major new data management system as an adjunct to the NOSS program. Handling increased data volume requires new organizations and management methods for data cataloging, storage, archiving, processing, and distribution.

A related issue is defining the role of the Federal Government in providing services and software to make oceanographic data available to researchers in the scientific community, the commercial sector, and the general public. Future trends in data-processing technology indicate a large increase in the use of electronic data transmission, processing, and display. With only Federal archival and retrospective data responsibility clearly defined, there may be a gap in management responsibility which is filled on an uneven basis by each Federal agency with an operational mission.

Management systems and networks for future data handling could take various forms. A trend toward establishing regional data networks and distribution centers has been underway for some time by large, commercial firms for their own private work. It appears likely that regional networking of Federal oceanographic data systems may also be effective. If data management responsibility were centralized in one place, it might ensure easier planning and budgeting for future needs and might accommodate more effectively the needs of individuals and other small users. If data management responsibility and funds are not given to a Federal agency, this may be an incentive to commercial data networks or private institutions to operate data networks for a fee.

There are two steps that could be taken to make oceanic data systems capable of serving the growing user needs and of handling the growing data volume. The first step is assigning agency or program responsibility for comprehensive management geared to user needs. The second step is choosing a Federal, regional, or private data management system and upgrading it with modern technology for use as an oceanic data system.

Congress could initiate the first step by requiring that data management for all end-users be included in plans and budgets for major new programs, The second step could also be at the direction of Congress. For example, if the data management system choice were a major Federal system, Congress could provide NOAA with funds and added responsibility to establish a central Federal data network for all users of future oceanographic data. Otherwise, Congress could either establish regional oceanographic data networks for management and distribution of oceanic data outside of the Federal agencies or provide incentives for commercial data networks to be established for end-users.

## *Ships*

### Issue

The capabilities of the Federal fleet of research and survey ships will continue to degrade unless additional new funds are added or new, more efficient systems are devised to provide and operate these ships at less cost. Several years of debate have failed to resolve whether more centralized management systems with greater Federal control would produce savings so that capabilities could be maintained or enhanced, especially when funding does not match escalating costs.

### Discussion

The future of oceanographic ships appears to be constrained by limited Federal funding for ship operation, rehabilitation, and replacement. Thus, it is important to consider whether a system can be devised to maintain fleet capabilities with less funding or whether increased funding must be provided to maintain adequate numbers of capable ships. It will always be necessary to provide some new funds to replace and refit ships and to upgrade equipment and instrumentation.

Management of federally supported ships entails not only operating and maintaining the existing fleet, but also planning the mix of the future fleet. At present, the Federal fleet includes ships designed for general-purpose (flexible) applications and for special-purpose tasks. The fleet is operated by organizations that have a variety of missions ranging from basic research to routine surveys.

In the present Federal fleet, a distinction can be made between ships that are operated directly by Federal agencies mostly for routine surveys or applied programs and those operated by academic institutions mostly for basic research. The agency fleets tend to have more centralized management within each agency. The academic fleet, on the other hand, has been subject to very little Federal control over operations; but some agencies, like NSF, have recently tried to plan

*Photo credit Scripps Institution ot Oceanography*

R/V *Alpha Helix,* owned by NSF and built in 1966, has recently been transferred from Scripps Institution of Oceanography to the University of Alaska. The ship is 133-ft long and can accommodate 12 scientists

and effect cost -saving changes in the fleet makeup.

There are several studies underway that will provide planning information on the future management needs for oceanographic ships. These include studies of the academic fleet by the National Academy of Sciences/National Research Council, two oceanographic laboratory groups, Navy, and NSF; studies of NOAA's fleet by NOAA; and studies of Navy's fleet by Navy. A study by the General Accounting Office (GAO) in 1978 identified a decline in capabilities and efficiencies in the Federal fleet and recommended that a single manager be designated or that a Government-wide fleet-allocation council be established. Accordingly, in mid- 1980, the Federal Oceanographic Fleet Coordination Council (a subgroup of the interagency Committee on the Atmosphere and Oceans) was established in response to GAO's recommendation and to that of several agencies.

Several groups are also pursuing certain aspects of regional operations for the academic fleet. NSF and Navy have stated that moves toward regional academic fleet operations should and will be encouraged. Some proposals for regional operating centers for new coastal research ships have been made; and cooperative operations of large, special-purpose ships, such as a geological/geophysical vessel, have been discussed.

Those who argue for more centralized management or Federal control over the oceanographic fleet claim that the result would save money because some functions could be merged and some operations would be more efficient. Thus, central fleet management could facilitate more accurate planning for future fleet makeup, in particular for replacement or refurbishment of ships. A specific long-range plan for ships to be retired and new ships to be built could be laid out and consistently followed if only one office were in charge.

However, oceanographers consider central management and control detrimental to the flexibility and individual project efficiency that is so important to basic research, and to some applied research as well. They view the present system of decentralized management and planning, particularly in the academic fleet, as more satisfactory for individual research needs as well as for agency and program missions. Some argue that flexibility must be maintained if the opportunities for new discovery associated with basic research are to be pursued. The cost-effective planning needed in central operations may not be possible in basic research; and some claim that the small, decentralized ship operators can, therefore, provide services at less cost.

These concerns about centralization are reflected in several areas. USGS and EPA, who now operate just a few ships, claim that they could not relinquish control of their vessels to another agency because of their unique program needs and unique vessel capabilities. In the academic community, serious conflicts exist over whether NSF or other agencies supporting basic science should have the authority to decide on the makeup or operations of the fleet as a whole. In addition, many scientists and Government agencies have recognized a growing need for polar research ship capabilities, but the mission agencies have not been able to consolidate their needs and bring together the resources and justification for a polar ship.

Many of the needed efforts to resolve this issue are already underway in the Federal agencies and institutions. If Congress wished to oversee and direct these efforts more carefully, it could call for the submission of ongoing studies of the fleets when the studies are completed, and it could request a consolidation of study recommendations from all agencies. This consolidation could be done by an existing interagency committee or by a White House office. As part of these efforts, Congress could request a projection of the costs of maintaining the U.S. oceanographic fleet capabilities under the present and any proposed system. The choice could then be to either provide sufficient funds or eliminate certain capabilities.

Finally, to assist coordination among agencies, Congress could establish and fund an interagency ship planning council with the authority to specify management and planning practices, a move which could reduce costs.

## *Satellite Oceanography*

### Issue

Major satellite systems for oceanography are being planned that could become the dominant thrust in ocean technology in the next two decades. NOSS is one part of this thrust; however, several additional systems will be needed to meet the range of operational and research goals now established. Many research programs and ocean-user groups, including scientists and industry, could benefit from oceanic satellite data, but only a few Government agencies acting together can now afford the very high costs of this technology.

### Discussion

Satellite remote sensing could become the fastest growing segment of oceanography if certain agency plans are followed. NOSS, a proposed operational demonstration satellite system designed to meet the needs of Navy and NOAA for the collection of oceanographic data, may be the first of a new generation of oceanographic satellites. Twenty-five percent of the NOSS payload has been reserved for research purposes. Moreover, NOSS data have the potential to benefit a wide range of public and private applications by providing a long-term, synoptic, all-weather view of the ocean surface. If additional satellite programs follow NOSS, as many have advocated, the cost of oceanic satellite hardware and data systems for both research and operational users could be about another $1 billion in addition to the NOSS program.

The activities within the Department of Defense and NOAA that have considerable need for satellite oceanography are Navy and NOAA's National Weather Service (NWS). In Navy, the Fleet Numerical Oceanography Center provides near real - time synoptic ocean data for fleet operations because naval ships and weapons cannot operate effectively without current environmental information. In NOAA, NWS is expected to provide several services that rely on synoptic ocean data and routine weather forecasts. These data could be used for automated ship and aircraft routing, performance estimates for radar and sonar, and search and rescue operations. To accomplish these operational missions, meteorological and oceanographic forecast services over the oceans should be continually maintained. The information required range from complete satellite coverage data to subsurface measurements data from buoys, ships, and other stations.

A variety of important research programs could also benefit from satellite observations because some large-scale features of the ocean surface may be described adequately only by such remote sensing. Satellite data are useful for addressing problems relating to descriptions of the ocean's influence in world climate, observations of large circulation patterns, investigations of marine pollution, large-scale studies of oceanic productivity, and many other phenomena which occur near the sea surface. Those research projects that require observations beneath the sea surface will need additional tools and techniques that work in conjunction with satellites.

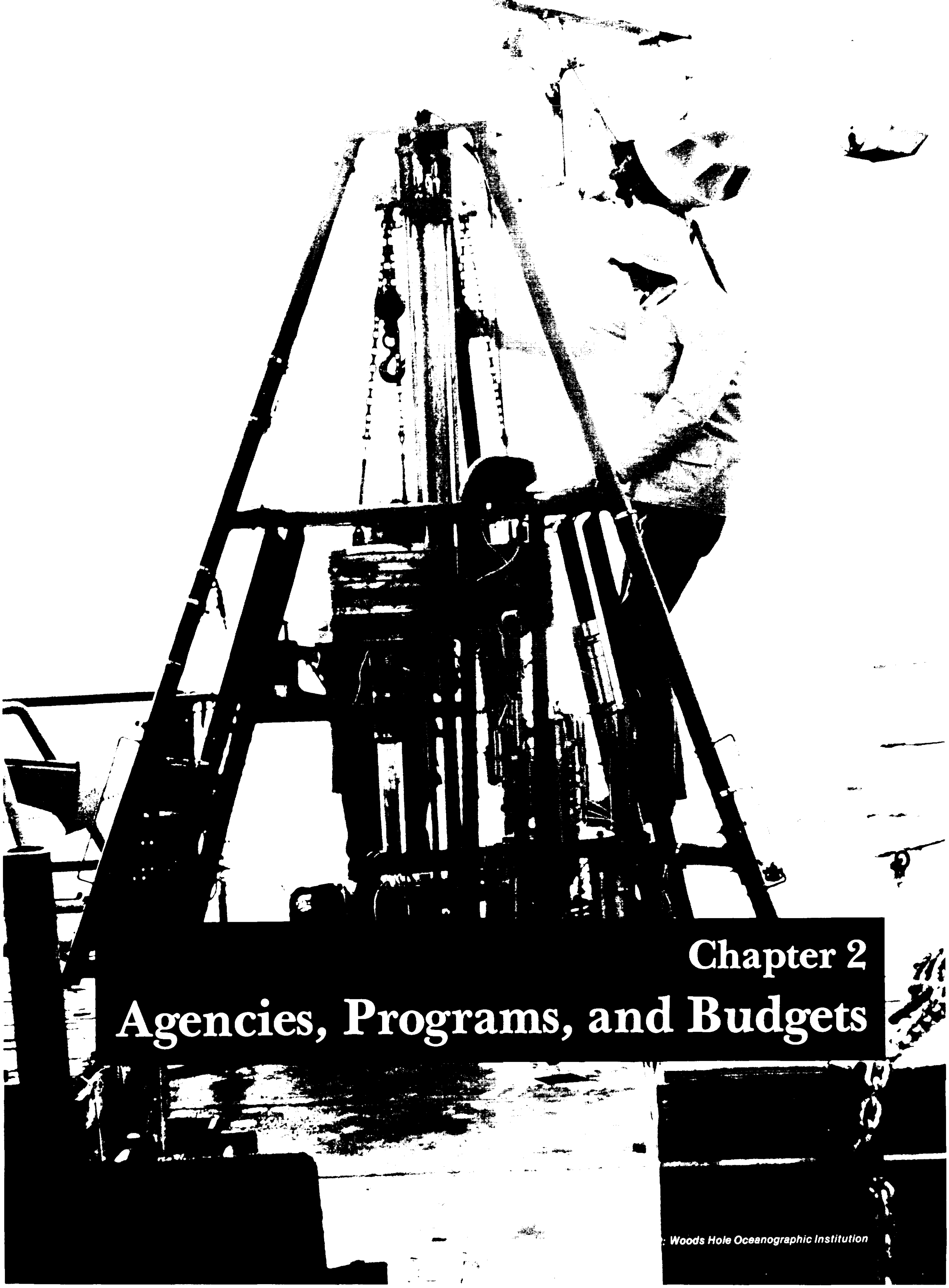
The extent to which satellites themselves will add new knowledge and thus justify very large costs is difficult to evaluate until more experience is obtained. A large investment in satellite oceanography in the future will probably draw funds and people from other programs of ocean observation or may make other methods, such as the use of surface and subsurface vehicles, more dependent upon work with satellites. In fact, many researchers believe that future uses of satellites will increase the need for ships to make surface-calibration measurements and other subsurface measurements not possible from spacecraft. In future debates over costs and benefits of satellite oceanography programs, researchers must consider both the intrinsic value of the programs as well as their possible effects on other ocean research technology.

Satellite systems, including ground support and data handling, require long development periods (5 to 10 years) before becoming operational. Consistent Federal support is necessary if the systems are to be useful to broad segments of public and private groups. Because of the large Federal support needed, long-range planning is also necessary. NASA has started a long-range planning process for satellite oceanography, and many other Federal agencies and private groups will probably participate in the process as it develops. Cooperative long-range planning is supported by many now working with the NOSS program, but is not supported by some researchers and agencies who wish to maintain the flexibility and uniqueness of their own programs. Some researchers also feel that new sensor development will be the key to future useful oceanographic measurements from satellites because NOSS-proposed sensors have limited capabilities.

While NASA has developed a broadly supported approach to the NOSS program to meet both the operational needs of Navy and NOAA, and the research needs of many users as well, agencies such as USGS remain convinced that a mission like that of a *Seasat-B*, which would be more research-oriented and limited in scope, would be preferable. Researchers also claim that major, long-range Federal support of satellite oceanography must await both the results of further experimentation with many techniques as well as the success of the NOSS prototype mission.

Because of the substantial funds required for a major satellite oceanography program, Congress will have a continuing interest over many years in plans, budgets, justifications, and possible alternatives. As with all major Federal efforts, the NOSS program will be subject to close congressional oversight. For such oversight it may be desirable to select each major program decision-point and evaluate specific cost and benefit justifications with the understanding that NOSS is just one step (a demonstration prototype) in a larger, satellite oceanography thrust. To assist this process Congress could call for a long-range plan for satellite oceanography, specifying research and operational program needs in each Federal agency and some optional methods of providing them, including nonsatellite means.

# Chapter 2
# Agencies, Programs, and Budgets



Woods Hole Oceanographic Institution

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## TABLES



## FIGURES

# Chapter 2
# Agencies, Programs, and Budgets

Current national programs in oceanography reflect an increasing emphasis on activities that will produce more efficient use of ocean resources, greater coordination between agencies engaged in ocean research, and improved ocean research methods. Legislation in recent years has focused specifically on climate research, ocean pollution, Outer Continental Shelf (OCS) development, and fisheries management and conservation. In these areas and others, primarily eight Federal agencies are currently engaged in 90 programs. The major agencies involved include:

- U.S. Coast Guard (Department of Transportation),
- Department of Energy (DOE),
- Department of the Interior (DOI),
- Environmental Protection Agency (EPA),
- National Aeronautics and Space Administration (NASA),
- National Ocean and Atmospheric Administration (NOAA) (Department of Commerce),
- National Science Foundation (NSF), and
- U.S. Navy (Department of Defense).

Two agencies that are not included are the Maritime Administration and U.S. Army Corps of Engineers. OTA judged that the missions of these agencies were not sufficiently related to oceanographic research or monitoring as addressed in this assessment.

Using the individual agency descriptions of their present programs, budgets, and plans for oceanographic research and data collection, OTA has broadly classified agency programs under the following nine categories in order to simplify their review:

- ***Technology Development*** programs created specifically to provide technological support to Federal programs in oceanography, including the design, construction, testing, and deployment of hardware and other equipment.
- ***Ocean science*** programs to advance scientific knowledge.
- ***Weather and climate*** programs dealing with the collection and analysis of oceanic and atmospheric data.
- ***Energy and mineral resources*** programs to explore and develop nonliving natural resources from the ocean.
- ***Environmental quality*** programs to improve or enhance the quality of the oceans, Great Lakes, and coastal regions.
- ***Fisheries resources*** programs to develop food resources from the oceans and the Great Lakes.
- ***Public service*** programs organized especially to communicate with the public and to assist the public in the solution of ocean-related problems, including marine safety.
- ***Management and enforcement*** programs to manage or assist in managing marine resources, or to enforce laws and regulations pertaining to the coastal and ocean environments.
- Agency ***support*** programs to support either in-house efforts and missions or those of other Federal agencies.

Although programs have been assigned to categories according to their apparent primary emphases (table 1), such categorization does not adequately represent a total program, since many programs perform tasks outside their primary missions. The following provides a brief summary of agencies and current program areas.

**Table 1.—Number of Programs by Category of Activity of Principal Emphasis**

| Agency | Technology development | Ocean sciences | Weather/ climate | Energy/ mineral | Environmental quality | Fishery resource | Public service | Management enforcement | Agency support | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Coast Guard | 1 | 0 | 0 | 0 | "2 | 0 | 2 | 2 | 0 | 7 |
| DOE | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 1 | 5 |
| DOI | 0 | 1 | 0 | 2 | 3 | 2 | 6 | 3 | 3 | 20 |
| EPA | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 3 | 11 |
| NASA | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| NOAA | 3 | 3 | 4 | 0 | 2 | 2 | 8 | 3 | 5 | 30 |
| NSF | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| Navy | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 |
| Totals | 12 | 12 | 4 | 4 | 17 | 4 | 16 | 8 | 13 | 90 |

NOTE: OTA has assigned each agency program to the category of its principal emphasis, based on agency-furnished descriptions of the program

SOURCE. Off Ice of Technology Assessment

# AGENCIES

The major ocean responsibilities of the eight Federal agencies surveyed for this report are listed briefly below.

U.S. Coast Guard: Marine safety programs to minimize loss of life and property; vessel, ports, waterways, and related facilities safety; management and enforcement activities in U.S. waters and the high seas where authorized; navigational research; ocean research and engineering; maintenance and improvement of the quality of the marine environment; the pollution fund; ice- and current-condition tracking and research.

Department of Energy: Research in deep-sea disposal of nuclear wastes; determination of environmental health and safety effects of energy technology and programs; carbon dioxide ($C0_2$) research and climate research; pollution research in the marine environment; ocean thermal energy conversion (OTEC) research and development; wind, waves, and current research; deep-drilling research for oil and gas exploration.

Department of the Interior: OCS resource evaluation and management; offshore geologic surveys; marine and coastal zone resource evaluation; oilspill trajectory and analysis; responsibility for fish and wildlife habitats and resources, including research and management; barrier island research; advancement of mineral technology and research.

Environmental Protection Agency: Environmental quality research of the oceans and the Great lakes; research on pollution problems of the coastal zone; petroleum and hazardous materials research in the marine environment; ocean-dumping research; water quality evaluation.

National Aeronautics and Space Administration: Development, construction, and operation of aeronautical space vehicles; development of capability to observe the oceans from space for operational and research purposes.

National Oceanic and Atmospheric Administration: Provision of weather forecasts for the United States; weather modification activities; management and research services related to the protection and use of living marine resources, including marine mammals; preparation and issuance of nautical and aeronautical charts; geodetic surveys; prediction of tides, currents, and state of the oceans; marine and atmospheric research; coastal zone management; management of all civilian operational remote-sensing activities from space; acquisition and dissemination of environmental data; Sea Grant; research and development of data-buoy technology; ocean engineering.

National Science Foundation: Support of basic research in the areas of Earth, ocean, and atmospheric sciences; partial support of the academic research fleet; research in the Antarctic.

U.S. Navy: Collection and dissemination of ocean environmental data and prediction services; research and development to advance knowledge of the physical, geological, chemical, and biological nature of the oceans; ocean engineering; diving medical research.

# CURRENT PROGRAM AREAS

## *Technology Development*

Historically, oceanography has relied on ships to explore the sea. In recent years, agencies have added aircraft, orbiting satellites, deep seabed stations, buoy networks, submersibles, and other equipment and instrumentation to their oceanographic capabilities. This technology has been essential for advancing ocean research, and its development has been supported by many agencies through individual programs.

Much of this technology development, particularly of sensors and recorders, has been done by individuals or groups of scientists from small Federal grants. As shown in table 2, technology development efforts do not seem to be emphasized in any one agency. Seven of the eight agencies have three or more technology areas where their programs have a focus.

A few Federal programs are working on new kinds of ship designs, such as DOE's ocean thermal test vessel; new underwater vehicles, such as Navy's deep submergence vehicle *Sea* Cliff; or new deep-sea drilling ships, such as that in NSF's Ocean Margin Drilling Program (OMDP). Four of the agencies in table 2 have technological efforts directed toward satellites.

Since high costs and long leadtime in the development of technology require planning, coordination, and sizable funding, technology development is perhaps the one area in which the greatest agency cooperation is needed. Some cooperation is evident; e.g., all activities given in table 2 which involve satellites are jointly sponsored, and many of the programs for developing sensors for installation on satellites are cooperative efforts. In another example, Coast Guard and NOAA have a formal agreement whereby the Coast Guard deploys and maintains NOAA's data-collecting buoys.

## *Ocean Science*

Increased understanding of ocean processes and the effect of the ocean on the global environment is the basis of the Nation's ocean science program. While scientific purpose is evident to some degree in all Federal ocean research programs, whether basic or applied, the primary mission of several efforts — particularly in NSF, NOAA, and Navy– is basic research, which is defined here as ocean science.

In fiscal year 1980, NSF spent $106 million on ocean-related projects out of a total science

**Table 2.—Federal Programs Involved in Developing Ocean Technology**

| | Types of technology | | | | | | |
|---|---|---|---|---|---|---|---|
| Agency | Ships | Underwater laboratories | Submersibles | Buoys | Satellites | Remote sensors | Instruments |
| Coast Guard | — | — | — | x | x | x | — |
| DOE | x | — | — | x | — | — | x |
| DOI | — | — | — | — | — | — | x |
| EPA | — | — | — | — | — | — | |
| NASA | – | — | — | — | x | x | 2 |
| NOAA | — | x | — | x | x | x | x |
| NSF | x | — | x | — | — | x | x |
| Navy | — | — | x | — | x | x | x |

SOURCE. Office of Technology Assessment

budget of almost $1 billion. Of this amount, $17 million supported the Deep-Sea Drilling Project (DSDP) and OMDP. An important NSF function is to provide partial support for the Nation's academic fleet, which accounts for about one-quarter of the budget. NSF-supported work is generally carried out through grants and contracts to individual scientists in universities, institutes, and industries.

NSF programs are focused in six fields:

- Earth sciences,
- atmospheric sciences,
- polar programs,
- environmental biology,
- applied research, and
- ocean sciences.

NOAA's ocean science efforts grow out of congressional assignments or from demands arising from NOAA operational components for increased information to meet mission objectives. The few NOAA programs that have basic science objectives are found at NOAA's Atlantic Oceanographic and Meteorological Laboratory and at the Pacific Marine Environmental Laboratory. Most of the other NOAA programs have some ocean science components. For example, the Hurricane Modification Program, conducted by NOAA's Environmental Research Laboratories, includes both atmospheric and ocean observations. The collected data provide a greater understanding of the ocean and atmosphere and have an immediate and direct application within the National Weather Service. Unlike NSF, whose cadre of scientific expertise extends to the academic community, NOAA's efforts are accomplished primarily through NOAA personnel.

More than 80 percent of Navy's ocean science effort is associated with basic research in support of future Navy missions. The programs are managed or funded by the Office of Naval Research, and research is conducted by Navy personnel and outside contractors. Primary program emphasis is on underwater acoustics. Basic biomedical research associated with underwater diving and divers is also a part of Navy's program.

## *Weather and Climate*

The ocean contributes significantly to the world's weather and climate because it is a major energy source for the atmosphere. Better understanding of heat storage in the ocean and heat transfer between the ocean and the atmosphere will improve the ability to forecast weather and climate.

The equatorial and polar regions of the globe are particularly important in understanding ocean/atmosphere exchange and interaction processes. Several major new studies in the equatorial Pacific and Atlantic are now underway by NOAA and NSF. Sea-ice studies are conducted by NOAA, NSF, Navy, and Coast Guard; and NASA has some plans for a program to provide satellite sensors and ground-truth stations to study the relationship of polar ice to climate.

With the research studies, it is important to maintain a long-term and consistent ocean climate-monitoring program. Some data-collecting programs are carried out, primarily through NOAA, but they do not result in a sustained ocean climate-monitoring program. NOAA has been designated as the lead agency for coordinating such a national climate-related program under the National Climate Program Act. At the same time, an international effort to monitor ocean climate is planned by the World Climate Research Program with U.S. participation.

## *Energy and Mineral Resources*

Substantial petroleum resources are found under the ocean's continental shelf. Other potential energy sources may include the harnessing of energy from ocean waves, currents, winds, and thermal energy. The Federal effort in this area is focused in two agencies. The U.S. Geological Survey (USGS) of DOI is concerned with the evaluation of the potential oil and gas resources to be found in federally owned submerged lands. DOE is concerned with the development of new technologies to exploit both oil and gas resources and other ocean energy potentials.

Of the almost $87 million spent in fiscal year 1980 by these two agencies, $40 million was directed toward a major program to develop and commercialize OTEC by DOE. This program would take advantage of the vast amounts of thermal energy in the ocean and is presently focused on an upcoming decision to build and test a *pilot* plant of 10 to 40 megawatts of electrical output. Other research at DOE includes developing techniques to extract energy from ocean waves and currents and developing deep-drilling technology for future offshore oil and gas production. Oil and gas are now being produced in many areas offshore of U.S. coasts. Selection of the offshore tracts which will be offered for lease to industry by the Government is the responsibility of DOI. USGS surveys and determines the market value of submerged lands and recommends to the Department those tracts which should be offered for lease.

Recent legislation on OTEC and Deep Seabed Mining has given new responsibilities to NOAA in the mineral and energy resources field. These acts task NOAA to perform a licensing function for OTEC and offshore mining.

## Environmental Quality

The 17 Federal programs which attempt to improve the environmental quality of the oceans, the Great Lakes, and the coastal regions account for approximately $207 million in Federal funds. Although the majority of these programs are within EPA, the bulk of Federal funds are in other agencies, such as NOAA, DOI, DOE, and Coast Guard. The Corps of Engineers also supports marine environmental programs.

Pollution problems of the immediate coastal zone, and particularly the toxicological effects of various pollutants on estuarine species, is the focus of much of EPA's work. EPA also coordinates all Federal cleanup activities when there is a discharge of a hazardous substance in inland waters. Research programs investigating the source, fate, and effects of pollutants in the Great Lakes, in an effort to protect and enhance the water quality of the region and to prevent deterioration of the water resources, are conducted by NOAA and EPA. Surveillance and monitoring activities are carried out by both agencies.

The fate and effects of petroleum and other hazardous materials on the marine ecosystem is investigated by DOE, NOAA, and EPA. DOE has an ongoing program to investigate the feasibility of deep seabed disposal of radioactive waste. Baseline surveys and a permitting program for the designation of ocean dump sites are housed within EPA, although permitting and enforcement is carried out by the Corps of Engineers and Coast Guard.

## Fisheries and Living Resources

In recent years, fishermen, sportsmen, environmentalists, and marine enthusiasts have used their collective influence to activate a substantial interest in fisheries resources at the Federal level, The result has been a steady flow of Federal programs concentrating on living resources of the sea.

Part of the present interest in fisheries research stems from the demand for better information needed to manage the fishery resources which were extended by the Fishery Conservation and Management Act of 1976 (FCMA) to include a 200-mile-wide zone bordering the coastlines. Federal activities in commercial and recreational fisheries, fish cultivation, marine mammal research and protection, and other living resources of the sea are focused in the National Marine Fisheries Service (NMFS) of NOAA and in the Fish and Wildlife Service of DO I.

NMFS programs are directed toward the conservation and management of all fisheries in offshore Federal waters between the State jurisdiction limit of 3 miles offshore to the Federal jurisdiction limit of 200 miles offshore. The programs include those to improve habitats as well as those to establish appropriate levels of harvesting by both U.S. and foreign fishermen.

DOI programs involve management of ocean fish that spawn in freshwater. A number of other Federal agencies, whose major emphasis is elsewhere, conduct programs that are closely related to fisheries, especially in managing resources and enforcing regulations governing fish catch and in protecting marine mammals and other endangered species.

## *Public Service*

Programs with public service as a major focus serve as channels for information from the Federal Government to the general public. In many instances, these programs work closely with research and technology development programs.

The most visible public service program is NOAA's Public Weather Service, which issues warnings and forecasts about the weather. Another NOAA program of public interest includes the Environmental Data and Information Service, which is the national data bank for oceanic information and includes the National Oceanic Data Center, the National Climatic Center, the National Geophysical and Solar-Terrestrial Data Center, the Environmental Science Information Center, and the Center for Environmental Assessment Services. These centers provide computer-stored data and publications to Federal agencies, scientists, and other users. NOAA's National Ocean Survey provides charts, maps, tide and current data, and other types of marine information for public use. DOI's USGS produces some maps of coastal lands and islands. NOAA and DOI cooperatively interchange data for their coastal area publications.

The Coast Guard's public service components include the search-and-rescue service for mariners and a program to construct and maintain navigational aids to ensure safe passage of marine traffic in coastal and inland waterways and in harbors.

Other public service programs are public granting services, including the National Sea Grant College Program, the Marine Extension Services, Federal Aid for Fish and Wildlife Restoration, and the Fisheries Financial Support Services. Sea Grant is a matching-grant program for conducting research, education, and public service related to marine resources development; socioeconomic and legal aspects of marine resources; marine technology research and development; and environmental research. Applied research projects are generally directed toward the solution of specific problems identified by the States and regions in which the program operates. The most visible public service aspect of Sea Grant is the marine advisory services effort. Its objectives are to assist industry and Government in marine resource development and protection and-to inform the public of problems, opportunities, and progress in marine affairs.

In a number of agencies, the public service ocean programs are large, and 16 programs in three agencies or departments of the Government directed more than $900 million toward public service in fiscal year 1980.

## *Management and Enforcement*

Federal involvement in the management of marine resources and in enforcement of laws and regulations related to marine activities is extensive. Resource management includes managing public coastal and offshore lands in oil and gas production, allocating fishery stocks and assigning optimum yield, and overseeing the development of the coastal zone. NOAA's Coastal Zone Management Program (CZMP) is carried out through cost-sharing grants with States, The States or other organizations plan resource use and development, while the Federal Government evaluates the plans. The assignment of planning responsibility to regional managers occurs in both CZMP and the Regional Fisheries Councils called for by FCMA.

In USGS, the Outer Continental Shelf Lease Management Program regulates OCS oil and gas production and reservoir shut-in operations, sets up natural gas-pricing categories, verifies drilling platform safety, and conducts some research and development in support of OCS activities.

The Coast Guard regulates recreational boating and licenses offshore terminals, merchant vessels, marine personnel, and floating drilling platforms.

Enforcement authority over foreign fishing in the 200-mile U.S. coastal fisheries zone rests with the Coast Guard, which also enforces international treaties. NMFS (NOAA) has a related responsibility to enforce any Federal ocean fishing regulation of U.S. fishermen operating in the 200-mile zone. The Fish and Wildlife Service manages coastal wildlife refuges and enforces laws to protect certain fish and wild life, particularly those that are endangered

## Agency Support

Several Federal marine programs provide supporting operations for the agency in which they are located or for other agencies. Typically, these programs offer centralized services which other agency components use, such as equipment, ships, aircraft, satellites, and facilities.

Stations for oceanographic observations are maintained by NOAA, NASA, NSF, DOE, EPA, and Navy. NSF, NOAA, and Navy have support programs for ships and ship bases while NOAA and NSF maintain centralized facilities for research aircraft. Satellites and services are provided by NASA and through NOAA's environmental satellite services.

A network for collecting and distributing weather data, primarily for the Public Weather Service, is operated within NOAA. Surveys to support charting and mapping services are provided by support programs in NOAA, Navy, and USGS.

AI other form of support are studies that provide information needed by agencies. The Fish and Wildlife Service, e.g., conducts a fish and wild ife research program that provides scientific and technical planning support for the operations of agencies and other organizations. The Environmental Studies Program of the Bureau of Land Management (BLM) supports the Federal OCS oil and gas leasing program by examining possible environmental effects of offshore production. NOAA manages BLM's program off Alaska and provides ship support for the project. The Strategic Petroleum Reserve Program of DOE provides the informa ion needed to satisfy EPA requirements for the use of salt domes to store crude oil.

These and other support activities accounted for $284 million in fiscal year 1980 and included 13 programs in all agencies.

# BUDGETS AND PERSONNEL

## Estimated Expenditures for Federal Ocean Programs

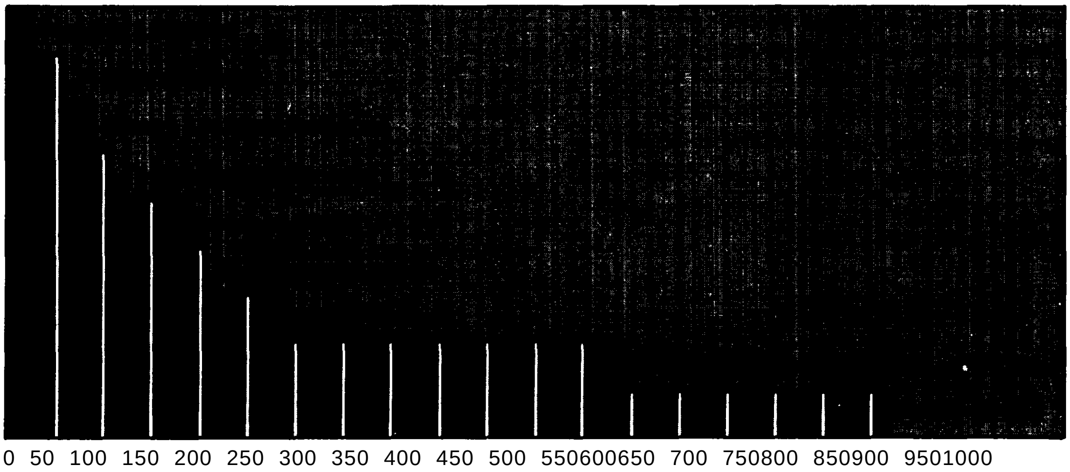
The Federal ocean programs of eight agencies and departments had expenditures of $2.5 billion in fiscal year 1980. The charts and graphs that follow show the distribution of these funds. Because some programs operated from income accounts, such as the Pollution Fund of the Coast Guard and the Fisherman's Contingency Fund, and others operated from prior-year carryover funds, such as NOAA's Coastal Energy Impact Fund ($132.6 million), the totals presented do not reflect just appropriated funds.

Figure 1 delineates the estimated amount of money spent in each ocean-related program category in fiscal year 1980. As shown, programs in the public service category accounted for the largest expenditures and represented an outlay of $919 million. Management and enforcement programs accounted for $647 million. Weather and climate programs received the least amount of support. There were, however, basic science programs of NSF which were directed toward weather and climate but which are categorized under ocean science for this report.

A review of the estimated expenditures of each agency, presented in figure 2, reveals that Coast Guard reported the greatest expenditure, that of $1.358 billion, in fiscal year 1980. This was more than the combined expenditures of all the *other* agencies.

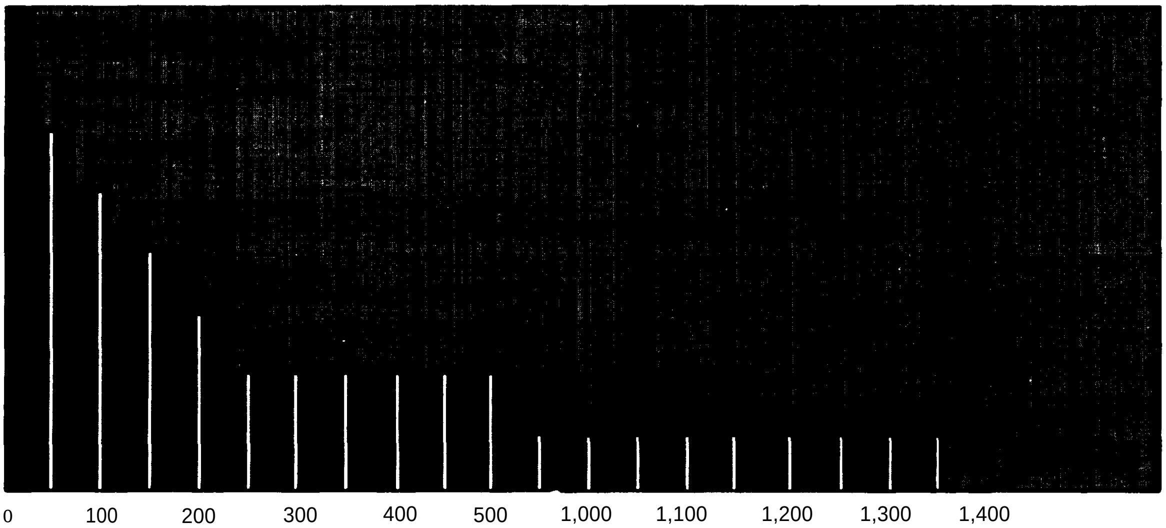
When expenditures are charted into program categories for each agency (table 3), it can be

**Figure I.— Estimated Expenditures of Federal Marine Programs, Fiscal Year 1980**
**(in millions of dollars)**




SOURCE. Office of Technology Assessment

**Figure2.— Estimated Expenditures of Federal Marine Programs, Fiscal Year 1980,by Agency**
**(in millions of dollars)**




SOURCE: Office of Technology Assessment.

**Table 3.—Estimated Expenditures of Federal Marine Programs: by Agency—by Category-Fiscal Year 1980**
**(in millions of dollars)**

| Category | Agency | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Coast Guard | DOE | DOI | EPA | NASA | NOAA | NSF | Navy | Total |
| Agency support | — | $ 2 | $ 70 | $ 4 | – | $ 68 | – | $139 | $283 |
| Energy and mineral resources | | | 44 | — | — | — | — | — | 87 |
| Environmental quality | $136 | 18 | 4 | 28 | – | 20 | – | – | 206 |
| Fishery resources | — | — | 12 | – | — | 45 | — | — | 57 |
| Management and enforcement | 477 | — | 41 | — | — | 130 | | | 648 |
| Ocean science | — | — | — | — | — | 4 | $106 | 88 | 198 |
| Public service | 686 | – | 19 | — | | 214 | — | — | 919 |
| Technology development | 59 | – | – | – | $24 | 13 | — | 10 | 106 |
| Weather and climate | — | — | — | — | — | 20 | – | – | 20 |
| Total | $1,358 | $ 63 | $190 | $ 32 | $ 24 | $514 | $106 | $237 | $2,524 |

SOURCE Off Ice of Technology Assessment

seen that over one-half of Coast Guard's expenditures ($686 million) were in public service programs. NOAA, second in overall expenditures, also spent the greatest portion of its funds in public service efforts. In addition, NOAA had the widest spread of activities, with expenditures in all program categories.

It is interesting to note in table 4 that the three agencies with the greatest expenditures — Coast Guard, NOAA, and Navy-account for over 80 percent of the total Federal marine program funds. The three largest categories – public service, management and enforcement, and agency support — accounted for over 70 percent of the total. Technology development accounted for only 4.1 percent of the total even though four agencies had technology development efforts.

Based on the funding, the principal program area emphasis for each agency appears to be as follows:

- Coast Guard –public service and management /enforcement,
- DOE –energy and environment,
- DOI –energy/mineral, management and support,
- EPA –environmental quality,
- NASA – technology,
- NOAA – public service and management,
- NSF–ocean sciences, and
- Navy-ocean science and support.

**Table 4.—Relative Estimated Expenditures for Federal Ocean Programs: by Agency—by Category-Fiscal Year 1980 (percentage of grand total of $2.5 billion)**

| Agency | Technology development | Ocean sciences | Weather/ climate | Energy/ mineral | Environmental quality | Fishery resource | Public service | Management enforcement | Agency support | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Coast Guard". . | 2.3 | 0 | 0 | o | 5.4 | 0 | 27.1 | '18.9 | o | 53.7 |
| DOE | 0 | 0 | 0 | 1.7 | 0.7 | 0 | 0 | 0 | 0.1 | 2.5 |
| DOI | 0 | 0 | 0 | 1.7 | 0.2 | 0.5 | 0.8 | 1.6 | 2.8 | 7.6 |
| EPA | 0 | 0 | 0 | 0 | 1.1 | 0 | 0 | 0 | 0.1 | 1.2 |
| NASA | 1.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.0 |
| NOAA | 0.5 | 0.1 | 0.8 | 0 | 0.8 | 1.9 | 8.5 | 5.1 | 2.7 | 20.4 |
| NSF | 0 | 4.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.2 |
| Navy | 0.4 | 3.5 | 0 | 0 | 0 | 0 | 0 | 0 | 5.5 | 9.4 |
| Totals | 4.2 | 7.8 | 0.8 | 3.4 | 8.2 | 2.4 | 36.4 | 25.6 | 11.2 | 100 |

SOURCE Office of Technology Assessment

## *Future Expenditures*

Projecting expenditures is part of the planning cycle of program development. For this report, (during 1980) NOAA, NASA, NSF, and Navy provided OTA with information on their projected funding levels for the categories listed in table 3. In fiscal year 1980 these four agencies accounted for expenditures of $881.6 million. All of the agencies except NOAA predicted increased expenditures through fiscal year 1984 (table 5). NOAA projected a sharp drop followed by a leveling off of expenditures after fiscal year 1982.

The greatest percentage of increase appeared in NASA's proposed spending levels; from fiscal year 1980 to fiscal year 1981, NASA planned an increase of almost 50 percent. A portion of this increase was earmarked for the National Oceanic Satellite System (NOSS), with the rest proposed for two other ocean satellite programs beginning after fiscal year 1982. Not reflected in table 5 is NASA's Ocean Research Mission which was planned in conjunction with the launching of NOSS. Over the 1980 to 1984 timespan, NASA's proposed funding level increases more than sixfold.

NSF planned increases of 13 percent in fiscal year 1981 and 17 percent in fiscal year 1982, followed by a decrease of 8 percent in fiscal year 1983 and an increase of 10 percent in fiscal year 1984.

Increases in Navy expenditures were expected to be approximately 14 percent in fiscal year 1981 and 12 percent in fiscal year 1982, leveling off at about 9 percent for the following 2 years.

NOAA had not planned any increases of ocean programs during the next few years. Most programs show slight increases or decreases or appear as level-funded for the term. The only increase in NOAA's projections was for the Global Atmospheric Research Program, expected to more than double in funding from fiscal year 1980 to fiscal year 1984. NOAA states that its projections have an "implicit downward bias" because no inflationary factors were included and no program increases were formally approved.

Two agencies, Navy and Coast Guard, provided information on expected expenditures for technology development in some programs.

The Navy's capital investment in oceanographic operations, amounting to $9.6 million in fiscal year 1980, is used mainly for modification and replacement of shipboard survey equipment. In fiscal year 1985, Navy expects to spend $25.7 million for capital expenses in oceanographic operations.

Although Coast Guard does not normally develop new technology, a considerable amount of its planned expenditures is dedicated to "acquisitions, construction, and improvements, " and in every program area such capital investment expenditures are found. The funds are used variously: to construct small boats; to purchase surveillance aircraft; to replace, renovate, or construct shore facilities, such as coastal and air stations; and to upgrade equipment. In all, Coast Guard estimated that approximately $280.8 million was used for these purposes.

**Table 5.—Estimated Expenditures in Selected Agencies, Fiscal Years 1980-84 (in millions of dollars)**

| Agency | 1980 | 1981 | 1982 | 1983 | 1984 | Total |
|---|---|---|---|---|---|---|
| NASA | $23.7 | $ 35.4' | $ 68.8b | $106.0' | $ 147.2 | $ 381.1 |
| NOAA | 513.9d | 444.4e | 382.0 | 381.9 | 381.8 | 2,104.0 |
| NSFf | 106.4 | 120.0 | 140.49 | 129.1 | 142.6 | 638.5 |
| Navy | 237.6 | 270.6 | 303.9 | 331.0 | 361.0 | 1,504.1 |
| Total | $881.6 | $870.4 | $895.1 | $948.0 | $1,032.6 | $4,627.7 |

[a] Funding for NOSS begins.
[b] Funding for NASA'S Ice Experiment (ICEX) begins.
[c] Funding fo, NASA's Topographical Experiment (TOPEX) begins.
[d] Includes $1344 million in prior-year carryover funds
[e] Includes $62.4 million in prior-year carryover funds.
[f] Includes support for deep-sea drilling and ocean margin drilling programs
[g] Includes construction cost for Ice-strengthened ship.

SOURCE. Off Ice of Technology Assessment, 1960.

In 1981 the new administration proposed substantial reductions in most nonmilitary programs for fiscal years 1981 and 1982. These proposals have not been analyzed for this report. However, they will undoubtedly have the most significant effect on major new and costly programs such as those noted in table **5.**

## *Personnel*

Seven agencies –Coast Guard, Navy, NOAA, DOI, NSF, DOE, and NASA –responded to OTA's request for staff allocations for fiscal year 1980. In these agencies, the number of personnel involved in Federal ocean-related programs is estimated to be about 56,000. Because each agency operates in a different manner, a comparison or evaluation of the staff level and the level of expenditures for staff is not possible. However, these estimates do provide a sense of personnel effort involved in ocean research in general and in each agency in particular.

It is of interest to note there are three different composition groups based on staffing levels within these agencies. The Coast Guard is in a group by itself with the largest number of personnel–43,757 (38,384 military and 5,373 civilian) and a very large portion of its budget allocated to direct agency-operated and staffed programs. This is because Coast Guard's work takes place mainly in the field; in ports, harbors, and at sea; and aboard its own ships or in its own facilities. The figures provided by Coast Guard represent the estimated number of people associated with all Coast Guard operating programs. In addition, Coast Guard is a multimission service; its personnel are generally not dedicated to one particular program, but may in fact support several programs.

A second group that includes NOAA, Navy, and DO I has a total of 11,000 staff working on its ocean-related programs — NOAA (4,704), Navy (3,972), DOI (2,324). These three have a mixture of work conducted by agency people at agency facilities and work conducted by contractors. The three are similar in total staff level and amount of money expended per staff person, and each has some major field operations and laboratory facilities. Table 6 shows the approximate allocations of these personnel to program categories.

The third group has very small staffs and includes NASA, NSF, and DOE. Each agency has 25 people or less working on ocean programs – NASA (9), NSF (25), DOE (24). Unlike the other agencies surveyed, these agencies maintain small core staffs and use contractors or grantees to perform all work. NSF and DOE rely on their staffs to evaluate proposals and to monitor contracts. NASA's ocean-related staff remains small, but if NOSS is funded, its Oceanic Processes Branch is expected to increase. This branch contracts out the majority of its research.

**Table 6.—Approximate Personnel Allocations to Program Categories for Three Agencies—NOAA, Navy, DOI — Fiscal Year 1980**

| Agency | Technology development | Ocean sciences | Weather/ climate | Energy/ mineral | Environmental quality | Fishery resource | Public service | Management enforcement | Agency support | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| DOI | 0 | 3 | 0 | 300 | 150 | 300 | 300 | 875 | 396 | 2,324 |
| NOAA | 141 | 26 | 294 | 0 | 143 | 1,509 | 641 | 635 | 1,315 | 4,704 |
| Navy | 70 | 672 | 0 | 0 | 0 | 0 | 0 | 0 | 3,230 | 3,972 |
| Total | 211 | 701 | 294 | 300 | 293 | 1,809 | 941 | 1,510 | 4,941 | 11,000 |

SOURCE Off Ice of Technology Assessment

# Chapter 3

# Discussion of Technologies

# Contents



TABLES



FIGURES

# Chapter 3
# Discussion of Technologies

## INTRODUCTION

There is no single technology system that is best suited for oceanographic research. A variety of federally supported ships, satellites, buoys, submersibles, and other technologies are used for oceanographic research and collection of data at sea. These technologies, plus the equipment, instrumentation, and other systems that are carried aboard or are part of them, comprise the ocean technology reviewed for this assessment. The objective of this chapter is to describe the status of this technology; to present existing data on the characteristics, costs, and uses of the equipment and systems; and to provide a brief analysis of capabilities. The chapter is divided into major sections addressing:

- Ships;
- Submersibles;
- Remotely Operated Vehicles (ROVs);
- Buoy, Moored, and Ocean-Floor Systems;
- Equipment and Instrumentation;
- Satellites;
- Aircraft; and
- Oceanic Data Systems.

Stations and instrument systems used in ocean research can only be evaluated in the context of specific tasks to be accomplished. Since ocean research covers such a broad spectrum of activities, it is difficult to compare the suitability or cost effectiveness of different technologies. Experimentation and data collection most often require a combination of systems and techniques. The following description of technologies by type includes both principal systems in use today as well as those which have growing future applications. It is followed by more detailed discussions of the Federal assemblage of technologies and the future plans for each type.

### *Oceanographic Ships*

Ships are used by oceanographers for carrying personnel and instrumentation to conduct experiments at sea. As both transport vehicles and floating laboratories, they are used for taking physical and chemical samples from the ocean, for deploying oceanographic instruments, for collecting data over large ocean areas, and for implanting and supporting other fixed and unmanned stations or smaller vehicles, such as submersibles, data buoys, remotely operated stations (fixed or floating), and diving systems.

Federally supported oceanographic vessels include 79 ships greater than 65 ft in length. The Federal fleet is comprised of a variety of types and is supported by six Federal agencies and programs. The total annual operating cost for all of the fleet is $130 million in 1979 dollars. A major problem now facing the fleet is the rapidly escalating operating costs caused by fuel price increases.

During the next 20 years, 95 percent of the Federal fleet will reach the age of 25. Economic studies indicate that it will be cost effective to rehabilitate or replace these vessels once they reach the point of technical obsolescence — about 15 to 20 years of age. Since replacement of the entire fleet of 79 vessels would cost about $1.4 billion in 1979 dollars, a policy of very selective new construction and rehabilitation of existing vessels will be required over the next 20 years.

Most oceanographers agree that a mix of various types of ships will be needed for the foreseeable future to conduct both deep-ocean and coastal research. As research priorities change, some newer (or less used) types will probably be developed. Among these are:

- *Polar research ships with ice-working capabilities:* While much planning has been done on polar ships, no major program has developed to support the construction of such a ship. The technology for working in ice from surface stations requires both engineering development and transfer of technology from other fields.



80-710 0 - 81 - 4

- *Adaptations of offshore oil and gas technology in industry to Federal oceanographic Programs:* The Ocean Margin Drilling Program (OMDP) is an example of plans to adapt and improve industrial technology for science. Many other commercial systems could be useful for Federal oceanic programs, either by adapting stations themselves or by developing cooperative projects,
- *Sail Powered ships:* Commercial fishermen are planning and building vessels with auxiliary or full sailpower to reduce fuel costs. The National Research Council's Ocean Sciences Board is studying sailpowered research ships.
- *Tugs and barges:* Towing various stations by one prime mover could be used by a number of ocean survey and monitoring projects and might reduce energy consumption.

## Manned Submersibles and ROVs

Manned submersibles are specialized vehicles used for some ocean research projects where direct human observation in the deep ocean is required. At present there are only five manned submersibles federally funded to do ocean research. Only one submersible, the *Akin, is* funded by Federal agencies for private-sector (non-Navy) research.

Although in the past decade manned submersibles were considered the most promising research tool of the future, it now appears that more attention will be given to remotely operated or other unmanned vehicles and platforms for many specialized data collection and monitoring tasks.

The value of manned and unmanned (remotely operated) submersibles for specific research projects has been demonstrated, but the cost and complexity of operating deep-ocean submersibles make alternatives or improvements attractive. Some new developments which may be useful in the future include:

- Improved systems for handling and providing surface support to submersibles to expand possible applications and to reduce operational complexity.
- Greater use of military systems or techniques for civilian research programs which could benefit from the substantial military capabilities (such as on the NR-1– Navy's Nuclear Research Submersible), but not detract from military missions.
- Development of improved ROVs, possibly adapted from recent military or industrial systems, to improve Federal capabilities for specific applications.

## Buoy, Moored, and Ocean-Floor Systems

Buoy, moored, and ocean-floor systems are instrumented systems for unmanned data collection, particularly at and below the ocean surface over a long period of time. They are thus invaluable for certain kinds of meteorological observations and for oceanic measurements of currents, tides, sediment transport, and seismic activity. In some cases, these systems can be sophisticated and are functional for more than a year. In other cases, they are relatively short-lived and simple, and may even be expendable.

Communication technology for buoys and other moored or free-floating systems has developed to the point where these systems are being more heavily utilized for routine surface and subsurface oceanographic data collection. Satellite data links currently provide near real-time access to moored and drifting buoys on a global scale. As a result, buoys are used extensively in worldwide monitoring of oceanographic and meteorological conditions. The National Oceanic and Atmospheric Administration's (NOAA) Data Buoy Office operates 19 large civilian U.S. buoys in U.S. coastal waters. Although several of the discus-type buoys have been lost due to toppling, sinking, and other reasons, overall performance of the large moored buoys has been steadily improving.

In the future, drifting buoys may be used increasingly for monitoring ocean surface and subsurface conditions. They have been successfully launched from aircraft and have provided excellent data in experiments such as the Global Weather Experiment and the North Pacific Experiment at Scripps Institution of Oceanography.

## *Equipment and Instrumentation*

A variety of equipment and instrumentation is carried on oceanographic research and survey ships.

Oceanographic instrumentation includes many types of sensors, the selection of which depends on the mission. In 1974, NOAA prepared an inventory of the U.S. stock of sensors and found there were about 21,000 sensor instruments of 34 generic types.

New oceanographic instrumentation techniques will probably be enhanced by the changes taking place in the field of electronics. Discrete components are being replaced by microchips. New electro-optic techniques are assisting in analytical chemistry. Both of these are assisting in the making of smaller, more reliable instrumentation. Ocean instruments may be developed or improved using these techniques. Examples of these and other aspects of new technology development for instruments are the following:

- Automated data telemetry for deeply placed instruments could improve their usefulness and reduce ship support time. Acoustic telemetry is used with some instruments to ascertain immediately after emplacement if the instrument is functioning properly. Some instruments enable a ship to query a bottom-mounted instrument to obtain the data that has been stored, and acoustic telemetry is being developed to transmit the data to a surface buoy. The retransmission of that data to a satellite and on to a data center could be accomplished in the near future.
- A series of techniques are being developed for profiling the ocean, such as free-fall current profilers, other shipboard acoustic remote-sensing techniques, as well as large moored arrays with acoustic sensors.
- Of particular interest to biological and chemical oceanographers are ways to sample water more rapidly at depths down to 800 m by towed, underway sampling systems. Continuous analytical chemical instrumentation systems from nonoceanographic laboratory and industrial chemical processing plants are being adapted to onboard analysis to provide near real-time measurements.
- In geological instrumentation, academia has developed such tools as the hydraulic piston corer and the very large free-fall corer. Geological research may require extensions of these as well as technology used by industry in offshore petroleum exploration. Industry has developed very long, towed, multichannel geophysical arrays, acoustical sources, and multichannel analysis computers.
- Understanding the perturbations of the ocean environment and, in turn, its effects on acoustic transmission in the ocean continues to be a major effort. In the past most of this effort was to advance undersea warfare. Emphasis in the future is to use acoustics to measure ocean-current density and temperature variations better and to aid in biological resource assessments. Efforts in acoustic tomography may lead to large-scale arrays useful for physical, chemical, and biological oceanography.

## *Satellites*

Satellites can measure ocean surfaces globally, providing data on a synoptic and timely basis. Some very large-scale ocean research projects– limited at present to sea-surface phenomena – can only be accomplished at reasonable cost by satellite.

Meteorological and oceanographic satellites began with the launch of *Sputnik I* by the U.S.S.R. in 1957. The first U.S. satellite series, Explorer and *Vanguard*, both carried meteorological experiments. The National Aeronautics and Space Administration (NASA) continued the development of operational meteorological satellites throughout the 1960's with its Nimbus series of research spacecraft. The last of that series, *Nimbus-7, is* currently operating.

In 1978 a research spacecraft, *Seasat-A*, designed for continuous monitoring of the world's oceans, was launched. The sensor systems of *Seasat* produced real-time data for determining ocean-surface winds, sea -surface temperatures, waveheights, ice conditions, ocean topography, and coastal storms. *Seasat-A* failed prematurely in October 1978. The next planned oceanographic satellite, the National Oceanographic Satellite System (NOSS), is scheduled for launching in 1986. Since it will not be possible to satisfy all oceanic research and operational data collection needs with NOSS, it appears that the following new technologies or adaptation of technologies from other fields may be beneficial in the future:

- Testing and development of research satellites in addition to NOSS for developing qualified sensors and measurement techniques for operational use.
- Continual use of ocean surface and subsurface sensors to provide satellite ground truth to validate synoptic sea-surface data from satellites.
- Data-handling technology to cope with the voluminous data flow from satellites to user networks.

## Aircraft

Aircraft are used to a limited extent for oceanographic research and survey work. Like satellites, they permit a synoptic overview of ocean-surface conditions. Even though aircraft operations are sometimes interrupted during adverse weather conditions, aircraft provide large payload capacity long-range, and adequate aerial coverage. They have been used for laying air-droppable instruments (such as buoy systems and arctic ice sensors), detecting ocean pollutants, measuring gravity and magnetic fields, measuring sea-surface conditions with high resolution, investigating hurricanes, and conducting research on marine mammals. Aircraft offer certain advantages in oceanic research or survey programs of the future.

Aircraft may become important stations for both sensor evaluation and scientific and applied oceanographic purposes. They may immediately be used for chlorophyll research as an alternative or supplement to satellites. They could also be used to reduce ship time for such operations as implanting buoy systems and free-fall ocean profiling sensors. Fixed-wing aircraft could operate in the Arctic and Antarctic where for a large part of the year ships, except for the largest of icebreakers, are immobilized.

## Oceanic Data Systems

Many Federal agencies are involved in the collection of oceanographic data. Although NOAA's Environmental Data and Information Service is the first agency specifically created to manage oceanographic data and information for use by Federal, State, and local agencies and the general public, it is currently chartered only to archive data from existing stations. Since there is a growing need for more current, near real-time environmental data, increased data volume in the future will require new organizations and management methods for data cataloging, storage, archiving, and distribution.

### Computers

This study has not addressed computers as a separate category of oceanographic technology. There are indications, however, that computers will play an increasingly important role in oceanographic research. Volumes of data from satellites and other ocean-monitoring systems require large computational capabilities for storage and handling. Numerical modeling of complex oceanic processes–such as heat transfer between the sea and the atmosphere — require the capability of large computers. Several groups are investigating the need for computers, especially very large capacity computers, in oceanography and how best to meet this need.

### Navigation

Satellite navigation, used by all major oceanographic ships, has revolutionized ship-position data. Continued development of oceanographic systems will make further use of satellite navigation technology.

- The new global satellite navigation system, GPS/NAVSTAR, is expected to improve oceanographic data-acquisition systems considerably by making position fixes available more frequently and by providing greater accuracy. The system will particularly aid navigation in the Arctic, although that was not a prime objective of the system when it was planned. Early development models of NAVSTAR receivers will be tested in fiscal year 1981. The total worldwide system is expected to be operational in 1986.

- There may be improvements in acoustic navigation systems for submersibles and ROVs through refinement of present systems to improve reliability and position accuracy.

# SHIPS

As of October 1980, the Federal fleet consists of 79 oceanographic research ships operated by or under the sponsorship of six Federal agencies. In addition, two new ships are under construction. One ship has just been built, and three others are in special status described later in this report.

The Federal fleet is a fleet in name only because of the diversity of its management, uses, and characteristics. In evaluating and comparing ship sizes within the fleet, it is important to note that a difference in length in a ship can significantly affect its capabilities. Large ships (over 200 ft) operate more safely and efficiently in the deep ocean in bad weather and can accommodate large scientific parties. Moreover, they are able to handle more than one type of over-the-side equipment, a necessity for interdisciplinary studies. A disadvantage of large ships is their fuel requirement. Smaller ships (less than 200 ft) use less fuel, but cannot cope with rough seas nor handle a variety of gear. They are, however, effective for some estuarine and coastal studies. Table 7 lists the numbers and sizes of operating research and survey ships over 65 ft that were federally funded as of January 1980. Some arbitrary exclusions were made from the list.

The Academic fleet has the greatest number of ships and is operated by universities and academic institutions around the United States. It is supported primarily by funding from the National Science Foundation (NSF) and the Office of Naval Research (ONR) (table 8) and is engaged principally in basic research. Next in size is NOAA's fleet (table 9), which is the principal Federal civilian survey and research fleet. It is operated by NOAA's National Ocean Survey out of east and west coast operational facilities and is directed toward more applied research work (and substantial survey work) than the academic fleet. Although NOAA's fleet is smaller in number than the academic fleet, it is greater in overall tonnage (thus having more large ships). The Navy fleet has fewer ships than either of the preceding groups, but is considerably larger in tonnage because of its very large ships. Navy's fleet is engaged in research and surveys directed toward military missions (table 10). The Coast Guard fleet, listed next, consists mainly of icebreakers, which only incidentally are engaged in ocean research, however, these are the only U.S. ships capable of work in the polar regions when icebreaking and navigation is required. Other Coast Guard cutters are fitted with oceanographic and meteorological instrumentation and laboratory space and are all used on occasion to support research projects. EPA's fleet of three small vessels — two in the Great Lakes and one on the east coast — is engaged primarily in ocean monitoring. The two U.S. Geological Survey (USGS) vessels, next on the list, are operated out of the

**Table 7.—Federal Ocean Research Fleet (July 1980)**

| Group | Number of ships | Size range (length in feet) | Total tonnage (displacement) |
|---|---|---|---|
| Academic fleet (UNOLS) | 27 | 65-245 | 23,000 |
| NOAA | 24 | 90-300 | 32,700 |
| Navy | 15 | 210-565 | 87,200 |
| Coast Guard | 7 | 180-400 | 50,400 |
| EPA | 3 | 124-165 | 1,000 |
| USGS | 2 | 180-210 | 2,200 |
| NSF | 1 | 125 | 600 |
| Totals | 79 | | 197,100 |

NOTES 1 The academic fleet IS composed of 10 NSF-built ships and 12-Navy built ships The remainder were built or converted by State or Insitutlons themselves. Operational funds for these ships are related to the oceanographic programs using the ships and are pl!nclpally funded (In 1979) by NSF(66 percent) and the Navy (12 percent) Rehabllltatlon of present ships, as applicable, IS under negotiation between NSF and Navy
2 Under Coast Guard, only one oceanographic cutter (Evergreen) and SIX Icebreakers are listed. In addition, all of Coast Guard's *40+* seagoing cutters have some oceanographic capablllty, but are not often used for this purpose.

SOURCE Off Ice of Technology Assessment

**Table 8.—The Academic Fleet (UNOLS)** (July 1980)

| Operator | Name | LOA (ft) | Built/ converted | Number of scientists | Owner |
|---|---|---|---|---|---|
| University of Hawaii | *Kana Keoki* | 156 | 1967 | 16 | U.H. |
| | *Moana Wave* | 174 | 1973 | 13 | Navy |
| University of Alaska | *Alpha* Helix | 133 | 1966 | 12 | NSF |
| University of Washington | *T. G. Thompson* | 209 | 1965 | 19 | Navy |
| | *Hoh* | 65 | 1943/1962 | 6 | Navy |
| | *Onar* | 65 | 1954/1963 | 6 | Navv |
| Oregon State University | *Wecoma* | 177 | 1975 | 16 | NSF |
| Moss Landing Marine Laboratories | *Cayuse* | 80 | 1968 | 8 | Osu |
| University of Southern California | *Velero I V* | 110 | 1948 | 12 | Usc |
| University of California, San Diego Scripps Institution of Oceanography | *Melville* | 245 | 1970 | 31 | Navy |
| | *E. B. Scripps* | 95 | 1965 | 8 | U.c. |
| | *T. Washington* | 209 | 1965 | 23 | Navy |
| | New *Horizon* | 170 | 1978 | 13 | u. c. |
| University of Michigan | *Laurentian* | 80 | 1974 | 10 | U.M. |
| Texas A&M University | *Gyre* | 174 | 1973 | 18 | Navy |
| University of Texas | *Longhorn* | 80 | 1971 | 10 | U.T. |
| University of Miami | *Iselin* | 170 | 1972 | 13 | U.M. |
| University of Georgia | *Blue Fin* | 72 | 1972/1975 | 8 | U.G. |
| Duke University | *East ward* | 118 | 1964 | 15 | D.U. |
| Johns Hopkins; University | 1?. *Warfield* | 106 | 1967 | 10 | J.H.U. |
| University of Delaware | *Cape Hen/open* | 120 | 1975 | 12 | U.D. |
| Columbia University (Lamont-Doherty Geological Observatory) | *Conrad* | 209 | 1962 | 18 | Navy |
| | *Vema* | 197 | 1923/1953 | 14 | Cu. |
| University of Rhode Island | *Endeavor* | 177 | 1976 | 16 | NSF |
| Woods Hole Oceanographic Institution | *Atlantis II* | 210 | 1963 | 25 | WHOI |
| | *Knorr* | 245 | 1969 | 23 | Navy |
| | *Oceanus* | 177 | 1975 | 12 | NSF |

SOURCE Unlversity National Oceanographic Laboratory System

west coast and are engaged in geologic research on the Outer Continental Shelf. Last, NSF has a small wooden ship engaged in Antarctic research during the southern summer.

In addition, two new coastal research ships funded by NSF are under construction. They are to be added to the academic fleet for operation by the University of Miami and by a consortium of Duke University (which will lay up the *Eastward)* and the University of North Carolina (figure 3). The contract for these two 130-ft long ships was negotiated in June 1980. The University of Miami has retired its much larger vessel (the Gillis–208 ft). Another coastal research ship of the same size is being planned by NSF, but because of operational funding shortages NSF is planning to reprogram fiscal year 1981 construction funds to operations.

Another ship, recently built, is a 127-ft long fisheries research ship for NOAA's Pacific fleet of fisheries ships (figure 4).

The following three ships, engaged in or proposed for NSF programs, have special uses and are not included in the tables:

- *Glomar Challenger:* A large, deep-ocean drilling ship, owned and operated by a private company, but under charter to NSF for the Deep-Sea Drilling Project (DSDP).
- *Glomar Explorer:* A ship originally built for the Central Intelligence Agency to recover a Russian submarine now owned by Navy and recently chartered by an industrial group engaged in ocean-mining experiments. This ship is proposed for the next phase of deep-ocean drilling bv NSF.

## Table 9.—Ships of the NOAA Fleet (July 1980)

| Class | Vessel | Length (ft) | Base location[a] | Primary mission | Year built | Number of scientists |
|---|---|---|---|---|---|---|
| I | *Oceanographer* | 303 | PMC | Oceanography | 1966 | 30 |
| I | *Discoverer* | 303 | PMC | Oceanography | 1966 | 24 |
| I | *Researcher* | 278 | AMC | Oceanography | 1970 | 14 |
| I | Surveyor | 292 | PMC | Oceanography | 1960 | 16 |
| II | *Fairweather* | 231 | PMC | Nautical charting | 1968 | 4 |
| II | *Rainier* | 231 | PMC | Nautical charting | 1968 | 4 |
| II | *Mt. Mitchell* | 231 | AMC | Nautical charting | 1967 | 4 |
| II | *Miller Freeman* | 215 | PMC | Fisheries research | 1967 | 11 |
| III | *Peirce* | 163 | AMC | Nautical charting | 1963 | 2 |
| III | *Whiting* | 163 | AMC | Nautical charting | 1963 | 2 |
| III | *McArthur* | 175 | PMC | Nautical charting/currents | 1966 | 2 |
| III | *Davidson* | 175 | PMC | Nautical charting | 1967 | 2 |
| III | Oregon II | 170 | AMC | Fisheries research | 1967 | 15 |
| III | *Albatross IV* | 187 | AMC | Fisheries research | 1962 | 15 |
| Iv | *George B. Kelez* | 177 | AMC | Oceanography | 1944 | 5 |
| Iv | *Townsend Cromwell* | 164 | PMC | Fisheries research | 1963 | 9 |
| Iv | *David Starr Jordan* | 171 | PMC | Fisheries research | 1965 | 13 |
| Iv | *Delaware //* | 156 | AMC | Fisheries Research | 1968 | 9 |
| Iv | *Ferrel* | 133 | AMC | Currents | 1968 | 0 |
| Iv | *Chapman* | 127 | PMC | Fisheries research | 1980 | 6 |
| v | *Rude* | 90 | AMC | Nautical charting | 1966 | 0 |
| v | *Heck* | 90 | AMC | Nautical charting | 1966 | 0 |
| v | *John N. Cobb* | 94 | PMC | Fisheries research | 1950 | 4 |
| VI | *Murre II* | 86 | PMC | Fisheries research | 1943 | 5 |

[a]AMC—Atlantic Marine Center, Norfolk, Va , PMC—Pacific Marine Center, Seattle, Wash

SOURCE' National Oceanic and Atmospheric Administration

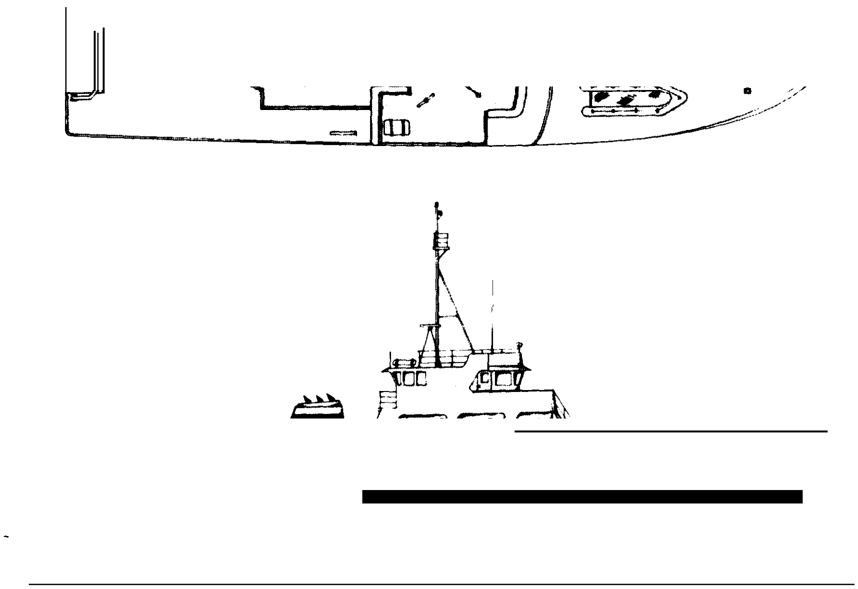
## Table 10.—The Navy Oceanographic Fleet (July 1980)

| Class | Vessel name | Length (ft) | Approximate operating region | Primary mission | Year built or converted | Number of scientists |
|---|---|---|---|---|---|---|
| AGOR | *Lynch* | 209 | Atlantic | Research | 1964 | 15 |
| AGOR | *De Steiguer* | 209 | Pacific | Research | 1969 | 15 |
| AGOR | *Bartlett* | 209 | Atlantic | Research | 1969 | 15 |
| AGS | *Silas Bent* | 285 | Pacific | General oceanography | 1965 | 30 |
| AGS | *Kane* | 285 | Atlantic | General oceanography | 1967 | 30 |
| AGS | *Wilkes* | 285 | Indian | General oceanography | 1971 | 30 |
| AGS | *Wyman* | 285 | Atlantic | Ocean survey | 1971 | 30 |
| AGS | *Chauvenet* | 393 | Indian | Coastal survey | 1970 | 12 |
| AGS | *Harkness* | 393 | Carribean | Coastal survey | 1971 | 12 |
| AGS | *Bowdich* | 455 | Atlantic | Ocean survey | 1958 | 40 |
| AGS | *Dutton* | 455 | Pacific | Ocean survey | 1958 | 40 |
| AGS | *Hess* | 564 | Pacific | Ocean survey | 1977(C) | — |
| AGOR | *Hayes* . | 246 | Atlantic & Pacific | Oceanographic research | 1971 | 30 |
| AGOR | *Mizar*•• | 262 | Classified | Classified | 1965(c) | 15 |
| AG | *Kingsport*•• | 455 | Classified | Classified | 1950 | 15 |

NOTE The above excludes those Navy-owned ships whtch are part of the Academic fleet
"The Hayes IS operated In support of the Naval Research Laboratory.
""&f/zar and *Kfngsport* are assigned to programs of the Naval Electronics Systems Command

SOURCE U S Navy

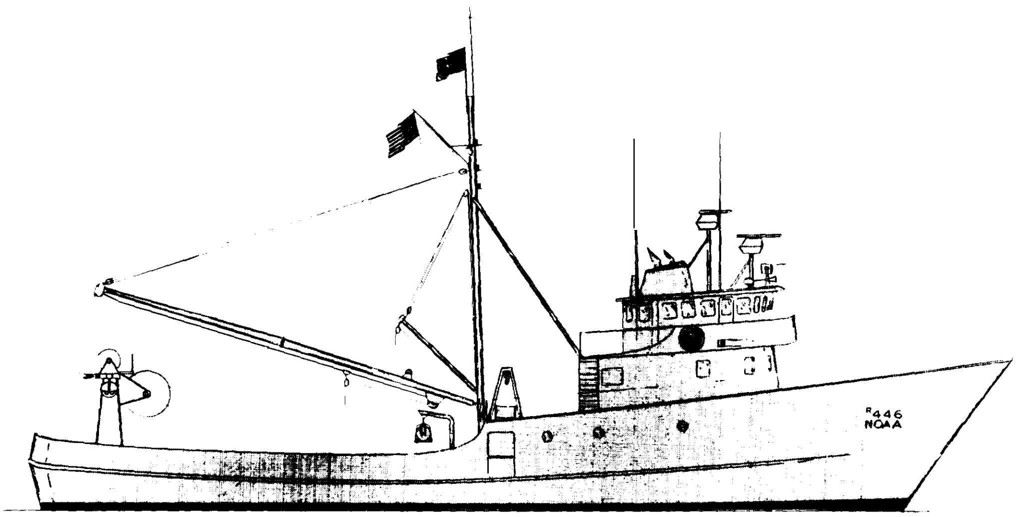
**Figure**



Main engines (2) caterpillar D-379 la, 540 hp ea. Generators: (2) caterpillar 3406 ta, 175 kW ea.
L O A .131 ft L B P..124 ft. Beam-30 ft. Depth-13.5 ft
Accommodations crew-9, scientists-11

SOURCE National Science Foundation

**Figure 4.— Design for New NOAA Fisheries Research Ship, Chapman**




Designer & builder— Bender Welding & Machine Co.
Hull—welded steel, displacement—520 tons
Length— 127 ft, beam—30 ft, draft— 14 ft
Cruising speed— 11 knots, range—6,000 miles, power—1 ,250 shp
Complement—4 officers, 7 crew, 6 scientists

SOURCE Nattonal Oceanic and Atmospheric Admfnlstratlon

- *Eltanin:* An Antarctic research ship which has recently been returned from loan to the Government of Argentina. NSF is considering its future use.

## Current Uses

The 79 ships in the Federal fleet are used for a variety of research and data-collection tasks. Large ships can conduct diverse research projects on a single cruise or on a series of successive cruises, Some ships combine research with operational duties; e.g., Coast Guard icebreakers are used where operational icebreaking is the primary mission and research is an important but secondary mission. Other ships, like Navy's survey vessels, collect both classified and unclassified data during their at-sea research operations.

The general uses (simplified for this report) of ships in the Federal fleet are shown in table 11. An example of the variety of uses of NOAA's fleet is given in figure 5, which displays the proposed fiscal year 1981 ship allocation plan.

## Age

The condition of ships in the Federal fleet and their potential replacement is a major concern because of the substantial capital costs involved. If a 25-year life is assumed for most of the research ships in this fleet, many current ships would need replacement within the next 20 years. Table 12 indicates when replacements would be built if each ship were retired after 25 years service. Since aging characteristics are not uniform, the table does not indicate a need for ship replacement nor the most effective plan for replacement if that need exists. Of note is the fact that the academic fleet has ships that are newer than those of the rest of the fleets.

**Table 11 .—The Federal Research Fleet— Principal Uses**

| Fleet group | Uses | Numbers in use categories |
|---|---|---|
| Academic. . | Basic oceanographic research | 27 |
| NOAA . . . . . | Surveys, charting | 10 |
| | Fisheries research | 9 |
| | General oceanographic research | 5 |
| Navy . . . . . . | Surveys, charting | 9 |
| | General oceanography operations | 6 |
| Coast Guard | Ice operations | 6 |
| | Data buoy servicing | |
| | Patrol and oceanography | (a; |
| EPA. . . . . . . | Pollution monitoring | 3 |
| USGS . . . . . | Marine geology | 2 |
| NSF . . . . . . | Antarctic research | 1 |
| Total. . . . | | 79 |

[a]Some minimal capability on all cutters.

SOURCE Off Ice of Technology Assessment

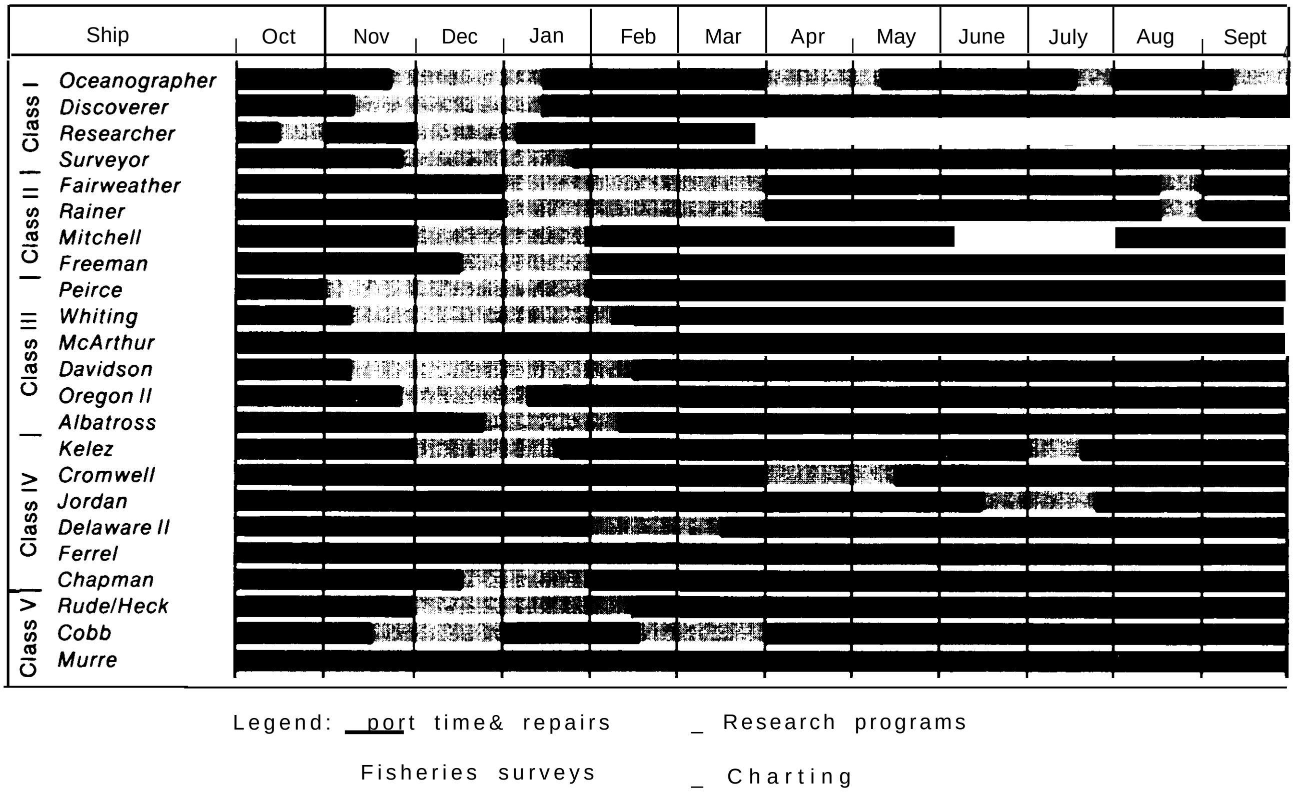
Economic studies by NOAA indicate that even though refurbishing and upgrading of key equipment is costly, it is an overall saving compared to replacing the ships at age 25. This approach appears to have been adopted as cost-effective by Navy with classes of warships. Furthermore, NOAA's analysis points out that there are no exact criteria for when to replace or to upgrade ships. Navy's experience with its Fleet Rehabilitation and Modernization Program indicates technical obsolescence occurs at a ship age of about 15 years. NOAA estimates its oceanographic ships might have a life of 25 years if no rehabilitation is made. At present, NOAA is considering a rehabilitation plan for ships in its fleet which are about 20 years old. This rehabilitation approach would shift the numbers in table 5 to later years.

## Size and Length Comparison With Foreign Oceanographic Fleets

The oceanographic research ships of the world over 100 ft in length are concentrated among eight countries. The United States and the Soviet Union, each with 34 research ships over 100 ft in length, have the largest fleets. The other six countries, Canada, France, the Federal Republic of Germany, Great Britain, Japan, and Norway, each have between 7 and 14 such research ships. Some fleets, like that of Canada, are heavily fishery-research oriented, Size and age characteristics of the large ships for these eight countries are given in table 13. Data for this table was

[1]U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *FY 1980 Issue Paper: Midlife Rehabilitation and Upgrade of NOAA Ships*, prepared for Director, National Ocean Survey, April 1978.

**Figure 5.—Schedule of NOAA Ships for Fiscal Year 1981 Showing Major Time Allocations**




SOURCE National Oceanic and Atmospheric Admlnlstratlon

**Table 12.—Number of Ships Reaching Age 25 in Next 20 Years**

| Fleet group | 1980-85 | 1985-90 | 1990-95 | 1995-2000 | Beyond 2000 |
|---|---|---|---|---|---|
| Academic . . . . | 3 (10°/0) | 9 (31%) | 5 (l%) | 10 *(34%)* | *2* ***(8°/0)*** |
| NOAA. . . . . . . . | 6 (25% | 12 (50%) | 6 (25%) | — | — |
| Navy. . . . . . . . . | 4 (27%) | 3 (2°/0) | 4 (27%) | 4 (27%) | — |
| Coast Guard . . | 5 (71°/0) | — | — | — | *2 (29%)* |
| EPA . . . . . . . . . | 1 (33%) | — | 2 (67%) | — | — |
| USGS . . . . . . . . | 1 (50%) | — | 1 (50% | — | — |
| NSF . . . . . . . . . . | — | — | 1 (10070) | — | — |
| Total. . . . . . . | 20 (25%) | 24 (30%) | 19 (23%) | 14(1 7°/0) | 4 (5°/0) |

SOURCE Office of Technology Assessment

taken from *Janes Ocean Technology 1979*[2] and includes only research ships. Survey ships, which vary widely from country to country in both size and purpose and are sometimes pressed into research use, were not included.

There are about 17 other countries adjacent to the sea that have between one and four oceanographic research vessels each. Many of these have been particularly important for both regional studies and for international programs such as the International Geophysical Year. These vessels will become increasingly important for global-type studies such as the World Climate Program.

Availability of charter ships is important in considering ship supply. Industries in Great Britain, Norway, the Federal Republic of Germany,

‘Robert L. Trillo (cd. ), *Jane's Ocean Technology})” 1979-1980,* 4th ed. ( New York: Franklin Watts, Inc. , 1979).

**Table 13.—Length and Age Characteristics of Major World Oceanographic Research Fleets**

| | Ship-length distribution | | | | Ship-age distribution | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 100-199 ft | 200-299 ft | 300-399 ft | Over 400 ft | 0-10 years | 11-20 years | 21-30 years | Over 30 years | Total |
| Canada. . . . . . . . | 8 | 3 | · | 2 | 1 | 10 | 2 | — | 13 |
| Federal Republic of Germany . . | 3 | 4 | | — | 3 | | | — | 7 |
| France . . . . . . . . | 9 | 3 | 1 | — | 7 | : | | — | 13 |
| Great Britain . . . | 6 | 6 | 2 | — | 5 | 7 | 2 | — | 14 |
| Japan . . . . . . . . . | 4 | 5 | — | — | 4 | 4 | 1 | — | 9 |
| Norway. . . . . . . . | 6 | 1 | | — | 4 | 1 | 2 | — | 7 |
| United States. . . | 22 | 10 | 2 | — | 10 | 19 | | 5 | 34 |
| U.S.S.R. . . . . . . . | 7 | 16 | 4 | 7 | 11 | 8 | 6 | | 34 |

NOTE. The U.S research ships in this table Include 20 from the academic fleet, 12 from the NOAA fleet, one NSF ship, and one Coast Guard ship
aLaunch dates were not available for many of the Russian ships

SOURCE. Off Ice of Technology Assessment.

France, and the United States offer charter ships that are research-equipped. Generally, these are smaller and more specialized ships such as seismic survey ships. Sometimes they are former government research ships.

Important features of table 13 include:

- The U.S.S.R. fleet includes more ships over 300 ft in length (very large by U.S. standards) than do the fleets of all free world countries combined.
- The fleets of the United States and the U.S.S.R. have similar numbers at very new (less than 10 years of age) and very old (over 30 years of age) ships.

## costs

To evaluate the dollar value of the ships in the Federal fleet, the present replacement costs for each ship were estimated, and then the estimates for the entire Federal fleet were tallied. These estimates were based on original construction costs (which were obtained from the agencies) plus an inflation factor. This system was used by NOAA in its recent report covering the ship rehabilitation plans, and the resulting costs are comparable to NSF's University National Oceanographic Laboratory System (UNOLS) estimates contained in a report on replacement of the fleet.[3]

Table 14 illustrates the data on replacement costs estimated as described. The costs shown do not represent needs or plans, but do illustrate relative replacement costs of the fleets in the future if the present use continues without major changes.

The total replacement cost of the entire 79-ship fleet is $1.4 billion in 1979 dollars. If replacement is spread over the next 20 years as shown, it will present a sizable funding problem. An important consideration is how to maintain needed capabilities in this fleet at a lower cost.

To estimate operating costs for the Federal fleet, the yearly fleet operating costs of the first four largest fleet groups (for 1979) was estimated using data supplied from the agencies (table 15). The total annual operating costs of the entire Federal fleet totaled about $130 million, which, if no changes are made in the future, could represent funding of $3.6 billion in current dollars over the next 20 years. Here again, Federal funding will undoubtedly limit this, and more cost-effective future planning may be required. Table 16 presents comparative estimates of the daily operating cost of the academic fleet and the NOAA fleet for 1979.4

[3]University - National Oceanographic Laboratory System, *On the Orderly Replacement of the Academic Fleet*, July 1978.

[4]National Science Foundation, *UNOLS Funding 1%)/tie, 1973 to Projected 1981*, May 1979.

**Table 14.—Oceanographic Fleet Replacement Cost Estimates in Million of Dollars in the Next 20 Years (based** on 1979 dollars)

| Fleet group | Replacement **year category** 1980-85 | 1985-90 | 1990-2000 | Beyond 2000 | Total |
|---|---|---|---|---|---|
| Academic | $ 10 | $ 75 | $ 75 | — | $ 170 |
| NOAA | 60 | 170 | 120 | — | 350 |
| Navy | 160 | 65 | 175 | — | 400 |
| Coast Guard | 230 | | — | 220 | 450 |
| EPA | 5 | — | 30 | — | 35 |
| USGS | 5 | — | 10 | — | 15 |
| NSF | — | — | 5 | — | 5 |
| Totals | $470 | $310 | $415 | $230 | $1,425 |

SOURCE Off Ice of Technology Assessment

**Table 15.—Oceanographic Fleet Operating Cost Comparison**

| Fleet group | Annual operating cost Millions of 1979 dollars | Number of ships |
|---|---|---|
| Navy | 50 | 15 |
| NOAA | 36 | 24 |
| Academic Fleet | 25 | 27 |
| Coast Guard | 20 | 7 |
| Total | 130 | 73 |

SOURCE Office of Technology Assessment

**Table 16.—Academic and NOAA Fleet Comparison of Daily Ship Operating Costs (size in length in feet–costs in $1,000 per day for 1979)**

| Academic fleet | | NOAA fleet[a] | |
|---|---|---|---|
| Size range | Costs (average) | Size range | Costs (average) |
| 60-99 | 1.3 | 86 | 1.7 |
| | | 90-100 | 2.3 |
| 100-149 | 3.2 | 133-170 | 4.1 |
| 150-200 | 4.7 | 163-187 | 6.2 |
| | | 215-231 | 10.3 |
| Over 200 | 6.9 | 278-303 | 13.5 |

[a]NOAA ships are generally staffed with a permanent crew of Government employees, including technicians trained to meet ongoing NOAA missions; whereas, the academic fleet uses students as research assistants at sea

SOURCES General Offshore Corp *NOAA Fleet Mix Study, FY 81, FY 84, FY 88*. prepared for the National Oceanic and Atmospheric Administration, Off Ice of Fleet Operations, contract No NA-79-SAC 00632, Aug 23. 1979, National Science Foundation, *UNOLS Funding Profile. 7973 to Projected 1981* May 1979

## *Present and Future Plans for Ships*

Much of the Federal technology now in use by the ocean community has been in place for many years but has not had recent careful evaluation. Although the need for seagoing vessels remains and is somewhat expanded by the addition of new ways to examine the ocean, there exists a general erosion of certain ship platform and research capabilities that will worsen in the future if the present trend continues. Most apparent in, but not exclusively in, the deep-water academic fleet, this erosion affects the ships themselves, the instrumentation and equipment aboard them, and their general condition of repair. The Federal agencies that have traditionally funded and supported oceanographic research and survey ships have not developed comprehensive plans for the fleets of the future; although planning is underway within the individual agencies and through the new Federal Oceanographic Fleet Coordinating Council.

### The Academic Fleet

NSF and ONR of the Navy are the principal agencies that fund the academic fleet.

Three divisions within NSF support construction and operation of academic research ships. The Division of Ocean Sciences funds the academic fleet, the Division of Earth Sciences funds the *Glomar Challenger*, which is used for DSDP; and the Division of Polar Programs funds Antarctic research ships (one small ship at present). Each of these divisions uses a different management approach. More than two-thirds of the cost of operating the academic fleet is funded by NSF grants to the operating institutions on an annual basis. Ship-time funding is determined by the level of NSF-funded science projects requiring ship time. Navy owns nine of the ships in the academic fleet, including all but one of the largest class of ships and all but two of the next largest class; and supports 10 to 15 percent of the oper-

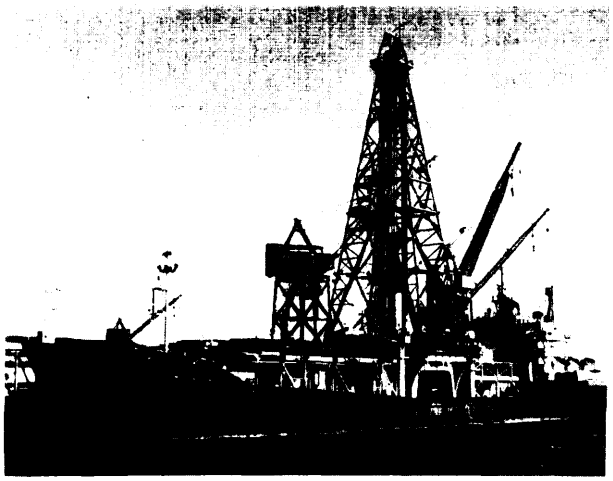


Photo credit Scripps /nst/tut/on o/ Oceanography

D/V *Glomar Challenger,* under contract to NSF, is utilized in the Deep Sea Drilling Project and managed by Scripps Institution of Oceanography

ating costs of the academic fleet through research project funding.

Additional funds for the academic fleet are provided by other Federal agencies (10 to 15 percent) and from States and private groups. Some ships are federally owned and some are not, but all are operated by individual institutions with their own personnel and management.

In July 1978, UNOLS made some recommendations on the size and composition of the academic fleet. The projections suggested that the basic size of the fleet required little change in the short run because the research budget was very stable, Since emphasis would be placed on research in coastal and continental margin waters, more and better equipped coastal vessels would be required. Larger ships would be needed for coastal work in the winter, for multidisciplinary studies in all areas, and for distant water and open-ocean operations.

UNOLS also proposed a program of orderly renovation and modification of vessels to maintain the fleet. It suggested that an annual expenditure of $3 million over the next 15 years would be adequate to replace intermediate and smaller vessels and that additional funding of about $48 million would be required for replacing four major vessels which should be retired between 1982 and 1993.

NSF's Division of Ocean Sciences Ship Plans. – With advice from academic institutions, particularly through UNOLS, NSF's Division of Ocean Sciences periodically reviews the current and future uses and needs of the academic fleet in order to effect changes in the fleet, including the construction of new ships and the retirement of old ones. In 1979 the Division of Ocean Sciences made several analyses of trends and of the near-term future of the academic fleet. The analyses noted that the downward trend in ship use for scientific funding support could only be changed by a massive increase in field research support.[5] This conclusion led to the decision to support construction of new coastal ships (135-ft size range) and encouraged the retirement of at least one large ship (AGOR class, 208 ft). Two coastal vessels are now under construction.[6] The first will be operated by the University of Miami; the second will be operated by a Duke University and University of North Carolina consortium.

At present, the Division of Ocean Sciences concludes:

1. There are no major new demands for ship time over the next 5 years, mainly because future funding of ocean sciences is expected to remain level;
2. There is more potential demand for smaller ships than for larger ships because of a reduction of major field projects in geology, chemistry, and physical oceanography; and
3. There are more possibilities of projects in the fields of coastal biology and pollution.

It should be noted that the first conclusion is in contrast to those of the Division of the Earth Sciences and the Division of Polar Programs, both of which anticipate major new projects requiring new large ships.

Over the next 5 years, NSF has projected $4 million to $5 million per year for capital addi-

[5]National Science Foundation, Division of Ocean Sciences "Report on Oceanic Research Facilities," draft paper, June 1979.

[6]National Science Foundation, Project Solicitation, "Construction and Operation of a Coastal Research Ship," February 1979,

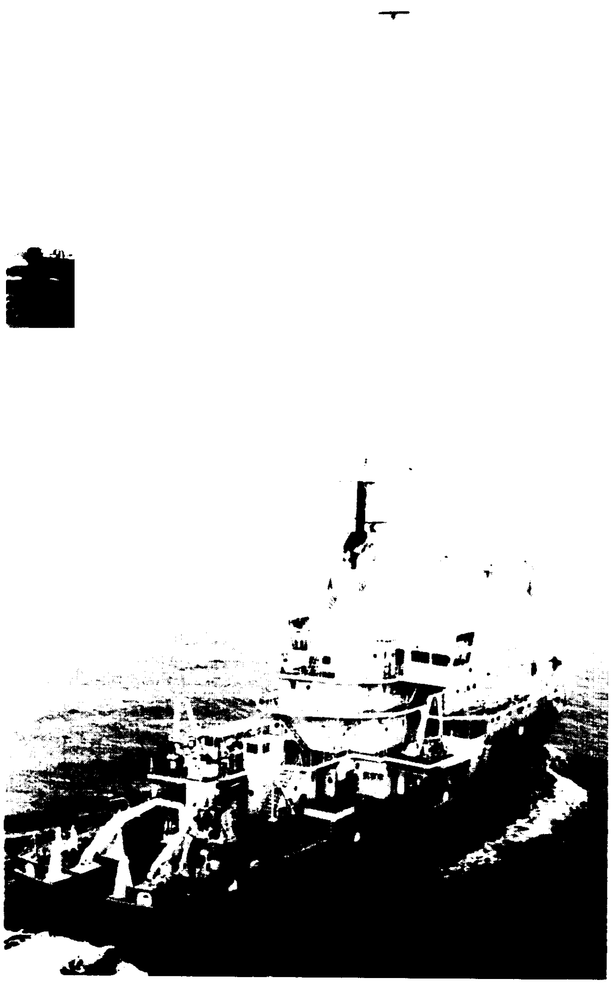


Photo credit: Scripps Institution of Oceanography

Two of the larger, deep-ocean ships of the Academic Fleet are the *Atlantis II* (top) from Woods Hole Oceanographic Institution and the *Melville* from Scripps Institution of Oceanography

tions to the academic fleet. About $1 million to $1.5 million of this is planned for ship equipment, such as winches, wire, and navigation equipment. This leaves about $3 million plus per year, or about the cost of one coastal ship per year. In the near term, however, a shortage of ship operating funds and an increase in fuel costs, not evident when UNOLS projections were made, may require NSF to reprogram capital funds to the operating accounts. Moreover, there is serious concern among the oceanographic research institutions that funding for current ship operations is so limited that more major ships with valuable and unique capabilities will be retired. There is particular concern that an adequate large ship capability in the academic fleet be maintained. Much of the research completed in the International Decade of Ocean Exploration in the 1970's was performed on large ships because many of the field projects were interdisciplinary, long-term, and long-range in nature and required a large crew of scientists and technicians. It is believed that to accomplish much of the future research work in fisheries, climate, pollution, geology, and basic research programs, large (seagoing) ships must be available.

NSF's Division of Polar Programs Ship Plans. –This program principally supports oceanographic and geologic projects in the Antarctic region and currently operates one small ship, the *Hero,* which has limited capabilities for major research work or for ice operations. NSF's Division of Ocean Sciences also supports cruises by some of the academic fleet for Antarctic work with funds from the Division of Polar Programs. Most of the academic ships and NOAA ships that now work in the high latitudes are not designed for even cold water operations. Much effort has been invested over the past several years to develop a suitable polar research ship (or ships) as a possible addition to the academic fleet.[7] Increased attention to the Arctic was the prime

[7] R. Elsner, *Polar Research Vessel, A Conceptual Design,* University of Alaska, May 1977.

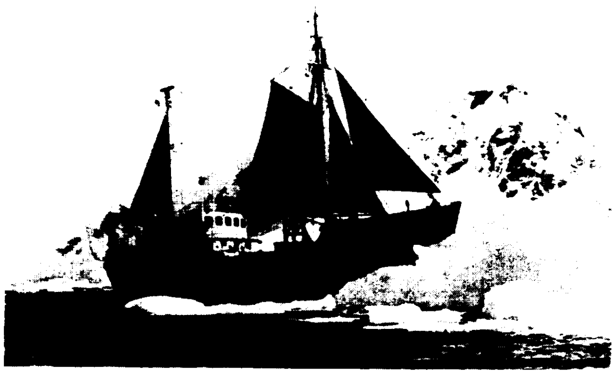


Photo credit: Wm. R. Curtsinger

NSF's R/V Hero, a small wooden ship with limited capabilities, faces major tasks in the frozen Antarctic waters motivation for the effort; however, the Division of Polar Programs is now principally focused in the Antarctic where there is a growing interest in Antarctic living resources, especially krill.

The iceworking capabilities of any polar ship are usually limited. None of NSF's designs for a polar research ship would be as capable in heavy ice as are existing Coast Guard icebreakers; although the new ship design could operate in moderate ice of 1.5-ft thickness, could do some icebreaking, and would also have capabilities in rough, open-ocean waters.

Instead of constructing a new polar research ship, the Division of Polar Programs may refurbish the *Eltanin,* an ice-strengthened ship. When NSF compared the cost and resulting capabilities between constructing a new ship or refurbishing and upgrading the *Eltanin,* it concluded that the *Eltanin* could be refurbished and upgraded for approximately one-third of the cost of the new ship. Refurbishment, operation, and maintenance costs of the *Eltanin* will begin to exceed those of a new ship by 1990.[8] In mid-1980, funding for the conversion of the *Eltanin* was favored, but no final decision has yet been announced.

NSF's Division of Earth Sciences Ship Plans. – In this division, DSDP utilizing the *Glomar Challenger is* scheduled to be phased out in fiscal year 1982, and OMDP is scheduled to take over where the *Challenger* left off. Since OMDP is a major new initiative in technology development and ocean science, OTA has presented an evaluation of it in a later section of this report. The plans include the conversion of a ship *(Glomar Explorer)* for deep-sea drilling. This program overshadows most of the other plans for oceanographic ships in NSF and could affect funds available for other ocean science programs and facilities.

[8]Harbridge House, Inc., "Eltanin Cost Analysis," prepared for National Science Foundation. November 1979.

*Photo credit: National Science Foundation*

R/V *Eltanin,* now inactive, was constructed in 1957 as an ice-strengthened cargo ship and converted in 1961 to a research ship for the Antarctic

Navy Academic Ship Plans. –The Navy is now examining its future role in support of oceanographic ships. It continues to have a strong interest in basic military oceanographic research, which has traditionally been accomplished by several oceanographic institutions. Funding of this research, however, has not kept pace with inflation over the last decade and is now projected to continue into the 1980's at about the present level. Future Navy funding of new ship construction for research institution use is not in the present plans. It is hoped, in cooperation with NSF, to fund the upgrading and new equipment needs for Navy-owned, academically operated ships. Navy will also consider on a case-by-case basis sharing the upgrading costs for those ships owned by NSF or by the institutions themselves. Navy cites two factors as justification for this support: 1) there is a need to maintain capabilities in locations important to Navy; and 2) other programs may not cover high latitude areas and open oceans far from U.S. shores. These basic research needs also support a need for the larger oceanographic ships.

In 1980, Navy proposed $2.3 million in its fiscal year 1981 budget for upgrading the scientific suite and major midlife overhaul for Navy-owned academic research ships. This will be a planned budget item for the next 4 to 5 years.

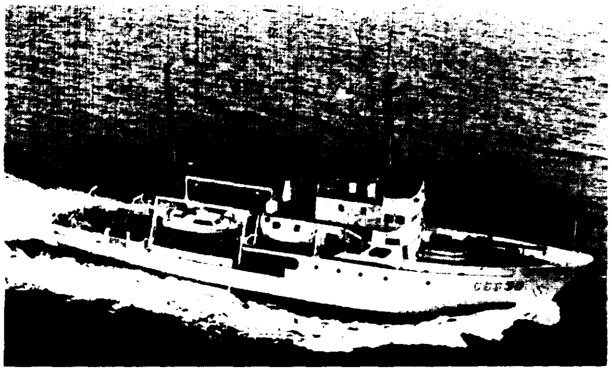
### NOAA and Other Agency Fleet Plans

NOAA's operational ships have been studied and reviewed several times recently. In August 1979 a fleet-mix study prepared by an outside contractor, but not released by NOAA, projected needs and costs through fiscal year 1980 for oceanographic ships. It found that NOAA's fleet was reasonably appropriate for the existing

NOAA program needs; and only a shift to smaller sizes, the addition of a few ships, and some efforts to modernize were needed to satisfy future research and data-collection needs. The study recommended a variety of approaches for upgrading the fleet, including some rehabilitation, some construction of smaller ships to replace larger ones, and more long-term chartering to fill the gaps.[9] NOAA is now studying three aspects of that study to define more accurately its needs, including:

1. whether to charge specific programs for ship costs rather than to fund all the ships from one large account;
2. the possibilities of long-term charters or other chartering changes; and
3. new program requirements (for fisheries, pollution, climate) for future ships and other technology.

[9] General Offshore Corp., *NOAA Fleet Mix Study, FY 81, FY 84, FY 88*, prepared for NOAA, Office of Fleet Operations, contract No. NA-79-SAC600632, Aug. 23, 1979.



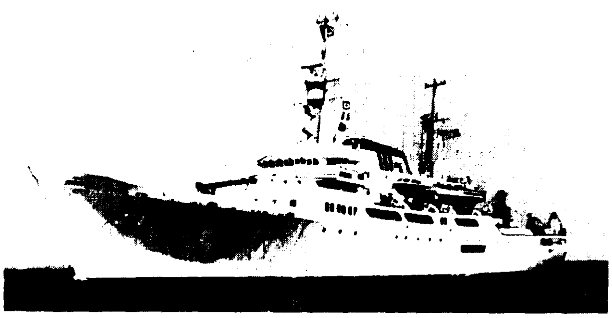


*Photo credits: National Oceanic and Atmospheric Administration*

NOAA's survey ships: (top) *McArthur,* 175-ft long and the 303-ft long *Oceanographer*

NOAA projects fleet operations expenditures to continue at about the same level into the near future, with ship operating costs equally divided between east and west coast bases (Norfolk and Seattle).[10] In the fiscal year 1981 budget, it allocated $3.5 million for upgrading and rehabilitation of some ships as part of its plan to upgrade 15 ships, including 3 of its 4 large ones, during the 1980's.

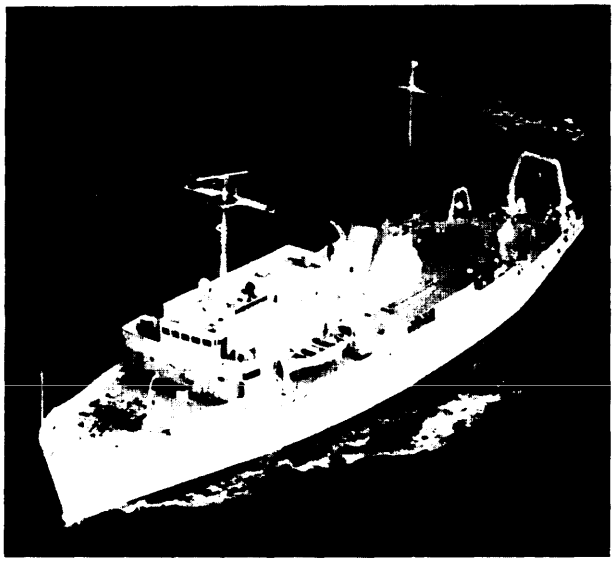
The missing aspects of all of the recent studies by NOAA are considerations of major new research problems, of coordination with academia, and of consolidation of NOAA ship needs with those of other agencies. NOAA has established an internal working group to examine these issues. In a letter to OTA, NOAA claimed that its present study proposes a set of decisions based on NOAA's best projection of future requirements of the fleet over the next decade. Some of these future NOAA research needs can be found in its fisheries program, development of plans for pollution monitoring, and the emergence of a need for information concerning the global ocean's physical structure and circulation in connection with the climate program. NOAA will also examine relevant marine programs to determine possible changes in ship requirements and will offer a reasonable set of options for projecting demands. It will also consider the effect of changes in technology and of the use of other stations, such as buoys or satellites, on ship requirements.

### The Navy Oceanographic Fleet

There is a continuing need for Navy to conduct surveys and to collect oceanographic data to support fleet operations. This is separate from Navy research sponsored in the academic fleet in which most of Navy's oceanographic fleet (9 out of 15 ships) are engaged.

Four ships conduct research work at Navy laboratories, the *Lynch, De Steiguer, Bartlett,* and *Hayes,* and two ships are used in the Naval Electronic System programs, the ***Mizar and*** *Kingsport.* Much of this work is classified, and

[10] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *National Ocean Survey Annual Report/Fiscal Year 1978,* March 1979.



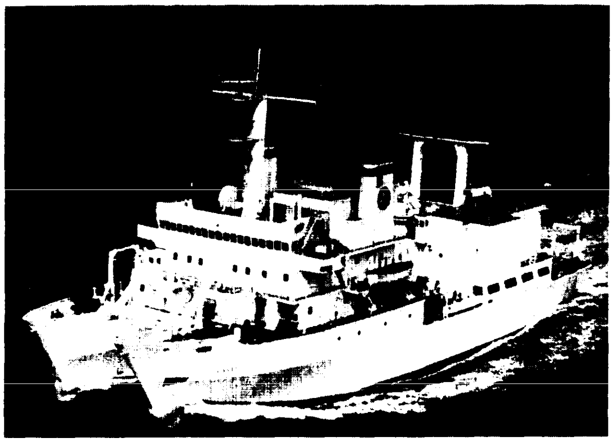


*Photo credits. US, Navy*

Two of Navy's research ships *De Steiguer* (top) and *Hayes*

future ship needs will be determined by the programs they support. Currently some Navy labs use academic or other vessels. One future change is that the Naval Oceanographic Research and Development Administration (NORDA) may be assigned the major oceanographic research ships in Navy's fleet and thus have operational responsibility for them.

### Environmental Protection Agency (EPA) Fleet

EPA owns and operates three ships engaged in applied research work — two in the Great Lakes and one on the east coast — and has invested about $300,000 each to convert them for its use. The Great Lakes ships are used principally for water quality studies. Presently, only one of them is in service. They are each operated by a private company under a 3-year contract.

The east coast vessel, the *Antelope, is* engaged in surveys of dump sites for EPA's ocean-dumping permit program. EPA claims that its dump site survey ship is more cost effective than other alternatives, such as ship time from other agencies. It may be that agencies with specific research programs, such as EPA, can more efficiently provide their own ships for their purposes, but there is no available evaluation of the cost effectiveness of this approach versus that of using the Federal Government's established research fleet operators.

Future plans for EPA ships are not certain. There appears to be a long-term need for the services of at least one vessel on the Great Lakes for EPA's water quality program, one ship on the east and gulf coasts for the ocean-dumping permit program, and one ship (possibly chartered) on the west coast. At present EPA has no specific plans for the long-term future operation or expansion of its fleet. When the 3-year contracts for the existing ships expire, EPA will decide on a next step.

*Photo credit. Env/ronmental Protect/on Agency*

Environmental Protection Agency's *Antelope*

### Coast Guard Fleet

Coast Guard's icebreakers can support research operations and are used for this purpose by several other agencies, including **Navy, NSF,** and NOAA. Coast Guard also operates one research ship used principally for its own missions.

Future plans for the Coast Guard fleet include maintaining the capability for its mission of breaking ice for defense and civilian missions and surveying and tracking ice that may be hazardous to navigation. Oceanographic research, however, does not appear to play an important role in plans for future ships, partly because many scientists feel that icebreakers are not suitable for research and that their operational management is incompatible with research missions.

New icebreakers to replace the *Wind* class in the mid-1 980's are now being designed. It may be desirable to coordinate the design work with the design of polar research ships by NSF. Another consideration is whether Coast Guard's polar fleet could be better configured for a variety of ocean-science tasks in the Arctic and Antarctic, either in lieu of or in support of other aforementioned polar research ship developments.

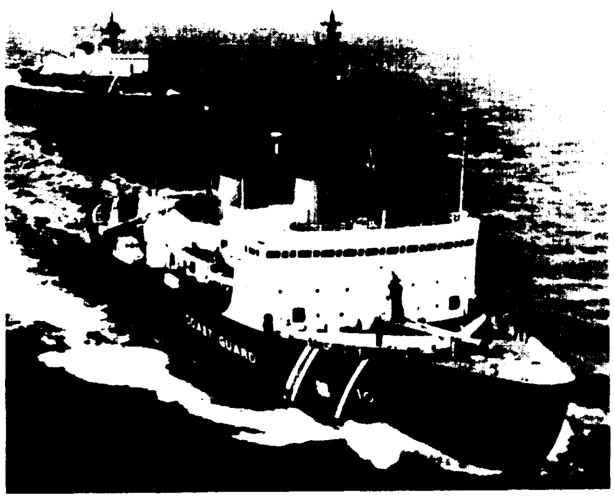


*Photo credit U S Coast Guard*

U.S. Coast Guard's *Polar Star* can break ice 6-ft thick while maintaining a 3-knot speed

### USGS Fleet

The ships supported by USGS represent a small portion of the entire Federal fleet, but do support important marine resource survey work of this agency in the Pacific and Alaskan areas. USGS relies on other agencies, such as NOAA, and academic institutions to provide ship support when needed.

In the Pacific and Alaskan OCS areas (until fiscal year 1980), USGS operated two ships–one for regional resource assessment, the other for environmental surveys. Because of fiscal constraints in fiscal year 1980, USGS now operates only one ship in these areas. USGS is presently evaluating the cost effectiveness of either a dual-operational role for the one ship, or the partial use of NOAA, university, and charter vessels to meet mission requirements.

Alaska presents unique problems for USGS work because its very large continental shelf and complex environmental problems are coupled with a short field season. At present, NOAA provides ship support to USGS in Alaska. In a recent letter to OTA, USGS stated that in the long term, an ice-strengthened vessel, fully committed to USGS marine environmental surveys, should be constructed. This commitment would require multiyear funding for construction, operation, and maintenance.

In the Atlantic OCS and the Gulf of Mexico, USGS does not own or operate oceanographic research vessels. Instead, through cooperation with UNOLS, it uses university ships during the relatively long field season.

## *Alternative Plans for Future Ship Operations*

The future structure, size, capability, and research technology of the oceanographic fleet, will be determined by the aforementioned plans and by the research to be done. There are some alternatives to present plans that are now under study that may improve capabilities or reduce costs.

### Alternative Management Systems for the Academic Fleet

Consistent, long-term planning and funding by all principal agencies that use the academic fleet may increase the operating efficiencies of the fleet. Part of such a system of future fleet support is now in place in NSF and UNOLS. However, other agencies, principally Navy and perhaps NOAA, the Department of Energy (DOE), and USGS, could be more involved in fleet planning than they are at present. Planning to this end has begun through the Federal Oceanographic Fleet Coordinating Council.

NSF Management Practices. – NSF's present management system is designed to review operation proposals each year (July through November for the following year) after major decisions are made on research projects requiring ship time. Grants are then usually made to those institutions operating ships for the total time that the ships are to be used on NSF projects and are based on the cost proposals submitted for the ships. Navy (ONR) funds project time and ship time together, but it makes decisions much later in the planning cycle than NSF does. NSF and Navy coordinate their processes informally. Some agencies, such as USGS, regularly contract for academic ship time by passing funds through NSF. Other agencies, such as NOAA and DOE, contract for academic ship time separately, with little or no long-range coordination with NSF,

While this system seems to offer needed flexibility, some problems exist. ONR and NSF are now working together to improve the coordination of ship funding and management practices. If other agencies such as NOAA or DOE become substantial users of academic ships in the future, more coordination may be necessary.

NSF has gradually assumed the major Federal responsibility for funding academic ships. Further efforts by NSF to coordinate other agency use or to consolidate management and funding procedures may result in increased use of academic ship at costs that are usually very competitive.

Future Academic Fleet Replacements. – The bulk of the academic fleet is new enough not to require replacement in the near term (less than 5 years). The present commitment to build two coastal ships by NSF is of concern because it is at the expense of the operation of other major ships in the fleet. The major immediate concern about this fleet is not for building new ships, but for providing adequate funds to operate and maintain the present fleet.

NSF and ONR have jointly sponsored a study by the Ocean Sciences Board of the National Academy of Sciences to examine the future of the academic research fleet. Several areas of fleet management, composition, and operation will be evaluated for both the short term and the long term. Specifically, the study will address the following issues: the long-term fleet size and mix, namely, the number and size of general-purpose vessels and special-purpose-vessel needs such as dedicated geology and geophysical vessels and high-latitude ships; an examination of the different approaches to fluctuations in fleet usage, such as layups, leasing, buying of excess Federal agency fleet time, and other options; a description of the different modes of fleet operation according to local, regional, and Federal agency practices; the acquisition of new vessels by new construction, a refit of federally owned vessels, or leasing; an examination of vessel maintenance, refitting, and upgrading; and the different approaches to the review and funding of ship needs.

Regional Operating Centers for the Academic Fleet. –- The major oceanographic institutions, UNOLS, and some of the Federal agencies have been discussing the feasibility of establishing some form of a regional operating system for the academic fleet. [11] Some groups claim that future tight budgets will force closer cooperative operating arrangements, at least for the larger, more expensive ships, and that a well-planned system could offer benefits for both the researcher and the Government. There is much controversy over this subject, and no consensus has been reached.

The present practice of assigning oceanographic ship operating responsibilities to institutions, based on the merits of their scientific programs and their operating or management capabilities merits a review in light of several changes

[11] University-National Oceanographic Laboratory System. "Report of the Working Group on Joint Ship Scheduling," May 1980.

in the nature of oceanographic cruises. For one, a significant amount of oceanographic ship time is spent on multi-institutional projects that are planned jointly by many participating scientists and are often integrated into international programs of long duration and large scope. Because research often takes the form of large-scale, planned data-collection efforts, scientific productivity and skills at ship management do not necessarily go together. The scientists from an institution and its ships and crews do not now form as close and as isolated a group as in the past.

Some groups have proposed operation of regional coastal oceanographic ships to serve many users on many short cruises in coastal research. For at least one of the possible future coastal ships, regional operation was proposed so that the ship could be operated by an institution which also operated several other major ships. It was also planned to have alternate ports for the ship so that the ship could be operated by the operator institution, yet could return to port easily for minor overhaul. Thus, it would be managed from, but would not necessarily operate from, the dock of the operator institution. In this way both flexibility and cost effectiveness could be attained by standardizing maintenance, spare parts, and some equipment.

It is clear that there can be different kinds of regional operations. One kind may be simply a home base for a number of ship facilities. Another kind may be a geographic operations area with one or more bases for ship facilities. Finally, regional operators may be a group of users whose laboratories have geographic proximity, but whose research interests are more cosmopolitan.

### Alternative Management Systems for the Agency Fleets

Navy and NOAA have major survey fleets that respond to a continuing long-term need for routine data collection. In fact, several major multipurpose oceanographic ships are in both Navy and NOAA fleets. Other agencies seem to have an uncertain commitment to future research and survey fleets.

Consolidating some Federal agency fleets that appear to have almost identical capabilities and uses and coordinating with different fleets that can from time to time efficient y match capabilities and needs may be cost-effective. Some consolidation has been suggested among NOAA, USGS, and EPA. Both USGS and EPA have a small number of ships with uses very similar to part of the NOAA fleet. In practice, however, it is quite difficult to maintain research program quality and flexibility in one agency when control of principal technology, such as ships, is in another agency. Most agencies with ships claim that their needs are sufficiently unique to require that their ships be under their own agency or program control.

Coordination among all agencies that operate oceanographic ships is taking place in the Federal Oceanographic Fleet Coordinating Council. Future trends in coordination may include planning for oceanographic capabilities for new vessels and considering whether these vessels can meet the program needs of other agencies prior to building. Also, there is a need to coordinate continually the requirements and capabilities of the academic fleet with those of the operating agencies, some of which is already being done. The possibility of more agencies chartering academic ships has been proposed to eliminate possible duplication of capability. Avoiding duplication may also involve sharing appropriate technological developments and many routine data-collection efforts among agencies like Navy, Coast Guard, and NOAA.

While coordination cannot cure all inefficiencies, it offers the possibility for improvements. A disadvantage of such a system is that it would complicate specific tasks and thus decrease flexibility. Since complexity might be inefficient for small programs and small ship operations, a simple analysis of specific costs and benefits would be useful prior to any major changes in the present system.

### Ships-of-Opportunity

Two types of ships-of-opportunity programs are now in effect. One program involves the World Meteorological Organization (WMO), that transmits ships' officers' observations of weather and sea conditions by radio to participating countries.[12] The U.S. Navy's Fleet Numerical Oceanography Center (FNOC) at Monterrey, Calif., processes such data for the United States and provides it for distribution to civilian users through NOAA.

The other ships-of-opportunity program involves specific merchant ships that traverse remote sealanes where oceanographic data are sparse and are needed. It is a cooperative NOAA/Navy program and at present is used to collect temperature/depth data exclusively. The cost of collecting such data is relatively low because the participating ships provide the manpower and the ships without cost. Navy furnishes the ships with expendable bathythermograph probes (XBTs), shipboard launchers, and recorders. Both NOAA and Navy provide liaison services to the participating ships.

The principal uses of data thus collected are for weather forecasting, ship operations and routing, commercial fishing, and some large-scale research projects. In the future, such data-collection systems could be expanded for climate and pollution studies. The ships-of-opportunity observations are especially useful if combined with measurements from buoys, satellites, and other stations.

The present NOAA/Navy ships-of-opportunity program operates through Navy's FNOC. Approximately 125 ships of both U.S. and foreign registry participate directly or through specific research programs, NOAA and Navy have signed a memorandum of agreement (November-December 1979) to enable future expansion of the program.

While the watch officers' meteorological report to WMO's net requires little technological support other than the radio net itself, the NOAA/Navy program requires considerable technological support. The shipboard instrumentation are furnished to the ship, and the ship's crew receive the data, "read" it, identify critical characteristics, and code the information into a standard format. The data are then sent by radio message to FNOC; the actual traces are sent by mail. NOAA and Navy liaison with the participating ships is of great importance to the successful operation of this program by providing instrumentation, instructions for their use, and discussions about operational details and problems.

There are several improvements being planned for the ships-of-opportunity program. Representatives from FNOC state that improved shipboard systems could enhance the program's data recovery rate and provide more accurate information. The research community, which has had data-handling problems with the traces from the XBTs, is testing a new system that provides a shipboard trace and a magnetic digital recording of the trace. NOAA is in the process of developing a shipboard automated station to receive, store, and transmit meteorological and oceanographic data, Moreover, NOAA's Public Weather Service is developing the Shipboard Environmental Data Acquisition System (SEAS), that will use communication satellites for relaying data to shore. The following sensors have been suggested for SEAS:

1. a module for routine meteorological observations,
2. an expendable ocean temperature and current-velocity profiler,
3. an expendable ocean temperature and conductivity profiler, and
4. a doppler speed log-current profiler.

The cost of each SEAS unit will depend on what sensors are included, but the minimum cost will probably be around $15,000. If meteorological, ocean sea-surface temperature, XBT trace information, and ocean-current information are included, the cost may well run close to $l00,000/unit. An analysis of optimum configurations to meet varying needs has not been conducted.

Commercial ships may furnish substantial observational data of importance to oceanography, meteorology, and climatology, provided instruments can be devised that operate with a minimum of attendance and provided the information generated can be effectively transmitted to data centers and thence to users. Satellite com-

[12] Intergovernmental Oceanographic World Meteorological Organization, *IGOSS The Integrated Global Ocean Station System, 1979.*

munication has made transmission possible; integrated circuit technology may make suitable instruments possible. Simple and precise navigation systems can assure correct navigational labeling of data. It may be possible, though controversial, to require all ships that receive the U.S. weather services to carry transponders to active satellite interrogation systems.

A modest scale study of the utilization of ships-of-opportunity that explores the technological need and feasibility could be undertaken. Such a study should involve fishermen and cargo ship operators as well as scientists and technologists.

NOAA plans for an initiative with the SEAS program is a first step for an expanded ships-of-opportunity program. However, some cost and benefit analysis of different approaches to instrument and data networks, as well as research program needs, would be desirable before a major commitment is made for program expansion.

# SUBMERSIBLES

Both manned and unmanned submersibles are uniquely capable of certain tasks in observing and conducting research activities below the ocean surface. Unmanned submersibles, or ROVs, are a burgeoning technology that gives the marine scientist an underwater view of the ocean via closed-circuit television (CCTV). They are used primarily by the industrial sector, and in the past several years have overtaken manned submersibles in number and use.

## *Manned Submersibles*

There are numerous operational manned submersibles in the world, many of which are in use in the offshore oil industry. For this study, emphasis is directed to active U.S. vessels performing oceanographic research under Federal Government support. For comparative purposes, submersibles of the private sector (national and international ) and of foreign governments are discussed.

### U.S. Government Sector

The Navy. –Five submersibles are owned by the U.S. Navy (table 17), but one of these, the *Alvin, is* managed by UNOLS and is operated by the Woods Hole Oceanographic Institution. This deep-submergence research vehicle (with its tender ship *Lulu) is* designated a national facility and is available to researchers through application to UNOLS for vessel time.

The Trieste II, technically a bathyscaphe submersible with the greatest operating depth, has been used for geological investigations of the ocean bottom at 20,000 ft below the surface. Two submersibles similar to the *Alvin* –the *Sea Cliff* and the *Turtle* — are used by Navy for locating and recovering small objects from the ocean bottom, as well as for performing geological research. The *NR-1*, a nuclear powered research submarine, has been used for geological research and classified projects for Navy. Most aspects of *NR-1* specifications and characteristics are classified.

Acquisition and operating costs for Navy submersibles *Turtle*, *Sea Cliff*, *Trieste-II*, and *NR-1* are shown in table 18. These data, supplied by

[13]University- National Oceanography Laboratory System, *Opportunities for Oceanographic Research, Alvin,* descriptive pamphlet, 1978.

**Table 18.—Costs for Navy Submersibles**

| | |
|---|---|
| *Tries/e //* (DSV-1 ) | |
| Acquisition cost (1965) . . . . . . . . . . . . . . . . . . . | $8,500,000 |
| Operation and maintenance (fiscal year 1981). | 1,460,000 |
| *Turf/e (DSV-3)* | |
| Acquisition cost (1963) . . . . . . . . . . . . . . . . . . . | 2,500,000 |
| Operation and maintenance (fiscal year 1981). | 1,960,000 |
| *Sea Clitf* (DSV-4) | |
| Acquisition cost (1963) . . . . . . . . . . . . . . . . . . . | 2,500,000 |
| Operation and maintenance (fiscal year 1981). | 1,906,000 |
| *NR-1* | |
| Acquisition cost (1965) . . . . . . . . . . . . . . . . . . . | 67,000,000 |
| Operation and maintenance (fiscal year 1981). | 3,760,000 |

NOTE Submersible acquisition costs are in then-year dollars Operation and maintenance costs are in fiscal year 1981 constant budget dollars

SOURCE U S Navy

**Table 17.—Federally Owned and Operated U.S. Submersibles**

| Vessel | Date built | Length (ft) | Operating depth (ft) | Power supply | Crew/ observers | Manipulators/ viewports | Speed (kts) cruise/max. | Endurance (hrs) cruise/maximum |
|---|---|---|---|---|---|---|---|---|
| UNOLS | | | | | | | | |
| Alvin . . . . . . | 1964 | 25 | 12,000 | Battery | 1/2 | 1/4 | 1/2 | — |
| *Navy* | | | | | | | | |
| Sea Cliff . . . | 1968 | 26 | 20,000a | Battery | 2/1 | 2/5 | 5/25 | 812 |
| Turtle . . . . . | 1968 | 26 | 10,000 | Battery | 2/1 | 2/5 | 5/25 | 8/2 |
| Trieste II. . | 1969 | 78 | 20,000 | Battery | 2/1 | 1/3 | 1 .5/11.9 | — |
| NR-1 . . . . . . | 1969 | 136 | — | Nuclear | 71 | — | — | — |

[a]By 1982

SOURCE Office of Technology Assessment

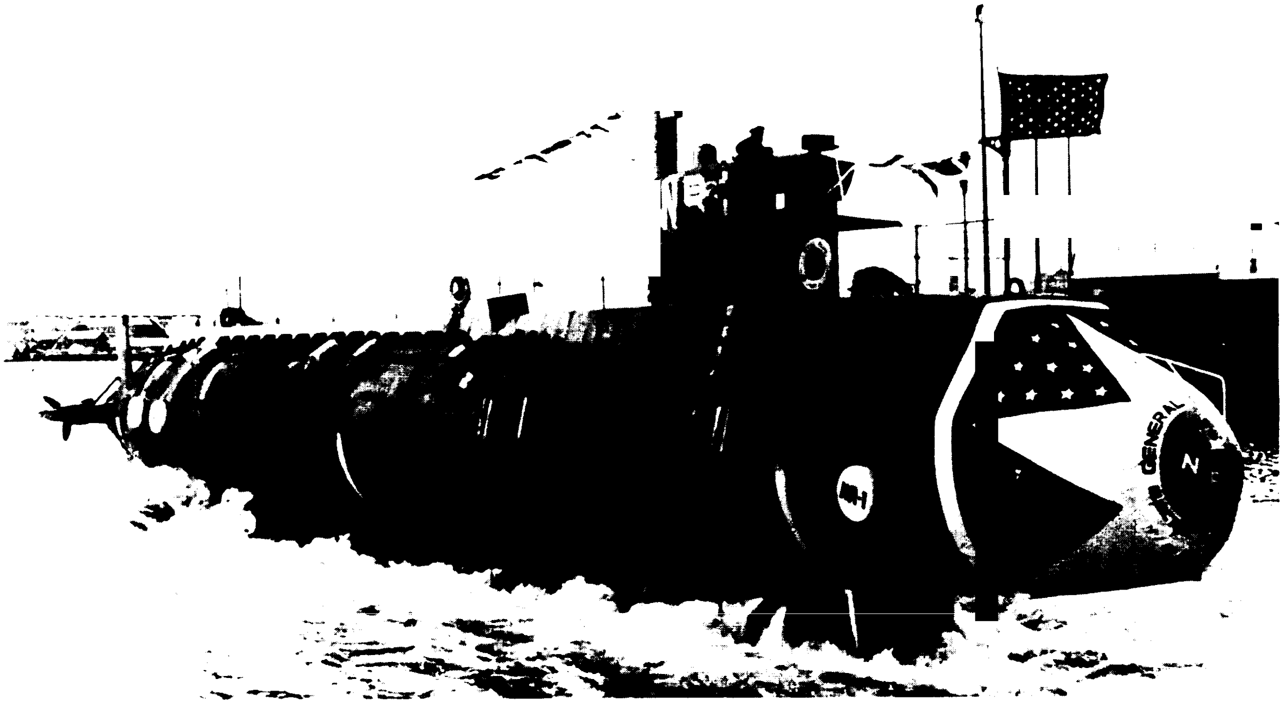



Photo credff U .S Navy

*NR- 1,* Navy's underwater research and ocean-engineering vehicle being launched, January 1969, New London, Corm.

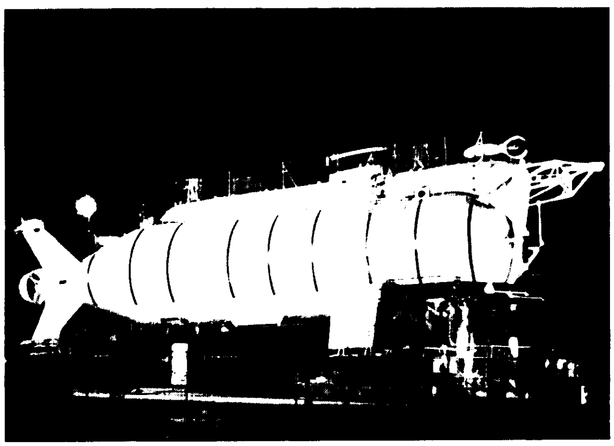


Photo credit U S Navy

*Trieste II*

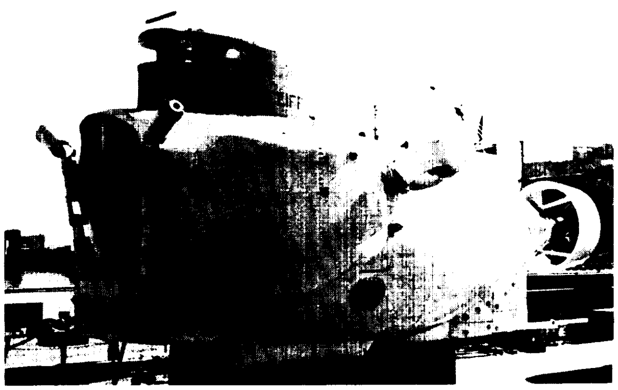


Photo credit U S Navy

*Sea Cliff*

Navy, do not include costs for special support equipment, field change modifications, major maintenance and overhaul, support ships and staff, and special facilities.

*Alvin is* the most capable submersible available to civilian oceanographers, and as such it is in great demand. In the summer of 1978, the *Alvin* was used to explore waters near the Azores on geophysical and geological research. Subsequently, it was used to make a few dives at Woods Hole on fisheries research. After a few days of upkeep, the Alvin assisted in setting up a biological station at 12,000 ft below the ocean's surface near Puerto Rico; and at the start of 1979, the *Alvin* went to the Galapagos Islands to study biological conditions around the hot thermal vents previously discovered at a depth of about 9,000 ft. In 1975 *Alvin* was not fully utilized but by 1978 and through 1980, total at-sea days ranged from 197 to 228 per year and the total number of dives went from 81 to 117 per year. These numbers plus the necessary port preparation time represent essentially full utilization.

UNOLS management of *Alvin is* through an *Alvin* review committee, consisting of 10 members, that convenes annually to review accomplishments, discuss problems, review proposals, and recommend scheduling of the *Alvin* time. In 1977 UNOLS issued a report that summarized the following uses of *Alvin* in geological and biological studies:[14]

- investigating seafloor strata;
- studying sedimentary processes in the benthic boundary layer;
- surveying the ocean bottom to help evolve the theory of plate tectonics;
- conducting geochemical experiments on the ocean floor;
- measuring geodetic characteristics (crustal uplift in an area of seafloor spreading);
- utilizing new instrumentation for studies at very great depths;
- making single-site periodic surveys of deep-sea biology;
- finding new deep-sea species;
- sampling deep-sea bacteria; and
- setting up deep-sea bottom biological experiments.

The UNOLS report recommended that at least a 3-year coordinating, planning, and funding support effort be established for the *Alvin* to assure most effective use and that actual yearly funding be apportioned among sponsoring agencies. Recently, in 1979, UNOLS scheduled the *Alvin* to spend alternate years operating out of the U.S. east and west coasts, with 1980 as a west coast year.

In 1977, a memorandum of understanding among Navy, NOAA, and NSF recognized the importance of the *Alvin* and concluded that:

- The supporting agencies will provide operating support funds through December 31, 1980.
- Major programs requiring the use of the *Alvin* should be identified 2 years in advance.
- A full schedule should be 180 days (rather than the previous schedule of 150) .-

*Alvin* was built in 1964 at a cost of just under $1 million and its hull converted to titanium in 1973 for an additional $1 million. Its replacement cost is probably $4 million to $5 million. The yearly operating cost for *Alvin* and its support ship was $1.9 million in fiscal year 1980, based on 200 operational days per year. While the *Alvin is* considered in good condition for continued operations, its support ship *Lulu has* for some time needed upgrading or replacement. Various alternatives for an *Alvin* support ship have been proposed.

In the fall of 1979 a UNOLS-sponsored study, *Research Submersible Facility Requirements for Short- and Long-Term Needs Within the U.S. Scientific and Technical Community*, commenced. The study was designed by the Alvin Review Committee of UNOLS and is jointly funded by the. U.S. Navy's Office of Naval Research, NOAA (Research and Development Special Projects Office), and NSF (Office of Oceanographic Facilities and Support). The objectives of the study are to develop a comprehensive facilities plan which identifies and satisfies UNOLS submersible science requirements from the pres-

[14] University-National Oceanographic Laboratory System, *Report of the UNOLS Alvin Review Committee to the UNOLS Advisory Council of The Continued Role of DSR V Alvin,* March 1979.

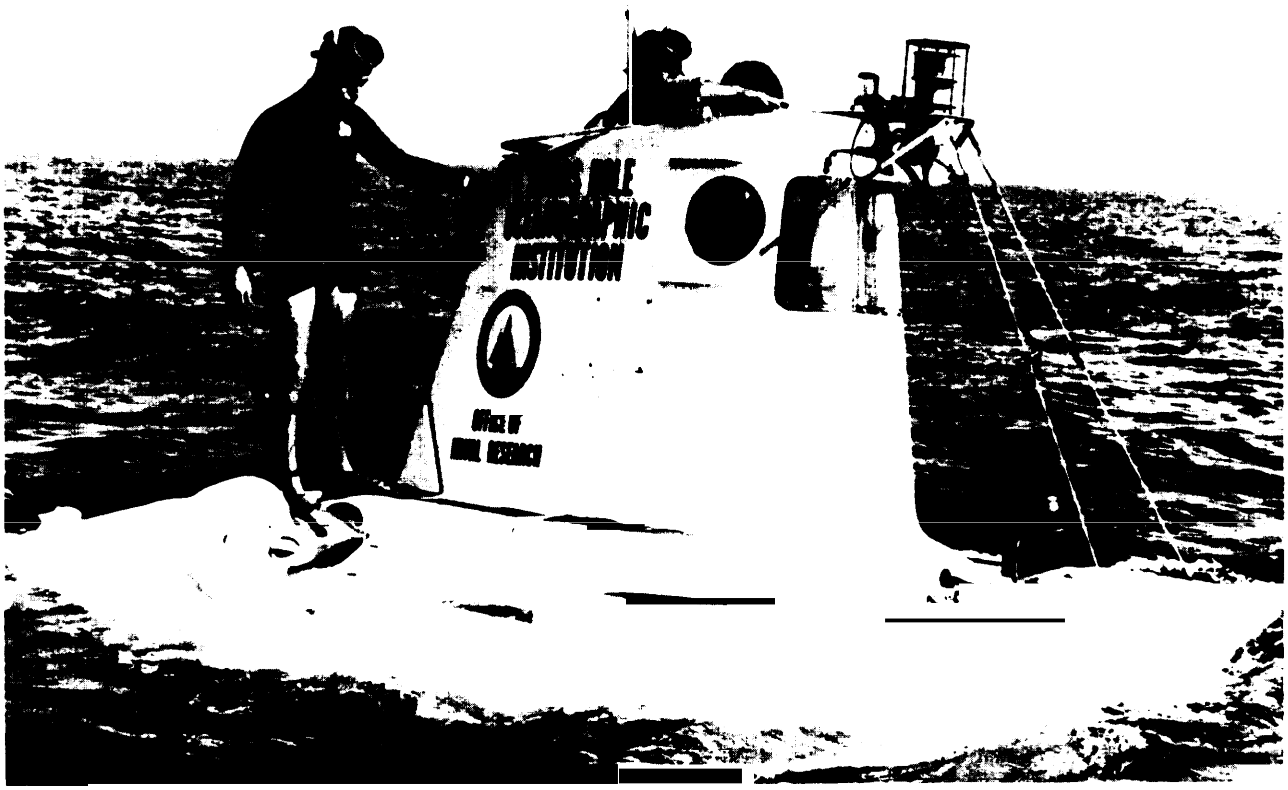


*Photo credlf Woods Ho/e Oceanographic Institution*

DSRV—Alvin

ent through the year 1990. The plan will consider *Lulu/Alvin* modifications, leasing of submersibles systems, capital expenditures for reactivation of existing facilities, construction of new or additional systems, and plans for maintenance and operations.

NOAA. –For several years NOAA has been involved in planning manned undersea facilities. In 1979, an analysis prepared by NOAA's ocean engineering office concluded that there was a need for a high-performance, long-range submersible with diver-support capabilities. Plans for this submersible, known as Oceanlab, were begun. Because of high cost estimates (over $25 million) for Oceanlab and disagreements over the scientific needs, the project was shelved and the NAS Ocean Sciences Board was requested to restudy requirements and to consider alternative approaches. That study considered a variety of surface and subsurface vehicles to satisfy a range of requirements for research tasks requiring underwater observation and manipulation.

As a result of the study and of decisions by NOAA, Oceanlab funds were reprogrammed to a new undersea research program. The program plans prepared in 1980 included the support of Hydrolab, the only U.S. undersea manned habitat in operation. This facility is located at Fairleigh Dickinson University's West Indies Laboratory at St. Croix, U.S. Virgin Islands. The laboratory sits in 49 ft of water at the head of Salt River Submarine Canyon, off the northern coast of St. Croix, U.S. Virgin Islands. The science program focuses on marine problems common to many U.S. continental coast regions.

Other segments of the new undersea program are regional facility projects which have been proposed by the University of Southern California, the University of North Carolina, and the University of Hawaii. Diving and other facilities are planned to be located at these institutions under NOAA sponsorship.

NOAA also pursues an active leasing program whereby shallow-diving submersibles are chartered to conduct surveys and research. One of these, the manned submersible *Makalii* (formerly known as *Star 11)* is owned by the University of Hawaii and operated by it for NOAA's Regional Undersea Research Program. *Makalii is* a two-man (one pilot and one observer), one-atmosphere vehicle capable of diving to a maximum depth of 1,200 ft. In addition to direct in situ observation, it is capable of implanting instruments, retrieving samples, and conducting experiments using its manipulation and its externally mounted tools:

Participants in these diving programs, generally from 1- to 2-months duration, are from Government and academia. To date the major applications have been for baseline environmental measurements, monitoring and assessment of areas planned for ocean dumping; undersea mining; oil and gas production activities; development of. offshore powerplants and deep-water structures; fisheries research and management; and sediment transport studies assessing the fate of pollutants and bottom nutrients. The total annual NOAA funds expended for manned submersibles leasing are listed below. These funds do not include NOAA's annual contribution to the support of Alvin in the past 5 years.

| Fiscal yea r | Money spent on submersibles leasing |
|---|---|
| 1975 . . . . . . . . . . . . . . . | $ 234,875 |
| 1976 . . . . . . . . . . . . . . . | 210,600 |
| 1977 . . . . . . . . . . . . . . . | |
| 1978 . . . . . . . . . . . . . . . | 493,800* |
| 1979 . . . . . . . . . . . . . . . | 199,800 |
| **Total. . . . . . . . . . . , . . . .** | **$1,139,075** |

***Of these funds, $156,000 were contributed by USGS.**

U.S. Private Sector

Currently operating manned submersibles of the private sector that have over 600 ft of operating depth capability are listed in table 19. Of the vehicles listed, four are operated by non-profit organizations or academic institutions solely for research *(Diaphus, Johnson-Sea-Link I & II, Makalii).*

The *Johnson-Sea-Link* vehicles lockout divers at depths to 1,000 ft, operate without Federal support, and annually compile diving times in excess of 120 days. The remaining two vehicles, *Makalii* and *Diaphus,* although supported by their operators, conduct much of their diving with funds derived from projects with Federal Government support. The remainder of the submersibles listed are operated by private, profit-making organizations which are primarily involved in offshore oil- and gas-support work.

Three groups of vehicles–Arms, *Jim,* and *Wasp* – are tethered submersibles which are designed to provide manipulation for relatively

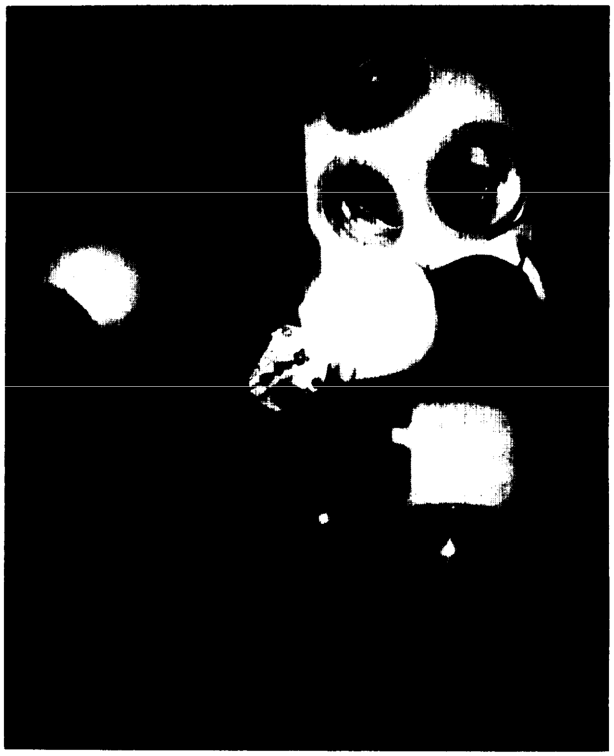


Photo credit National Oceanic and Atmospheric Adm/n/sfrat/on

The *Jim,* a tethered manned submersible

**Table 19.—U.S. Private-Sector Submersibles (Manned)**

| Vehicle | Date built | Length (ft) | Operating depth (ft) | Power supply | Crew/ observers | Manipulators/ viewports | Operator |
|---|---|---|---|---|---|---|---|
| Arms 1, II, and IIIa | 1976–1978 | 8.5 | 3,000 | Battery | 1/1 | 3/Bow dome | Oceaneering International, Santa Barbara, Calif. |
| Asherah | 1964 | 17.0 | 600 | Battery | 1/1 | 0/6 | New England Ocean Services, Boston, Mass. |
| Auguste Piccard | 1978 | 93.5 | 2,000 | Battery | 6/3 | 0/1 | Gulf Maritime Explorations, Solona Beach, Calif. |
| Beaverb | 1968 | 24.0 | 2,700 | Battery | 1/4 | I/Bow dome | International Underwater Contractors, *City Island, N.Y.* |
| Deep Quest | 1967 | 39.9 | 8,000 | Battery | 2/2 | 212 | Lockheed Missiles & Space Co., San Diego, Calif. |
| Diaphus | 1974 | 19.8 | 1,200 | Battery | 1/1 | I/Bow dome | Texas A&M University, College Station, Tex. |
| Jim (14 each.)a | 1974 | — | 1,500 | Human | 1/0 | 2/1 | Oceaneering International, Houston, Tex. |
| Johnson-Sea-Link I&IIb | 1971 1975 | 22.8 | 3,000 | Battery | 1/3 | I/Panoramic | Harbor Branch Foundation, Ft. Pierce, Fla. |
| Mermaid II | 1972 | 17.9 | 1,000 | Battery | 1/1 | I/Bow dome | International Underwater Contractors, City Island, N.Y. |
| Nekton A, B, & C | 1968 1970 1972 | 15.0 | 1,000 | Battery | 1/1 | I/Bow dome | Nekton, Inc., San Diego, Calif. |
| Pioneer | 1978 | 17.0 | 1,200 | Battery | 1/2 | 2/3 | Martech International, Houston, Tex. |
| Pisces VI | 1976 | 20.0 | 6,600 | Battery | 1/2 | 2/3 | International Underwater Contractors, City Island, N.Y. |
| Snooper | 1969 | 14.5 | 1,000 | Battery | 1/1 | 1/10 | Undersea Graphics, Inc., Torrance, Calif. |
| Makalii | 1966 | 17.7 | 1,200 | Battery | 1/1 | 1/6 | University of Hawaii, Honolulu, Hawaii |
| Waspa | 1977 | — | 2,000 | Surface | 1/10 | 2/Bow dome | Oceaneering International, Houston, Tex. |

[a] Tethered
[b] Diver lockout

SOURCE Office of Technology Assessment

complex tasks, but are limited to work at a specific site. The *Arms* vehicles are, essentially, one-atmosphere observation/work bells, connected by cable to the surface, designed to be highly maneuverable within a limited area, and capable of high-dexterity manipulation. The Jim and *Wasp* vehicles, on the other hand, are one-atmosphere diving suits which are lowered on a stage or are free-swimming (i. e., Wasp) and are controlled by the operator inside.

Industrial vehicles perform a variety of tasks: pipeline and structure inspection, bottom surveying/mapping, search and retrieval of lost and abandoned objects, exploratory drilling support, geological and biological sampling, coral harvesting, and maintenance repair. Additionally, these vehicles can and sometimes do perform scientific research tasks under contract to Federal Government agencies.

At present there are two submersibles under construction in the private sector in the United States. Since the commercial market is so dynamic and technological innovations are so frequent, all manned industrial vehicles are generally built under contract and not for the speculative market.

### Foreign Sector

A listing of manned submersibles operated by various foreign governments is presented in table 20.

The manned submersible operators in the foreign private sector, particularly the British and French, are far more active than their U.S. counterparts. This activity is centered around North Sea and Mediterranean oil and gas support. Whereas most U.S. private sector vehicles

**Table 20.—Foreign Government-Supported Submersibles**

| Country | Date built | Operating depth (ft) | Crew/observors | Operator |
|---|---|---|---|---|
| ***Canada*** | | | | |
| **Pisces IV** | 1974 | 6,600 | 1/2 | Department of the Environment, Victoria, B.C. |
| SDL-1a | 1970 | 2,000 | 1/4 | Canadian Armed Forces, Halifax, N.S. |
| **France** | | | | |
| Cyana | 1970 | 9,843 | 1/2 | CNEXO, Toulon |
| Griffon | 1973 | 1,969 | 2/1 | French Navy, Toulon |
| LaLicornea | 1980 | **656** | 1/4 | French Navy, Toulon |
| SM-97 | Under construction | 1,968 | 1/2 | CNEXO, Toulon |
| **Italy** | | | | |
| MSM-la | Under construction | **1,968** | NA | Italian Navy. |
| **Japan** | | | | |
| **DSV-2K** | Under construct ion | 6,561 | 1/2 | JAMSTEC, Yokosuka. |
| **Peoples Republic of China** | | | | |
| **SM-358a** | 1979 | 984 | 1/3 | NA |
| **SM-360a** | 1980 | 984 | 1/3 | NA |
| **Rumania** | | | | |
| (Name NA) | 1979 | **984** | 1/3 | NA |
| **Sweden** | | | | |
| URFa | 1978 | 1,509 | **5/25** | Royal Swedish Navy |
| **U.S.S.R.** | | | | |
| Atlant (3 ea.) | 1975 | 660 | 1/1 | VNIROb |
| Argus | 1975 | 8,968 | 2/1 | Institute of Oceanology, Moscow |
| Benthos 300 | 1976 | 990 | **2/4** | VNIRO |
| Osmot Ra | 1980 | 990 | **212** | Institute of Oceanology, Moscow |
| Pisces Vll &Xl | 1975 | 6,600 | 2/1 | Institute of Oceanology, Moscow |
| Sever **2(2 ea.)** | **1976** | **6,605** | 1/2 | VNIRO |
| Tinro 2 (2 ea.) | **1975** | **1,321** | 1/1 | VNIRO |
| **Yugoslavia** | | | | |
| Mermaid Va | 1979 | **984** | **2/2** | NA |

[a]D iver lockout
[b]All Union Research Institute of Marine Fisheries and Oceanography.
NA.information not available

SOURCE: Office of Technology Assessment.

employ very basic instrumentation, such as, visual observations, CCTV, and still photography, the European operators use a variety of sophisticated electronics and support systems in addition to optical- and direct-viewing techniques.

There are approximately 56 non-U. S. operating submersibles in the private sector. Table 21 shows the national distribution, type, and depth range of these capabilities. The surface support ships of European operating companies are equipped with highly sophisticated data acquisition and processing systems which permit online processing and presentation of the data within hours after it has been obtained and, in some instances, in real time.

## *Comparison of Submersible Capabilities*

### United States—Federal v. Private Sector

Since the Federal submersible fleet is designed to conduct military and scientific missions, and most of the private fleet is aimed at conducting industrial work tasks, a comparison of their capabilities has limited usefulness, An analysis of the diversity of vehicle capabilities in the Federal v. **private fleet** and the reasons for this diversity can help to explain this situation.

Depth Capability. –Federal submersibles have a far greater diving capability than those of

**Table 21.—Foreign Private-Sector Submersibles**

| Country | Maximum depth range (ft) | One atmosphere | Lockout | ADS | Obs/work bell |
|---|---|---|---|---|---|
| Brazil. . . . . . . . . . . | 984 | — | 1 | — | — |
| Canada . . . . . . . . . | 1,500 | 2 | 1 | — | — |
| France. . . . . . . . . . | 6,600 | 10 | 6 | — | 3 |
| Italy. . . . . . . . . . . . | 3,000 | 2 | 1 | — | 2 |
| Japan. . . . . . . . . . . | 984 | 2 | — | — | — |
| Netherlands . . . . . | 843 | 1 | — | — | — |
| Norway . . . . . . . . . | 1,000 | — | — | — | 1 |
| Switzerland. . . . . . | 1,640 | 1 | — | — | — |
| United Kingdom. . | 3,281 | 12 | 5 | 4 | — |
| West Germany . . . | 984 | — | 2 | — | — |
| Totals . . . . . . | | 30 | 16 | 4 | 6 |

SOURCE Office of Technology Assessment

the private sector because of the needs of military missions. At present there is no industrial market for vehicles with depth capabilities of 10,000 to 20,000 ft; although there are identified needs for scientific research to be conducted at those depths. Conducting dives with, e.g., the *Alvin* in 500 ft or so of water is not a cost-effective utilization of its capabilities. For this reason, the NOAA lease program uses shallow-diving industrial submersibles to satisfy its shallow-water requirements.

Lockout Capability. – Lockout is the capability of a submersible to let personnel exit or enter the vehicle while it is submerged. This capability complicates the design of the submersible because of the need to transport and support divers, and it provides increased ballasting and deballasting of the vehicle to hold it at a constant depth.

There are no Federal vehicles, except the Deep Submergence Rescue Vehicles (Mystic and *Avalon)* capable of lockout. (These vehicles can only lockout in a dry-transfer mode, not in the normal dry-to-wet mode. ) The Navy would normally rely on more conventional diving techniques (saturation bell) if a diver were required. Industrial lockout vehicles are necessary since a diver (who may be a welder, mechanic, or other technician) can be delivered to some worksite more efficiently than he could be with a conventional diving bell.

Specialized Vehicles. –The specialized nature of industrial vehicles *(one-atmosphere* submersibles, *ADS*, observation bells, lockout submersibles) reflects the wide variety of the work tasks and the constant competition within industry. For example, ADS (a one-atmosphere underwater suit) is meant to compete with the use of a scuba diver since it provides near-human manipulative capabilities and does not require lengthy decompression schedules. The observation bells compete with *one-atmosphere* submersibles by providing unlimited power (through an umbilical), greater maneuvering capability, and greater manipulative capability for working within a limited (300-ft radius) area around structures.

Expense. – On a vehicle-by-vehicle basis the Federal fleet is more expensive to maintain, simply because there is more to maintain. There is more complexity in a 10,000- or 20,000-ft vehicle than in a 600- or 1,000-ft vehicle. It follows that normal maintenance is more extensive, and equipment components are more expensive. Also, lack of competition in the Federal fleet and unique uses of vehicles may contribute to higher costs.

### U.S. Federal Government v. Foreign Federal Government

If U.S. Navy submersibles are considered scientific assets, then the U.S. Federal submersible fleet *is* fully comparable to that of any other nation. If *Alvin* alone is considered (the only Federal submersible solely dedicated to science), then the U.S. Federal fleet may soon fall behind those of other nations, particularly France and the Soviet Union. The following discussion relates only to *Alvin* and does not consider U.S. Navy vehicles.

At present France has a vehicle, *Cyana,* which is essentially the depth-equal of the *Alvin* as well as its equal in most other major categories. When the French vehicle SM-97 is launched (projected for 1983 at this time), France's fleet will be ahead of that of the United States in depth capability and in numbers of vehicles (if *Cyana* remains active).

The Soviet Union now has 11 known vehicles under the aegis of its Institute of Oceanology and the All Union Research Institute of Marine Fisheries and Oceanography. A lockout submersible and a 660-ft depth-capable habitat are now under construction. In addition, the Soviet Union is currently attempting to have a 20,000-ft vehicle built in Canada; but, at this time, the Canadian firm is experiencing difficulty in obtaining necessary export licenses. At this moment, the Soviet fleet exceeds the U.S. fleet in numbers of vehicles.

It should be pointed out that the only advantage France and the U.S.S.R. will have is a depth advantage. How much this is worth from a scientific viewpoint is speculative. In the sophistication of its scientific equipment, the United States probably leads other countries and appears likely to maintain this advantage in the future. In fact, the major scientific equipment on the Soviet Pisces vehicles were made in the United States.

Future Plans. –There are, at present, no plans in the Federal Government to build new submersibles, although the UNOLS study group is considering whether this should be done. The UNOLS group is also considering alternate approaches, such as deep ROVs.

## *Remotely Operated Vehicles*

ROVs, or unmanned submersibles, have been in existence for the past 27 years; but their utilization in ocean projects as practical, economic, work stations has only recently been accepted. Since 1976 their numbers have increased; and while there is a wide variety of ROVs, they can be grouped in four categories:

- *Tethered, free-swimming vehicles.* – Powered and controlled through a surface-connected cable; self-propelled; capable of 3-dimensional maneuvering, remote viewing through CCTV.
- *Towed vehicles.* – Powered and controlled through a surface-connected cable; propelled by surface ship; capable of maneuvering only forward and up/down by cable winch; remote viewing through CCTV.
- *Untethered vehicles.* –Self-powered; controlled by acoustic commands or preprogrammed course; self-propelled; capable of maneuvering in three dimensions; no remote viewing capability.
- *Bottom-crawling vehicles.* – Powered and controlled through a surface-connected cable; maneuvered by friction-drive against the bottom or a structure; remote viewing through CCTV.

Industry is the major user of ROVs, and here again the primary employment is in the offshore oil and gas industry. Table 22 presents the major tasks performed by the different types of vehicles for their various customers. The advantages of ROVs over manned vehicles are their unlimited power (which, except for untethered vehicles, is delivered from the surface station via an umbilical cable), their relatively low cost, and the fact that they do not jeopardize human life. Major disadvantages are that the cable frequently entangles or breaks, and the high-hydrodynamic drag on the cable at depths greater than 3,000 ft makes the ROV cumbersome to maneuver.

### U.S. Government Sector

The distribution of federally operated ROVs is listed in table 16. As shown, the primary–and almost exclusive — user of tethered, free-swimming ROVs in the U.S. Government is Navy. Although Navy uses these ROVs occasionally for very specific scientific research, they are used primarily for salvage and weapon recovery.

Scripps Institution of Oceanography, Woods Hole Oceanographic Institution, and Lamont-Doherty Geological Observatory are academic institutions operating the federally funded deep-towed vehicles, *Deep Tow, Angus,* and *Katz Fish.*

**Table 22.—ROV Applications**

| Industrial | Military | Scientific/research |
|---|---|---|
| **Tethered, free-swimming vehicles** | | |
| Inspection<br>Monitoring<br>Survey<br>Diver assistance<br>Search/identification<br>Installation/retrieval<br>Cleaning | Inspection<br>Search/identification<br>Installation/retrieval | Inspection<br>Survey<br>Installation/retrieval |
| *Towed vehicles* | | |
| Survey | Search/identification/location<br>Survey<br>Fine-g rained mapping<br>Water sampling<br>Radiation measurements | Geological/geophysical investigations<br>Broad area reconnaissance<br>Water analysis<br>Biological/geological sampling<br>Bioassay<br>Manganese nodule survey |
| **Untethered** *vehicles* | | |
| Iceberg measurements | Conductivity/temperature/pressure-profiling<br>Wake turbulence measurements<br>Under-ice acoustic profiling | Bathymetry<br>Photography<br>Arctic ice<br>Underside roughness |
| **Bottom-crawling vehicles** | | |
| Pipe trenching<br>Cable burial<br>Bulldozing<br>Dredging<br>Survey/inspect ion | None | Implanting ocean-floor instruments |

SOURCE Off Ice of Technology Assessment

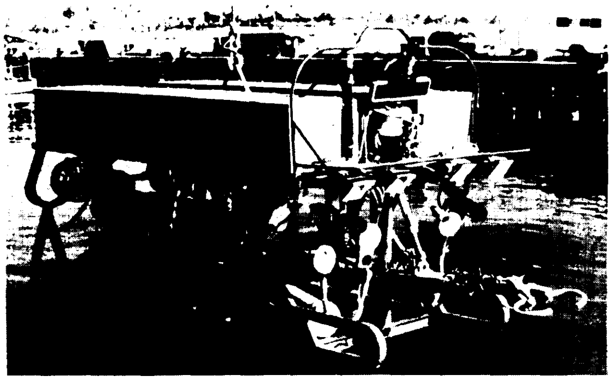


*Photo cred(t U S Navy*

Navy's tethered, free-swimming *CUR V-///*

Two of these vehicles, *Deep Tow* and *Angus,* are capable of operating to depths of 20,000 ft (table 23). The Jet Propulsion Laboratory, Pasadena, Calif., is developing (with Federal funds) the towed vehicle *Digitow* to serve as a testbed for oceanographic equipment as it is developed.

The untethered vehicles listed in table 23 that are not Navy-supported are being developed by

**Table 23.—U.S. Government-Supported ROVs**

| Type | Depth (ft) | Operator |
|---|---|---|
| **Tethered tree-swimming** | | |
| Snoopy (2 ea.). . | 1,500 | U.S. Navy |
| Deep Drone. . . . | 2,000 | U.S. Navy |
| CURV II (2 ea.). | 2,500 | U.S. Navy |
| URS-1. . . . . . . . . | 3,000 | U.S. Navy |
| CURV Ill. . . . . . . | 10,000 | U.S. Navy |
| RUWS . . . . . . . . | 20,000 | U.S. Navy[a] |
| **Towed** | | |
| RUFAS II . . . . . . | 2,400 | NOAA (National Marine Fisheries Service) |
| Digitow . . . . . . . | 20,000 | Jet Propulsion Laboratory |
| Teleprobe . . . . . | 20,000 | U.S. Navy |
| Deep Tow . . . . . | 20,000 | Scripps[c] |
| Angus . . . . . . . . | 20,000 | Woods Hole[c] |
| Katz Fish. . . . . . | 2,500 | Lamont[c] |
| **Untethered** | | |
| Eave East . . . . . | 150 | University of New Hampshire[d] |
| Eave West. . . . . | 200 | U.S. Navy[d] |
| SPURV 1. . . . . . . | 12,000 | University of Washington |
| SPURV II . . . . . . | 5,000 | University of Washington |
| UFSS . . . . . . . . . | 1,500 | U.S. Navy |

[a]Vehicle was lost in 15,000 ft of water in February 1980. Plans to recover it are not firm at this time
[b]Funded by National Aeronautics and Space Administration and National Oceanic and Atmospheric Administration
[c]Construction funded by the U S Navy
[d]Funded by the U S Geological Survey, Department of the Interior

SOURCE Off Ice of Technology Assessment

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USGS to demonstrate the feasibility of underwater-structure (fixed platforms and pipelines) inspection in the oil and gas industry. The results of this program could find application in the scientific research community.

Four towed vehicles, financed in part or entirely by the Federal Government, are used for scientific research: *Rufas II, Digitow, Deep Tow,* and *Katz Fish*. They are employed in fisheries research and geophysical research and surveys.

NOAA's Office of Ocean Engineering conducted a comprehensive study of ROVs worldwide[15] and prepared a program development plan for ROV instrumentation and support systems. NOAA also conducted a short-term evaluation of a leased, tethered, free-swimming vehicle to assess its potential use for scientific research.[16] It appears that no decision has been made on whether NOAA will pursue development of this technology.

## U.S. Private Sector

The six U.S. manufacturers of tethered, free-swimming ROVs have produced 57 vehicles over the past 5 years. Of the vehicles produced, 14 have been sold to foreign customers and 43 to U.S. companies. Private vehicles in this category are shallower diving (6,600 ft is the maximum operating depth) than those of the Government, but are in every other way capable of performing similar tasks. Until now, virtually all of these vehicles were used in support of offshore oil and gas, but in the summer of 1980, a commercially operated vehicle was used for the first time in a scientific endeavor to study reef fish in the Gulf of Mexico for the Bureau of Land Management (BLM). There are no deep-towed vehicles known to be operated by the U.S. commercial sector; although one U.S. company does manufacture such devices for foreign customers.

[15] R. Frank Busby Associates, Inc., *Remotely Operated Vehicles*, prepared for U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Ocean Engineering, August 1979.

[16] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Manned Undersea Science and Technology, *Remotely Operated Vehicle Scientific Application Assessment*, December 1979.

## Foreign Government Sector

There are at least eight foreign governments involved in either the utilization or development of ROVs. All vehicle development in the U. S. S. R., can be classified as governmental. The United Kingdom, on the other hand, has an industry/government program under the Offshore Supplies Office whereby the government funds some portion of the developmental costs, and industry the remainder. If the resulting technology is profitable, then the government's funds are returned and the vehicle belongs to industry, The United Kingdom is now supporting an ambitious ROV development program for wide application in the North Sea oil and gas industry.

The Soviet Union's current activities with ROVs is minimal at present. Until 2 years ago, the U.S.S.R.'S Institute of Oceanology developed two ROVs for scientific research; one of these is now operating. Research and development is currently underway to develop for scientific investigation an untethered preprogrammed vehicle with pattern-recognition capabilities as well as towed vehicles for deep-water reconnaissance.

## Foreign Private Sector

Except in one instance, tethered, free-swimming ROVs of private sector operators and manufacturers are aimed at the offshore oil and gas service support market. By and large, the vehicles employed and manufactured are much like those of the United States in capabilities. To date, 375 of these ROVs have been manufactured in Canada, France, Italy, Japan, the Netherlands, Norway, Sweden, West Germany, and the United Kingdom. The leading manufacturers are in Canada (35 vehicles) and France (164 vehicles). Unlike those in other countries, all but three of the French vehicles are defense-oriented. The Societie Eca of Meudon has produced over 160 ROV's called *Pap-104*, which are used by various North Atlantic Treaty Organization's Naval Forces to identify and neutralize explosive ordnance on the sea floor. There are, in addition, five deep-towed 20,000-ft vehicles in the foreign private sector. Three are found in Germany and two in Japan.

# BUOY, MOORED, AND OCEAN-FLOOR SYSTEMS

Many varieties of buoys, moored systems, and ocean-floor systems are in use in oceanographic research and monitoring.

Buoys include surface and subsurface floats that may be either moored or drifting. They usually contain instrument packages with sensors, power supplies, data recording gear, and some means of communication or data transmission to shore. Large buoys may be moored by ship and stay in one place collecting data for many months; smaller units may be dropped from aircraft to make measurements for a few days. Buoys may be launched by ships or aircraft to drift with ocean currents or winds and to transmit data as long as they can be tracked.

Moored systems usually consist of one or more sensors and other instruments that are fixed in the ocean using cables or lines, anchors, and subsea flotation. They may be used in very deep water, making measurements anywhere from just below the sea surface to the ocean floor. Ocean-floor systems are assemblies of instruments which are contained on a structure that is fixed or anchored to the bottom. Both of these systems, when used in the deep ocean, require a remote power supply, reliable data transmission to the surface, and effective installation procedures. These systems are usually launched from ships, but some smaller units can be airdropped.

Instrumented, buoy, and other systems are being used worldwide to monitor meteorological and oceanographic conditions and, in some cases, to transmit the data to shore via satellite communication links. Academic institutions such as Woods Hole Oceanographic Institution, Scripps Institution of Oceanography, and the University of Miami have developed sophisticated designs and deployment techniques for buoys to collect data for a variety of oceanographic purposes. Buoy systems supported by NOAA and a few other agencies have been developed mainly for specific program data-collection purposes – e.g., the data buoy program for meeting weather service needs of measurements over the ocean.

## *Buoys*

### Moored Buoys

The NOAA Data Buoy Office (NDBO) owns and operates the large U.S. buoys that collect synoptic ocean and meteorological data. Each of the 19 moored buoys now operating around the U.S. coastline, has one of four different hull configurations:

- A 10-m discus-shaped hull displacing about 60 tons, about half of which is hull weight. This buoy carries a 2- to 5-ton payload of batteries and instruments; the remainder is ballast.
- A 12-m discus-shaped hull that displaces about 100 tons, and carries about 2- to 5-tons of payload.
- A 5-m discus-shaped hull, displacing about 6.5 tons and carrying 2 tons of payload.
- A 6-m boat-shaped hull (called NOMAD), displacing 8 tons, about one-fourth of which is payload.

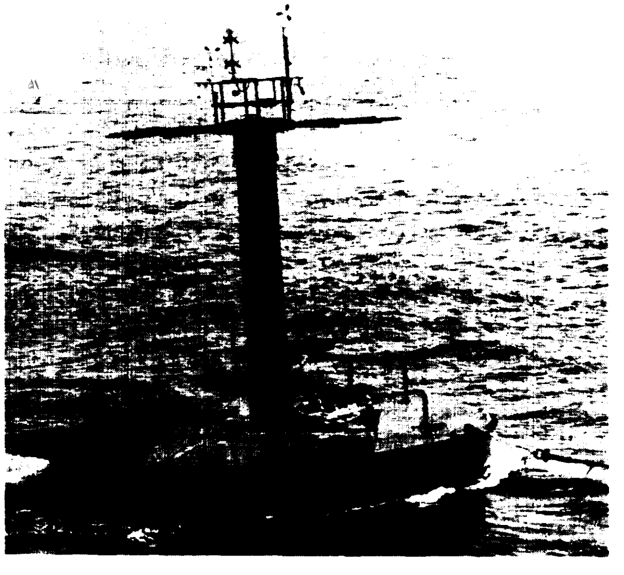


*Photo credit General Dynamics*

NOAA moored data buoy

Five different sensor/communication packages are used on buoys to collect data that is principally meteorological but includes wave and sea-surface temperature measurements. For the 10- and 12-m buoys, goals are for 1 -year unattended operation, yearly maintenance, and overhaul every 3 years. The smaller buoys have the same operation and maintenance goals but require yearly overhaul. Because many of the buoys have some data collection and transmitting problems, the program is not yet fully operational.

A 1978 report by the Director of NDBO outlined the uses and maintenance of data buoys. It noted that NDBO serviced four moored buoys about once every 36 days from 1972 to 1975[17] and visited 15 buoys once every 150 days in 1977. Several buoys were lost in severe weather due to toppling, sinking, and other reasons. In assessing data collection, the report revealed that from 1972 to 1975, 220 synoptic weather messages were transmitted per buoy per year. In 1977 these messages increased to 2,550. Over and above this level, in 1977 the buoys transmitted 22,000 wave spectra and 8,000 bathythermograph reports. Data quality was reported to have improved; errors in measuring air temperature and windspeed were reduced by large factors; and errors in barometric pressure and wind direction were cut in half. Presently, bathythermograph data are not collected because of technical difficulties.

The National Data Buoy program has not succeeded in attracting much interest from oceanographers — again, in part, because of the strong meteorological /weather service orientation, rather than an oceanographic orientation. For example, the data from the present oceanographic data buoys are not timely nor routinely available from the National Weather Service or the National Oceanographic Data Center.

Use of moored buoys as meteorological and climatological benchmark stations at the former weathership stations and at other representative places in the oceans has been advocated by scientists. Continued surface observations at the former weathership sites would provide valuable extensions in the lengths of the various surface climatic records. They would also improve numerical atmospheric circulation models; although the absence of upper air data would rather limit their usefulness at present. Moreover, midocean buoys, if maintained over an indefinite period, could provide needed time-series data at fixed locations in the oceans.

However, at a capital cost of about $400,000 each, in addition to expenses for annual maintenance, space-satellite data transmission, and data recording, the funds needed for this purpose are considerable.

A problem facing researchers who need global, synoptic ocean measurements is whether very large numbers of open-ocean buoy systems could be deployed at a reasonable cost. Such research programs involving climate monitoring or large-scale atmospheric and oceanic modeling could use hundreds or thousands of moored buoys. Whether the costs of a global, open-ocean, multibuoy system can be justified on climatological or oceanographic grounds alone will require much consideration. It would be difficult to justify the cost of a worldwide array of tethered buoys designed to supply data just for atmospheric modeling. A buoy system for the initialization of global oceanic circulation models would be expensive because of the necessarily large number of buoy stations required.

The economic case is more favorable for deployment of moored buoys that are more capable than the existing data buoys on the Continental Shelf and in coastal regions. This approach would entail minimum maintenance costs and would multiply the data use. Data from near-coastal buoys could be used to improve short-term coastal weather forecasts; to help predict storm surges; and to provide wave forecasts for coastal shipping operations, drilling operations, marine construction, and fisheries, The buoys could monitor the boundary currents and coastal upwelling that are prevalent in these regions. On the other hand, the existence of such near-coastal buoy stations is only of limited use for global atmospheric or oceanic modeling.

[17] J. C. McCall, *NDBO Mission and Payloads,* prepared for U.S. Department of Commerce, NOAA Data Buoy Office, paper presented at Marine Electronics Communications Panel of U.S. / Japan Cooperative Program in National Resources, Tokyo, 1978.

## Drifting Buoys

Drifting buoys are used extensively for **measuring subsurface currents.** As **surface floats, many** have been used during the First GARP Global Experiment (FGGE) in which a total of 368 such buoys were launched, 307 in the Southern Hemisphere. Sixty-four of these buoys belonged to the United States. Other U.S. programs which involved the use of drifting buoys are large ocean circulation, air-sea interaction, and ice dynamic studies.

In some ways, drifting buoys are a refinement of the ancient drift bottles. The use of very high frequency, of satellite communication, and of underwater acoustic signals have allowed the drifters to transmit not only a series of signals by which to locate them, but also information about other physical variables. Surface atmospheric pressure and near sea-surface temperature measurements were transmitted in FGGE; and temperature and depth measurements were transmitted in the Mid-Ocean Dynamics Experiment.

The instantaneous surface-pressure data from these buoys in remote southern ocean regions were appreciated by the weather services of Australia, New Zealand, and South Africa for direct operational purposes. The data about surface currents remain somewhat controversial, however, because of near-surface current shears, imperfect buoy-drogue (underwater parachute) action, and wind pressure on the part of the buoy above the water. The modeling and improve-

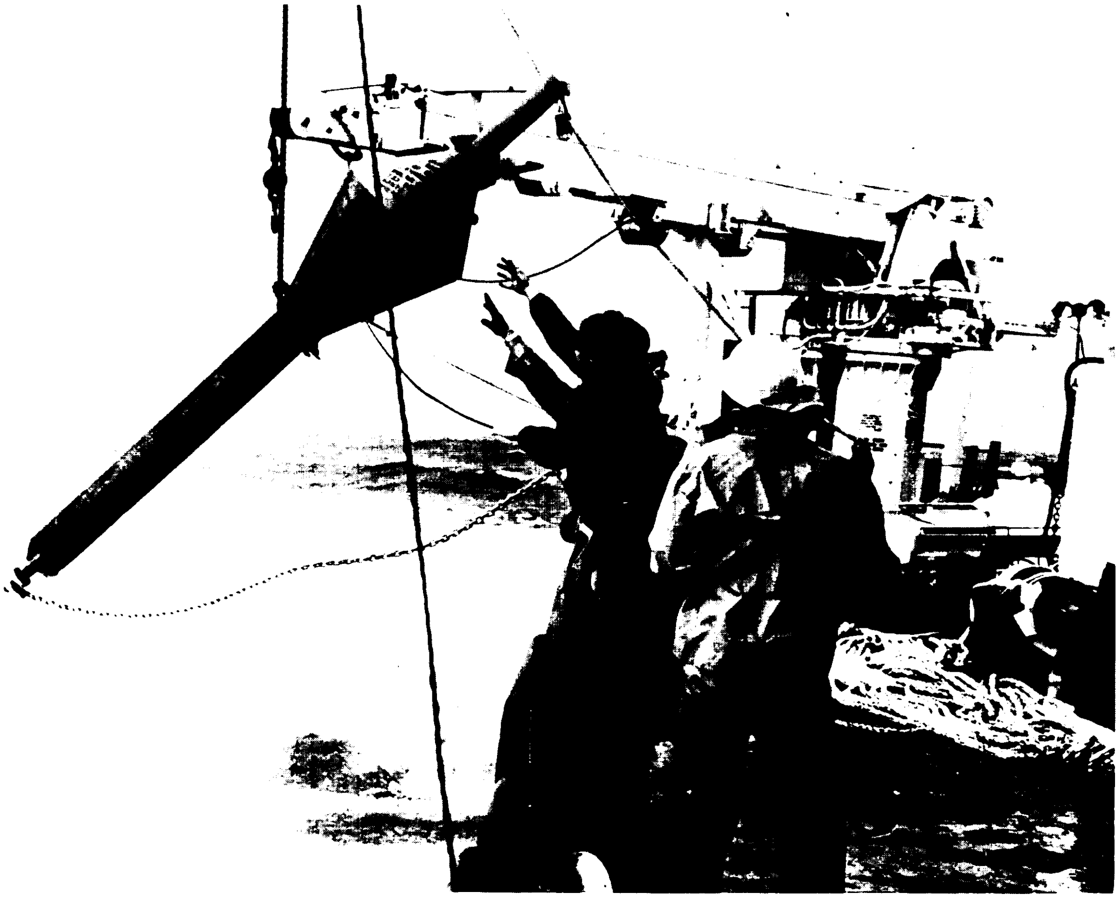


*Photo credit Peter Wiebe, Woods Ho/e Oceanographic Institution*

This drifting buoy will follow water movement of eddies in the Gulf Stream. It will be tracked by satellite with position and temperature reports available twice daily for up to 1 year. Such buoys are considered expendable but may be recovered and repowered for another experiment

ment of the drogue system is a matter of active study by NDBO.[18]

Because drifting buoys can be launched from aircraft they are especially valuable in remote areas not normally traversed by ships. They have also been installed successfully on ice to measure meteorological data and ice movement.[19]

A series of about 30 drifting buoys has been airdropped into the South Pacific to measure barometric pressure and sea-surface temperature as part of the Global Weather Experiment. The data from these Tires Meteorological Drifting Buoys are being transmitted via satellite to NOAA for distribution and archiving. These buoys are about 10-ft long, with a maximum diameter of 27 inches and a total weight of 294 lb. The performance of the buoys is reportedly excellent and the data are unique for this geographical region. Although the powerpacks of most of the U.S. drifting buoys were designed only for 1 year of operation, preliminary performance statistics indicate that only about 50 percent of the meteorological drifting buoys actually survived for 12 months.

An NDBO air-launched drifting buoy with barometer, temperature sensor, battery pack, and drogue, costs at present about $7,500, not including the costs of deployment or satellite communication. This price could decrease somewhat with mass production. Cost considerations and limited usage have prevented large numbers of drifting buoys from becoming regular components of a routine, global ocean-monitoring system. Although they have been cost effective for limited operational purposes for countries like Australia, which is affected by weather systems developing in infrequented ocean areas, they are not so cost effective for the United States, which is less subject to such conditions. Drifting buoys will probably continue to play a role in scientific research, particularly in process-oriented experiments. They can also be expected to remain useful for tracing ice movement for research, prediction and warning to ships, and drilling platforms.

## Moored Systems

### Subsurface Moorings

Deployed by the Woods Hole Oceanographic Institution, Oregon State University, Scripps Institution of Oceanography, NOAA Pacific Marine Environmental Laboratory, University of Miami, Navy, and others, subsurface moorings are used by physical oceanographers for long-term (1 to 1 1/2 years) measurements of current, temperature, salinity, and optical transmission in the study of mesoscale and intermediate scale fluid-flow in both deep and intermediate shelf-water environments. Acousticians use the moorings to place hydrophores, data recording capsules, and sound sources at specified depths for extended periods. The moorings are also used by geologists to deploy sediment traps.

The moorings consist of a bottom anchor, one or two acoustic releases —such that the moorings can be freed from the anchor for recovery lines — and a wire rope connecting the releases to current meters, sediment traps, acoustic sources, and floats that maintain a taut mooring and provide the lift that brings the array of instruments to the ocean surface after the system is commanded to release the mooring from its anchor. The moorings do not appear at ocean surface level for two reasons:

- to minimize the influence of surface-wave action, currents, and windstress on the moorings' motion;
- to eliminate the risk of theft of the mooring assembly.

The Woods Hole Oceanographic Buoy Group, which has had considerable experience with the launch and retrieval of moorings, finds that large oceanographic vessels of the *Knorr*-, *Melville*-, or *At/antis* II-types are necessary when deploying more than one deep mooring on a cruise. The vessels used must have sufficient deck space to store large quantities of equipment such as anchors, flotation spheres, lines, and current meters. The vessel must have large capstans, A-frames, and cranes. The stern should be low to

[18] J. H. Nath, "Drifting Buoy Tether- Drogue System,"' *Drifters*, U.S. Department of Commerce, NOAA Data Buoy Office, NDBO F-230-2, March 1979.

[19] E. G. Kerut and T. L. Livingston, "Air r-Droppable Buoys for Remote Sensing," *Antarctic Journal Of the United States*, June 1976.

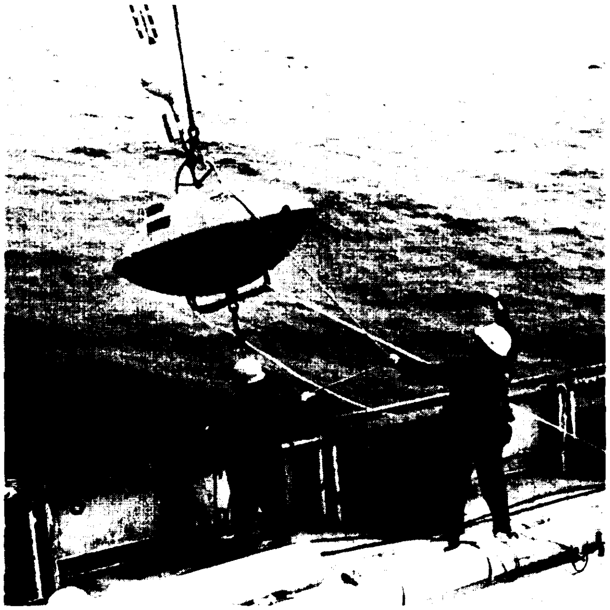


*Photo credif Woods Ho/e Oceanography /nstltuflon*

Mooring buoy being launched

the water, and the vessel must have adequate maneuverability to maintain position and be able to support acoustic communications systems.

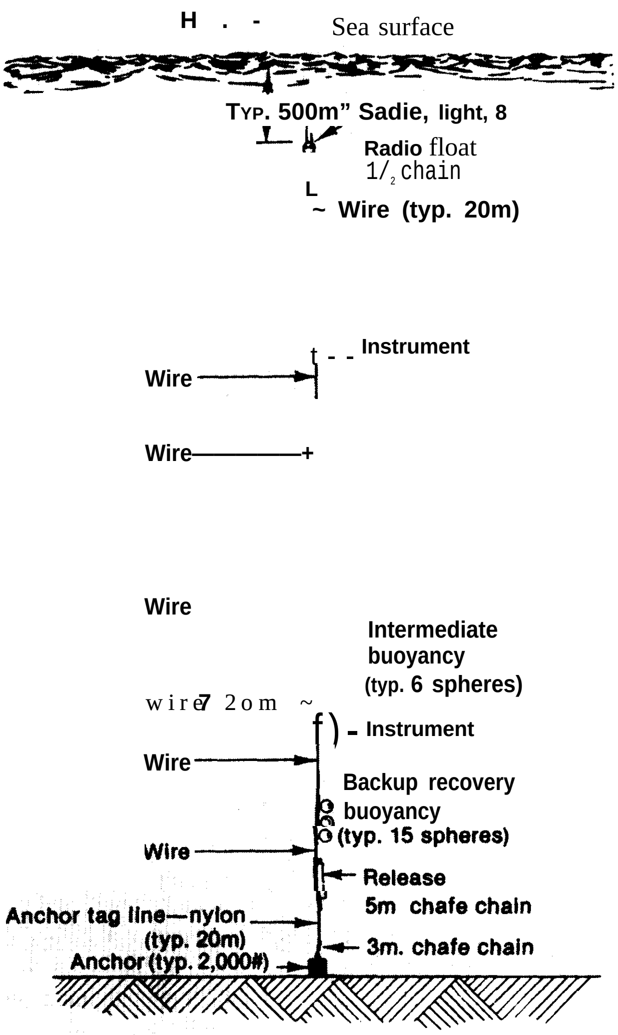
## Mooring Configurations

The Woods Hole Oceanographic Institution and other institutions have developed reliable mooring techniques, and all use basic design principles similar to the following descriptions.[20]

Moorings used at the Woods Hole Oceanographic Institution incorporate three general design configurations. The intermediate mooring, shown in figure 6, is a subsurface mooring with buoyancy sections at several depths. The lowest buoyancy section provides backup recovery in the event of mooring failure. The depth of the top of the mooring can vary up to within 200m of the surface or less.

The deep-sea surface mooring, shown in figure 7, uses a variety of floats. The weight of its anchor varies with the expected current profile. On

**Figure 6.— Intermediate Mooring**




SOURCE: Woods Hole Oceanographic Instltutlon

surface moorings, the backup-recovery section is a single cluster of glass spheres in hardhats on chain near the bottom, instead of in nets on nylon line as used in earlier practice. This section eliminates the need to test spheres because the mooring will not be endangered if a sphere implodes on chain.

Bottom moorings, shown in figure 8, are used to make near-bottom measurements and for transponder (a sensor/transmitter) placement. They are usually 200m or less in length, have no

[20] James D. Baker, "Ocean Instruments and Experiment Design," a chapter for *Reviews Of the Marine Environment, Department of Oceanography, University Of Washington*, Carl Wunsch and Bruce Warren (eds.) (Cambridge, Mass.: MIT Press, August 1979).

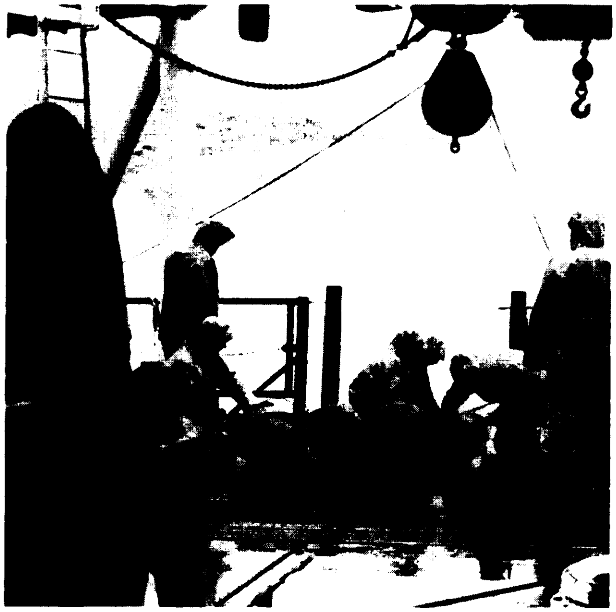
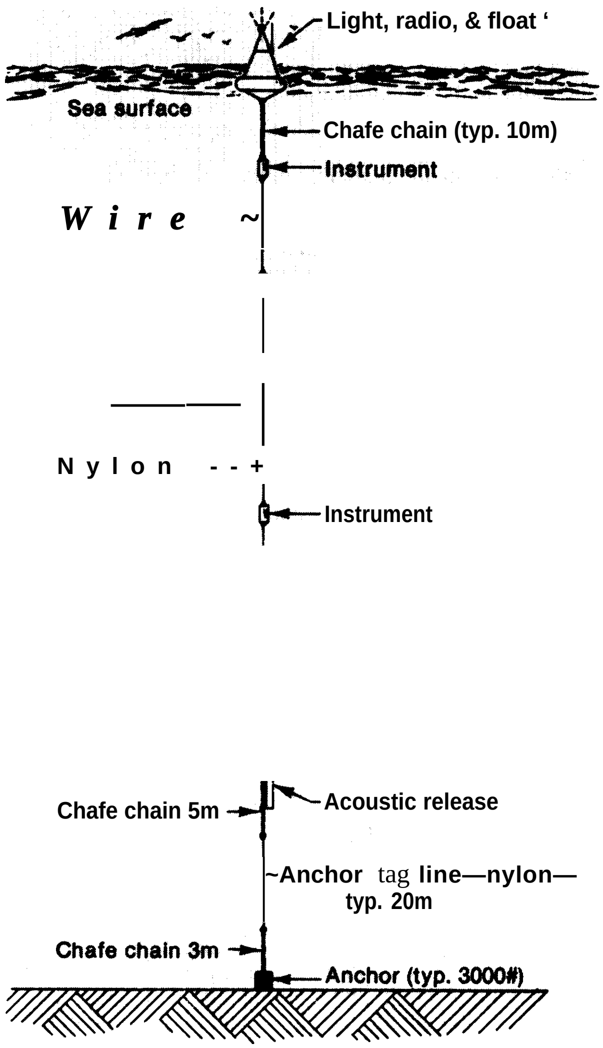


*Photo credit Woods Hole Oceanographic Institution*

Buoy group preparing mooring flotation

**Figure 7.— Deep-Sea Surface Mooring**




SOURCE: Woods Hole Oceanographic Institution

backup recovery section, and typically carry only one or two instruments.

Mooring failures occur during launch, during recovery, and on-station. Numerous on-station failures occurred when surface moorings, lines, and fittings failed from fish attack or from corrosion or fatigue. Surface floats have been swept under and crushed in high currents. In many cases, surface moorings were less reliable than the subsurface moorings because of fatigue caused by waves.

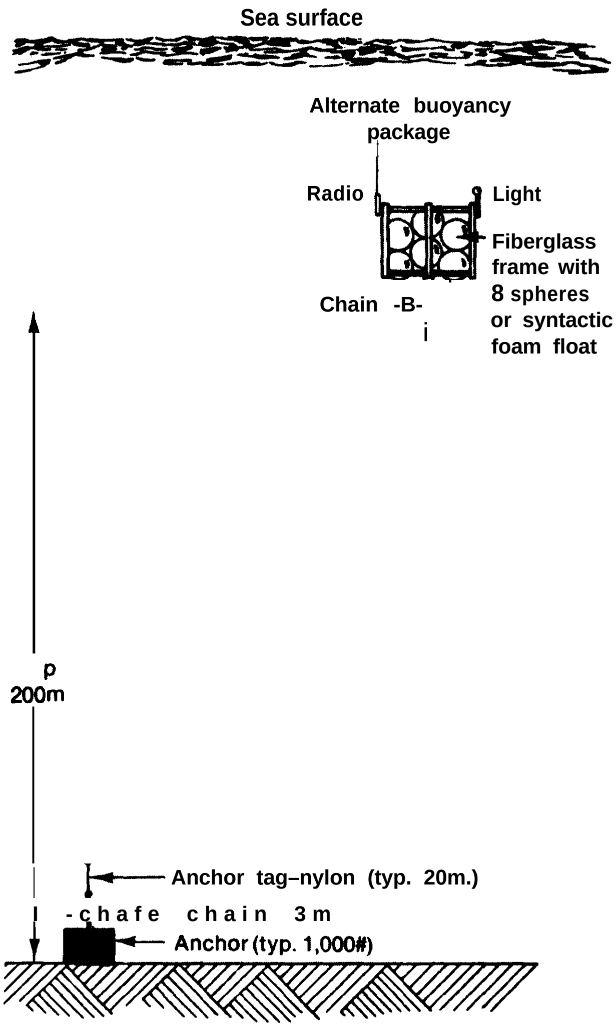
Acoustic release became a key item as soon as it was confirmed that the subsurface moorings were significantly more reliable. The timed releases and weak links used earlier were adequate as long as mooring durations were short; but with longer and longer mooring durations being dictated by program needs to look at lower frequency variations in currents and pressure fields, the timers became unworkable.

Many other buoy systems exist. Some are totally submerged and anchored to the bottom; some are released at the end of a given period; and some are released on command. The sensors and data-recording devices used on the moorings depend on the scientific data requirements.[21]

Special custom-made buoys have occasionally been developed and deployed. A buoy used in research on ocean thermal energy conversions (OTEC) has been built by NDBO. This vehicle tested candidate tubing for possible use in OTEC

[21] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of R & D, Office of Ocean Engineering, Data Buoy Office, *Final Report of the NDBO Severe Environment and Buoy workshop,* July 1979.

Figure 8.— Bottom Mooring




SOURCE Woods Hole Oceanographic Instltutlon

heat exchangers to measure heat transfer coefficients, biofouling, and corrosion. Water quality indicator systems, installed on OTEC and other buoys, have been used in bays and estuaries to measure chlorophyll, conductivity, dissolved oxygen, pH, water temperature, and water clarity.

## *Ocean-Floor Systems*

There are numerous instruments and devices that oceanographers deploy in and on the ocean floor. Examples of these instruments include: ocean-bottom seismometers, sediment traps, current meters, temperature-gradient sensors, coring devices, shear-strength measuring devices, pore-pressure sensors, nephelometers, biological tools such as traps, and photographic and television cameras and recorders. The deployment of these instruments can be accomplished by a number of techniques: lowering from ships, free-fall from ships, and placement by submersibles such as the Alvin, or by bottom-crawling vehicles. Deployment often incorporates buoyancy elements, some sort of detachable weight for anchoring, and acoustically activated release mechanisms. This combination permits recovery by surface ships on command.

An example of a new ocean floor instrument system is the work undertaken by the HEBBLE (High Energy Benthic Boundary Layer Experiment) program in which an underwater platform is planned for long-term stationary operation. The purpose of HEBBLE would be to support a number of instruments which would measure deep, ocean-bottom processes such as currents,

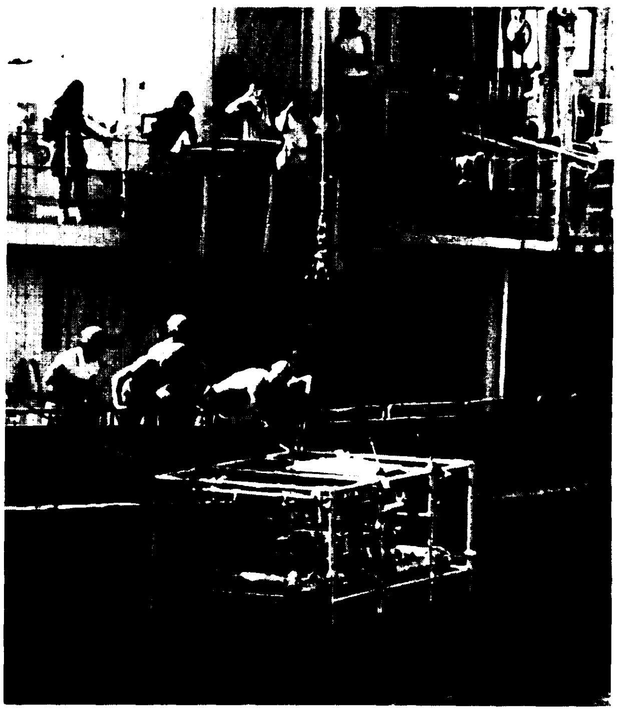


*Photo credit Woods Ho/e Oceanographic /nst/fut/on*

Seafloor sampling device being lowered over the side of R/V Oceanus for studies of transport and degradation of aromatic hydrocarbons sediment transport, and biologic patterns, and then record the data for retrieval. The program will study the dynamics of the benthic boundary layer and its interaction with the seabed. Information gained from HEBBLE experiments will be used in feasibility studies of nuclear waste disposal in the subseabed, toxic waste disposal in the ocean, and deep continental margin drilling.[22]

This program in basic oceanography is supported by Navy and NASA. The NASA Jet Propulsion Lab is designing conceptual hardware systems for the project. Near-term efforts are expected to produce a HEBBLE platform design for deployment to depths of 4,000 to 6,000m. The platform, or seabed lander, will consist of an array of about 12 instruments with associated electronics and onboard microprocessors for data acquisition and storage. A prototype is estimated to cost approximately $2.5 million per lander.[23]

## *Other Vehicles*

Various other vehicles have been considered for oceanographic research, ranging from fixed "Texas-Tower" types to large, moored barges. One in particular, has proved exceedingly useful in certain studies: the manned, Floating Instrument Platform (Flip) operated by the Scripps Institution of Oceanography.

[22] National Aeronautics and Space Administration, Jet propulsion Laboratory, High Energy Benthic Boundary Layer Experiment, *Preliminary Program Plan and Conceptual Design,* JPL publication No. 80-2.1980.

[23] A. J. Williams 111, et al., *The HEBBLE II Report,* Woods Hole Oceanographic Institution technical report No. 79-71, August 1979.

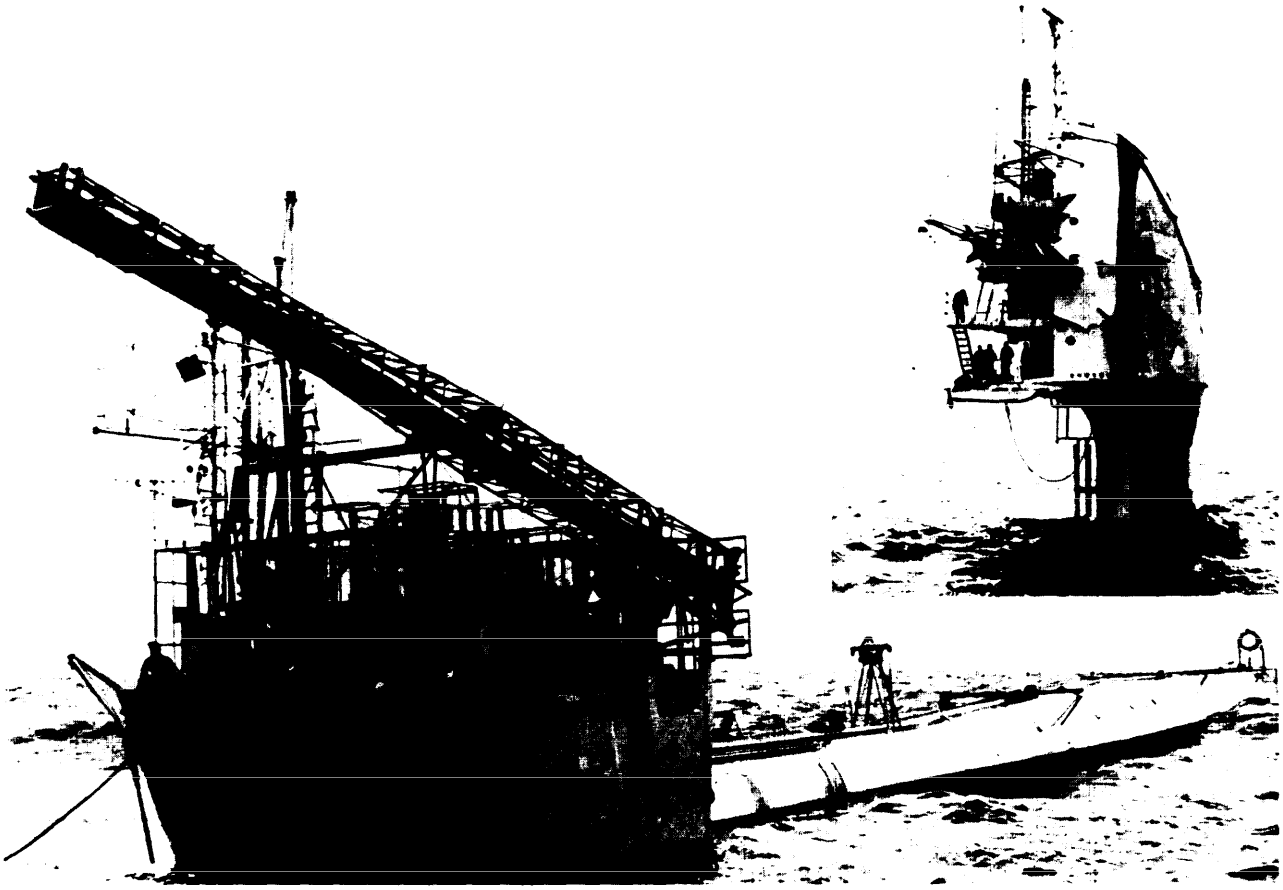


*Photo credit: Scripps Institution of Oceanography*

*Flip,* 355-ft floating instrument platform

Flip is a 355-ft long cylindrical platform which is towed horizontally and then ballasted to a vertical, operating position. *Flip* was built in 1962, primarily to provide a stable platform from which to do underwater acoustic research. In 1964, special tasks in physical oceanography were begun using *Flip*. The first project was a study of the properties of long waves in the Pacific Ocean. Both basic oceanographic research and applications to military oceanography have been important aspects of projects conducted by this platform.

In its early years, Flip drifted with the currents, but in 1968-69 a three-point mooring system was installed. This installation permitted fixing *Flip's* position to within 100m in a fairly deep ocean in moderate currents.

In 1979 and 1980 *Flip* operated for about 50 days. Two areas studied were:

- sound propagation using a vertical **array** of hydrophores suspended below *Flip;* and
- internal waves, using narrow-beam sonar and temperature sensors.

Occasionally a self-propelled version of *Flip is* suggested. Also, consideration has been given to a proposed barge-like *Flip* with a large deck area. This construction would permit carrying of heavy deck loads and even perhaps a small submersible. Navy also operates a large, unmanned, Flip-type buoy known as *Spar*. This platform has been extensively used for acoustic research.

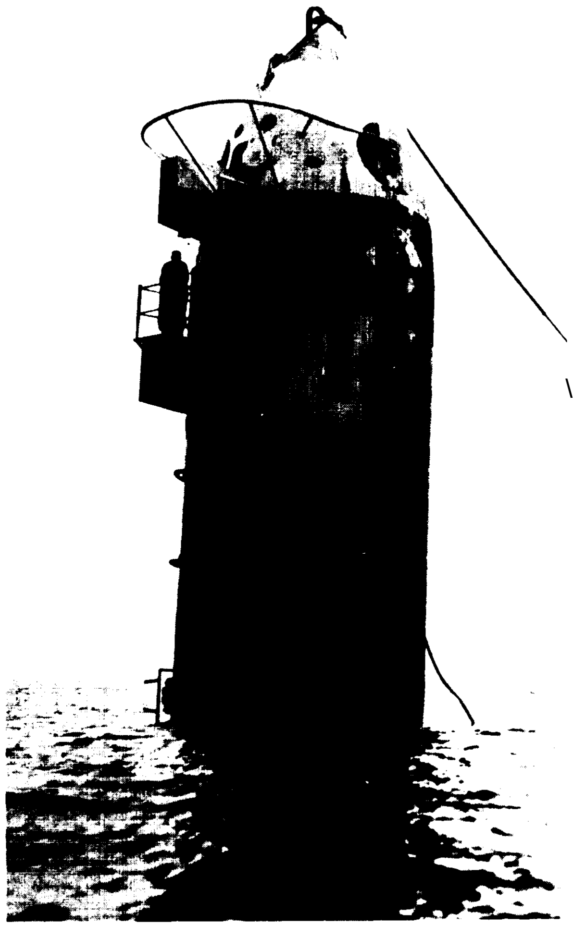


Photo credjt U S Navy

Spar

# EQUIPMENT AND INSTRUMENTATION

Oceanographic research and survey platforms carry different types and combinations of equipment and instrumentation, depending on the purpose and design of the overall mission, Equipment installed aboard most research and survey ships is briefly discussed below followed by a general review of oceanographic instruments that are used in a variety of settings. Remote sensing from satellites is covered in a subsequent section on satellites.

## *Equipment*

Shipboard equipment and services include winch-es, deck handling gear, laboratories, and the specific hardware to accommodate scientific operations. The equipment used depends on the type of ship and its mission. For example, winches, cranes, A-frames, capstans, and open decks near the water are usually necessary for servicing buoys, lowering dredging or coring gear to the sea floor, taking samples, towing nets or other sensors, and installing any number of special measurement systems. Special handling gear is necessary for very heavy instrument systems, for submersibles, for large moorings, or for ROVs.

Some ships are built to accommodate specific handling gear, while others are built with enough flexibility to add or modify such gear as operational needs change. Special winches and-even laboratories, such as those in a van, are often

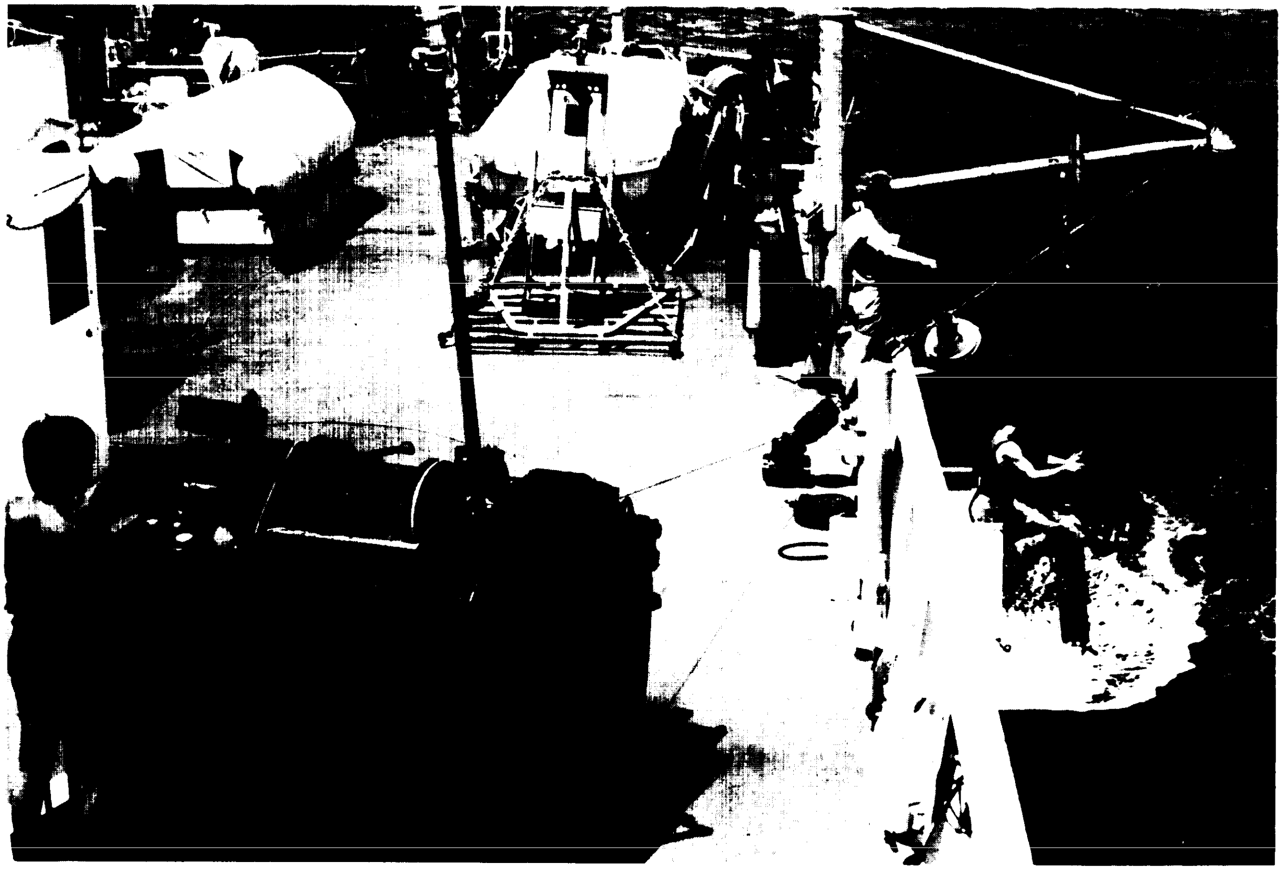


*Photo* **credit National** *Oceanic and Atrnospher/c Administration*

Federal research programs require the use of ships and instrumentation technology. Here a seawater sampler is lowered to the ocean floor from a research ship participating in the NOAA-sponsored Deep Ocean Mining Environmental Study portable and designed for specific experiments. Since many ships are usually in service over 25 years, they must be able to handle the significant changes in technology for ocean-data collection that are likely to occur during the life of one ship. The present practice in the academic fleet is to use operating funds for equipment, with the result that much equipment is not upgraded nor standardized adequately. Many research ships have a lot of ad hoc equipment with the attendant difficulties in getting spare parts. It will be important in the future to maintain and upgrade shipboard equipment and to highlight problems of inadequate or obsolete equipment within responsible agencies.

## Instrumentation

The heart of any ocean research project is its instrumentation. The need to develop instrumentation systems for general oceanographic measurements is driven by the need to observe certain phenomena.

Instruments take many forms and are used for all specific measurements. Measurements of general physical properties and processes have always been important to oceanographic research. Such measurements include ocean temperatures, salinity, density, and depths; dynamic properties produced by waves, currents, and tides; meteorological conditions at the sea surface such as winds, humidity and pressure; chemical properties of the sea and its constituents, biological processes in the ocean; and descriptions of bottom and subbottom geology. Measurements of ocean transport processes, such as the north-south transport of heat, are especially crucial to climatology. To understand heat transport in the ocean, better techniques are needed for measuring large flows of both surface and deep-ocean water.

Biological sampling techniques are extremely important for understanding behavior and productivity of ocean fishstocks. Most existing sampling systems are rudimentary and slow in collecting data. Substantial improvements in biological instrumentation would be useful to major Federal efforts in fisheries and pollution monitoring.[24]

The variety of oceanographic instruments and instrument needs is huge. Most present-day programs require an extensive array of sensors to collect data on physical, chemical, biological, and other properties simultaneously and over large regions. Many measurements must also be made over long periods of time so that the slow-moving dynamics of the ocean can be adequately recorded.

In 1974, NOAA inventoried U.S. stock of sensors and samplers of ocean parameters. It found that there were about 21,000 ocean instruments of 34 generic types.[25] It also found that the technological focus of most oceanographic research, survey, and monitoring programs lay in the instrumentation available. Survey and monitoring programs generally use state-of-the-art instrumentation available commercially. Research programs use a mix of commercial and often one-of-a-kind experimental units.

While it is often convenient to separate programs into physical, biological, geophysical, and other disciplines, many instruments are common to all disciplines. Furthermore, the large field programs, such as climate, are interdisciplinary and require a variety of instruments. Procurement, checkout, and calibration of off-the-shelf instruments requires significant leadtimes to be incorporated into programs. Often experimental systems, having been proven of value, require additional development before they are sufficiently reliable and applicable to the larger field experiments, surveys, and monitoring efforts.

Technology development of new instrumentation is funded by Navy (ONR), NSF, NASA, and NOAA; however, there is no well-funded overall instrumentation development program, that is

[24] ONR Sponsored Workshop on "Advanced Concepts in Ocean Measurements, Problems in Marine Biological Measurements," conducted by the University of South Carolina, Oct. 24-28, 1978.

[25] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *Ocean Instrumentation,* a report for the Interagency Committee on Marine Science and Engineering, November 1974.

separate from scientific programs. It is estimated that 10 percent of the funding of oceanographic research programs of Navy and NSF are directed toward instrument procurement and development. The commercial oceanographic instrument market is so small that it is difficult to attract sector investment in the development of proprietary, new instrument concepts. Therefore, wide dissemination of academically developed technology is necessary to avoid nonproductive expenditures. Interagency information exchange on instrumentation development is badly needed as are realistic budget allocations.

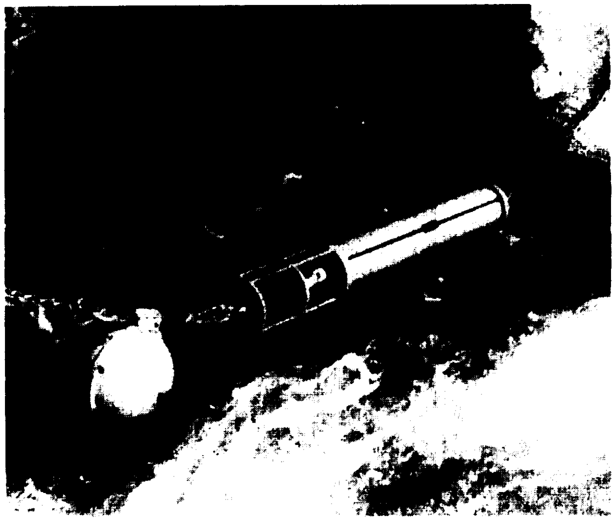
### Instruments and Related Hardware

The four general aspects of instrumentation systems are the:

1. package and related equipment to support the instrument from a ship, on a mooring, or on its own;
2. sensors;
3. power supply; and
4. subsystem for data recording, storage, and transmission.

The following discussions include descriptions of typical and important oceanographic instruments. The instruments chosen are only illustrative examples of a subject that is too large for comprehensive coverage in this report.[26,27]

Current Meters. – Current meters measure the velocity and direction of ocean currents and are used widely throughout the ocean depths. Many fixed meters have the same basic elements as those in use for the past 20 years — a rotor to sense the speed of the water and a vane to sense the direction. They are usually fixed to moorings or buoys and contain their own data recorders. The modern versions have improved recorders to average the frequent direction changes and improved sensors utilizing acoustics, electropotential, and magnetic techniques to measure flow and direction.



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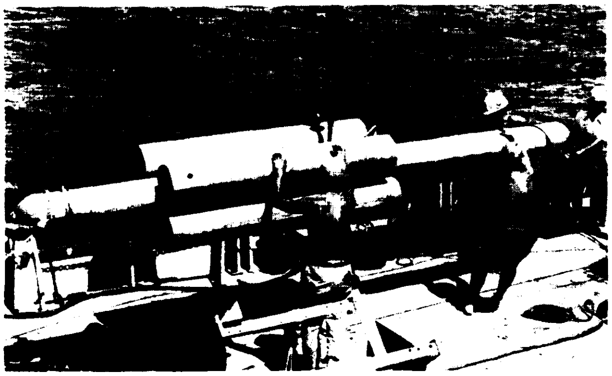
Neutrally Buoyant Floats. –Neutrally buoyant floats are special versions of current meters which are launched into the ocean to drift with the currents and are then tracked by a surface ship. Measurement of currents by the use of floats requires sophisticated methods of tracking the floats. The great strides made in acoustics during World War 11 yielded such adaptable technology.

Early versions of floats were developed just after the war and were known as "Swallow Floats" after their inventor, John Swallow. Tracing of them was difficult, however, until long-range floats were developed to use the SOFAR (Sound Fixing and Ranging) channel. The SOFAR channel is found in the many parts of the ocean and is caused by the combination of pressure and temperature effects on the speed of sound. In the SOFAR channel a few watts of sound can be heard thousands of kilometers away.

Drifting surface buoys are an additional type of current indicating instrument that have been found to be of considerable importance. (The predecessor to drifting buoys was the drifting corked bottle. ) Drifting surface floats with subsurface drogues (parachutes) are controlled in postion by the subsurface currents that pull at the drogue. Position data, meteorological data, and

[26] Baker, op. cit.
[27] U S Department of Commerce, National Oceanic and Atmospheric Administration, Office of Ocean Engineering, *Marine Instrumentation: An Assessment of Technology Versus Needs,* technical report, May 1978.



O R g

ocean surface temperature are transmitted from these drifters via satellites.

An interesting extension of the idea of the neutrally buoyant float is the self-propelled and guided float. One such instrument, built at the University of Washington, is called *SPUR V* (self-propelled underwater research vehicle). *SPUR V* can maneuver underwater with acoustic signals to produce horizontal and vertical profiles of temperature, salinity, and other parameters. In fact, it is really an ROV, that illustrates the difficulty in putting oceanographic technology in neat categories.

Temperature Profilers. – The free-fall bathythermograph (BT) has advanced dramatically in design. The old BT with its pressure-driven bellows and temperature gauge that recorded temperature as a function of depth has been replaced by the electronic XBT. A radio link is now included so that the unit can be dropped from a data-recording aircraft. These expendable units provide data from the upper layers of the ocean. The XBT uses a thermistor to sense the temperature and depends on a known fall-rate to determine the depth.

XBTs are an invaluable tool for monitoring the upper layer thermal structure of the ocean. Merchant ships equipped with XBTs have yielded extensive sets of data for the study of the variability of the thermal structure of the upper ocean in both the North Pacific and the North Atlantic. By 1978, the Sippican Corp., suppliers of the XBT, produced more than 2 million

*Photo credit M Guberek, Scripps Ins!/tution of Oceanography*

Merchant marine cadet receiving instruction in the operation of an automated instrument to measure seawater temperature and depth. Climate research will require consistent, accurate measurements over long time periods such as can be provided by a network of "ships-of-opportunity" with trained officers aboard

probes. The scientific community alone uses approximately" 65,000 XBTs annually. Navy uses many more. To obtain deeper and more accurate measurements than are available with the XBT, ship-lowered systems, such as the salinity-temperature depth instrument or the conductivity-temperature-depth instrument are used.

Velocity Profiles. – The measurement of current as a function of depth is critical to the understanding of ocean circulation. The technology has advanced but not sufficiently to provide the quantitative and wide-area data needed in many oceanographic studies. Techniques used include three classes: the sinking float, the free-fall device, and the attached profiler. The sinking float, is tracked acoustically by ocean-flow transmissions as it sinks, and its path is differentiated to yield velocity as a function of depth. The free-fall device includes a current sensor. The attached profiler instrument that has a current meter that goes up and down a line attached to a ship, mooring, or drifting buoy. Since these three types provide data only at a single point and for a restricted time, they cannot provide the data required for many large-scale experiments and survey programs. Newer techniques using acoustic doppler and correlation (acoustic tomography) are being investigated to overcome these limitations.

Almost every oceanographic discipline has needs for improved instrumentation. In fisheries, limitations exist in the ability to identify species by acoustics, to conduct population surveys, and to net mid-water fish species. Technology for deepwater sampling at moderate ship speeds for chemical oceanography or nutrient-analysis purposes is not available. In seismic work, significant advances have been made by the petroleum industry; however, advanced instrumentation has not been available to academic and Government laboratories.

Associated Technologies. –There are many technologies associated with data acquisition that have considerable impact on sensor systems but are not classified as instrumentation, per se. These approaches include navigation and instrument position technology, data recording and transmission, instrument power supplies, and electronic technologies.

*Data Recording and Data Transmission.* –Sea Data Corp. has produced over 1,000 recorders since 1972. The present Sea Data (1978) model uses less than 4 watthours of battery power to record 11 million bits of data. The tape transport can write data as fast as 1,200 bits per second or as slow as one record per half hour. At this rate, with a maximum 396-bit data record, a cassette would take more than a year to fill. This data capacity is roughly equivalent to 500 ft of 4-inch-strip chart paper. Other commercial cassette tape recorders are also available for oceanographic use.

In many applications it is necessary to obtain oceanographic data in real time. Data transmission by satellite relay has replaced many radio frequency transmissions and has made communications possible from many small remote buoys.

*Navigation, Position Data, and Communications.* — Most oceanographic studies and surveys require position data. Advances in shore-based navigation, such as Loran and Omega, are complemented by satellite navigation systems. Within the next 5 years, further improvement of position data will be provided by the Global Positioning System (GPS).

Photo credit Scripps /nst/tut/on o! Oceanography

In the laboratory aboard a research vessel, a student studies recorded measurements from a temperature probe of heat flow through the ocean floor

*Batteries.* – Power consumption of data recorders is now lower because of improvements in battery capacity over the past few years. The new lithium-cell batteries provide a number of characteristics important for oceanographic use. They have the highest cell voltage, the longest shelf life, the greatest energy density, the best low-temperature performance, and a flatter voltage-discharge curve than any other battery except mercury cells. The last characteristic is especially important for use in logic circuits where the system is usually set to run at a given regulated voltage.

These batteries and the new high-capacity tape recorder allow measurements of various oceanographic parameters in excess of a year and do a certain amount of data processing in situ. One major data collection problem has been solved by the introduction of reliable tape recording systems now on the market.

*Electronics Technology.* – One of the most important steps in instrument design was the introduction of the new lower-power, integrated-circuit, solid-state electronics, known generally as COSMOS (complementary-symmetry metal ox-

Photo credit' Unwersfty of Ca///ora,a, San D/ego

Shipboard computer group at Scripps Institution of Oceanography has five computers—three 1800's and two satellite navigation systems. Operating 24 hours a day, both at-sea aboard research vessels and on land at the La Jolla campus, they collect and process data from oceanographic instrumentation

ide semiconductor). Solid state devices permit a number of data processing operations in situ that never could have been considered before. For example, the vector-averaging current meter computes north and east components of the velocity, and records the speed, compass and vane follower directions, time, temperature, and the components over a variable sampling time which can be set to fit the experiment. The total recording time can be longer than 600 days. The use of the COSMOS integrated circuit technology is crucial to this flexibility.

A future outgrowth of the above technology may be oceanographic instruments using integrated electronic circuit components on silicon "chips" if enough measurements for many stations are identified. The original chip will be expensive to design, but economical to replicate. For example, once a satisfactory digital output instrument has been developed, the next step would be to do the same thing that manufacturers of commercial electronic games do — namely, to make up a large-scale integrated (LSI) circuit chip. To make a chip may cost $250,000; replicas may cost about $5 each.

The major factor preventing the development of instrumentation chips is economics. The oceanographic market is insufficient to justify developing a chip in the hope of making a profit. Public funding, however, may be justified. The

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investment could return benefits, such as better and more complete data; fewer lost costs because of instrument malfunctions; and ease of replacement since ships can carry spare chips. The other advantages of LSI circuit chips would be durability, continuity of instrument design, less temperature sensitivity, insensitivity to accelerations, and much smaller circuits, with the attendant advantages in small size.

Many "control"-type chips are becoming available for other nonoceanographic use, such as that in appliances, automobiles, and special instrument control. Many of these special and general -purpose chips may be useful to oceanographic instrumentmakers.

Oceanographic equipment and instrumentation requirements are very dynamic due to the changing character of programs and available technologies. Each discipline and each program may have unique requirements; most have many technology requirements in common. The sharing of development costs to advance both technology and programs may offer new instrumentation and program alternatives. The significant problem in each program is that of gaining the technology and the required equipment and instrumentation on a time- and cost-effective basis.

# SATELLITES

The measurement of the ocean by satellite technology began with both the experimental satellites (such as the Nimbus series) that tested new satellite instrumentation and the global weather satellites (Tires and Improved Tires) that were able to provide day and night global ocean coverage. 28

Although several early satellite missions provided oceanic data, these data were usually outside of the mainstream purpose of the missions. Missions with a strictly oceanic objective began with a *Skylab* experimental mission, were followed by the GEOS-3 altimetric experiment, and culminated in 1978 by the *Seasat* experiment. Other missions dedicated to diverse or different interests have also provided valuable oceanic data.[29]

[28] John R. Apel, "Ocean Science From Space, " EOS, *Journal of the American Geophysical Union,* September 1976.

[29] A. Schnapf, *Evolution of the Operational Satellite Service, ]958-1984* (Princeton, N.J.: RCA Corp., 1979).

The many satellites that have carried sensors and yielded data useful to ocean, coastal, and polar science, and to oceanic environmental monitoring are listed in table 24. The concerted development of oceanic remote sensors for these satellites received a major impetus from a meeting of oceanic data users at Williams College, Williamstown, Mass., in 1969. At that meeting, goals and objectives for satellite observation, measurement, and interpretation of ocean phenomena were formulated (table 25). These measurement needs reflected the fact that the everchanging nature of the ocean requires continuous viewing at all times in the day, despite the cloud cover which can be prevalent in many important regions. Furthermore, the needs served as an important benchmark from which to judge the oceanic programs that followed this meeting and they had a direct effect *on* the formulation of measurement objectives for the proposed NOSS. Recent representative sensor tech-

**Table 24.—U.S. Satellites of Utility in Ocean, Coastal, and Polar Monitoring**

| Satellite | Launch date | Orbit | Character | Sensors | Oceanic Parameters |
|---|---|---|---|---|---|
| Nimbus 4 | 1970 | Polar | Experimental | IR and MW radiometers and bolometer; color scanner | Temperature, ice cover, radiation budget, wind, color |
| Nimbus 5 | 1973 | | | | |
| Nimbus 6 | 1975 | | | | |
| Nimbus-G | 1978 | | | | |
| ITOS 1-4 | 1966-75 | Polar | Operational | Visible vidicon; IR scanner | Imagery, temperature |
| ESSA 1-9 | | | | | |
| NOAA 1-4 | | | | | |
| ATS 1-3 | 1966-67 | Synchronous | Prototype | Visible, IR scanners; data channel | Imagery, temperature, data relay |
| SMS/GOES 1-5 | 1974-78 | Synchronous | Operational | Visible, IR scanners; data channel | Imagery, temperature data relay |
| GEOS 1-3 | 1965-75 | Variable | Experimental | Laser reflectors; altimeter | Geoid, ocean geoid |
| ERTS 1 | 1972 | Polar | Prototype | Visible, near-l R scanner; thermal IR scanner | Imagery, temperature |
| Landsat 2 | 1974 | | | | |
| Landsat 3 | 1978 | | | | |
| Skylab | 1973 | — | Experimental | Cameras; visible, IR scanner; spectro radiometer; MW radiometers; altimeter; scatterometer | Imagery, temperature wave height, wind speed geoid |
| Tires-N | 1978 | Polar | Operational | Visible, IR scanners | Imagery, temperature |

SOURCE: National Aeronautics and Space Administration

**Table 25.—Measurement Needs for Oceanographic Satellites**

| Measurement | | Range | Precision accuracy | Resolution | Spacial grid | Temporal grid |
|---|---|---|---|---|---|---|
| Topography | Geoid | 5cm-200m | +/- 10 cm | 10km | — | Weekly to monthly |
| | Currents, surges, etc. | IOcm-10m 5-500cm/s | +/-1ocm +/- 5cm/s | 10-1000m | 10km | Twice a day to weekly |
| Surface winds | Amplitude: Open ocean | 3-50m/s | +/- 1 TO 2m/s OR* 10% | 10-50km | 50-100km | 2-8/d |
| | Amplitude: Closed sea | | | 5-25km | 25km | |
| | Amplitude: Coastal | | | l-5km | 5km | Hourly |
| | Direct ion | 0-3600 | * 10.20"° | — | — | — |
| Gravity waves | Height | 0.5-20m | +/- 0.5m | 20km | 50km | 2-8/d |
| | Length | 6-1 1,000m | OR g+/- 10-25% 3 10.250/o | 3-50m | | 2-4/d |
| | Direct ion | 0-360° | * 1 ().3()0 | | | |
| Surface temperature | Open sea | – 2-35'C | 0.1-2 “relative 0.5-2° absolute | 25-100km | IOOkm | Daily to weekly with spectrum of times of day and times of year |
| | Closed sea | | | 5-25km | 25km | |
| | Coastal | | | 0.1-5km | 5km | |
| Sea ice | Extent and age | 6 me.— yrs. | l-5km | l-5km | l-5km | weekly |
| | Leads | 50cm | 25m | 25m | 25m | 2-4/d |
| | Icebergs | IOcm | l-50m | l-50m | 25m | — |

SOURCE: National Oceanic and Atmospheric Administration.

nologies on aircraft and satellites that provide oceanic and polar measurements are shown in table 26.[30]

Of the several more recent satellites, the most useful for oceanography are probably *NOAA-3* and *NOAA -4, ER TS-1, Landsat-2, GEOS-3,* the SMS/GOES series, *Tires-N, Seasat,* and *Nimbus-7*. The last three satellites were launched in 1978 and their impact is currently being assessed. *Tiros-N is* the first of the new generation of operational meteorological and environmental polar-orbiting satellites. *Nimbus-7* was designed to serve experimental ends for both pollution monitoring and oceanography. *Seasat-A* was the first satellite designed for oceanographic research but only lasted 3 months.

The Department of Defense (DOD) satellite systems, such as the Defense Meteorological Satellite System are also of value in making oceanic measurements but are not widely available outside of military programs.[31]

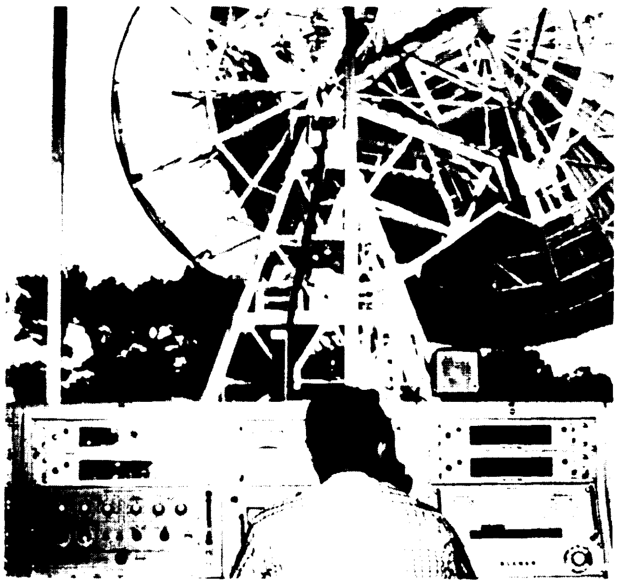

*Photo credit Nat/onal Ocearrlc and Atmospheric Administration*

NOAA’s satellite-tracking ground stations receive data from satellites on global ocean static and weather conditions

To fill the need for a dedicated oceanographic satellite, the operational satellite community has proposed development of an NOSS as a “limited operational demonstration” mission. The project would be a joint effort of NASA, NOAA, and

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[30] Samuel W. McCandless, *An Analysis of the National Oceanic Satellite System, NOSS,* **prepared for OTA, ‘Apr. 12, 1980.**

[31] Department of the Nav,, *Naval Oceanographic and Meteorological Support System Environmental Satellite Plan,* **Director, Naval Oceanography and Meteorology, July 1978.**

**Table 26.—Satellite Sensor Records of Interest in Ocean, Coastal, and Polar Monitoring**

| Short form | Sensor name | Wavelength or frequency | Spacecraft | Spatial resolution |
|---|---|---|---|---|
| SR . . . . . | Scanning radiometer | Visible and thermal IR | NOAA-1 through 4 | 7km |
| VHRR . . | Very high resolution radiometer | Visible and thermal IR | NOAA-1 through 4 | 1 km |
| V I S S R | Visible and infrared spin scan radiometer | Visible and thermal IR | GOES | I-7km |
| AVHRR . | Advanced very high resolution radiometer | Visible and thermal IR | Tires-N | 1 km |
| M S S. | Multispectral scanner | Four channels, visible and reflected IR; thermal I R | ERTS/Landsat-l through 3 | 75m, 250m (IR) |
| TM . . . . . | Thematic mapper | Four channels, visible and reflected IR; thermal I R | Landsat-D | 30m, IOOm (IR) |
| Czcs | Coastal zone color scanner | Six channels, visible, reflected and thermal IR | Nimbus-7 | 825m |
| ESMR | Electronically scanned microwave radiometer | 19 GHz | Nimbus-5 | 15km |
| SMMR . . | Scanning multichannel microwave radiometer | Five channels: 6.6, 10, 18, 21,35 GHz | Nimbus-7, Seasat | 15-140km |
| ALT . . . . | Short pulse altimeter | 13.9 GHz, 14.6 GHz | Skylab, GEOS-3, Seasat | 2km |
| SASS. . | Radar wind scatterometer | 13.4 GHz, 14.6 GHz | Skylab, Seasat | IOOkm |
| SAR . . . . | Synthetic aperture radar | 1.3 GHz | Seasat | 25m range-7m azimuth |
| MSU . . . | Microwave sounding unit | 4 or 7 channels 50 to 58 GHz | Tires or DMSS BLK V-D-2, respective y | 100km |

;OURCE Nattonal Aeronautics and Space Admlnistratton

Navy. An analysis of the NOSS program is in another section of this report.

## *Operational Weather Satellites*

The National Environmental Satellite Service (NESS) of NOAA, is responsible for the operation of polar-orbiting and geostationary satellites that collect weather and other environmental data. The principal user of this satellite data is NOAA's National Weather Service, but the data are also available to other Government agencies and to the public.

### Polar-Orbiting Satellites

Polar-orbiting satellites are generally in a low orbit (approximately 500 to 900 miles — 800 to 1,500 km – altitude) and they circle the globe from pole to pole 12 to 14 times each day, collecting data and imagery in a swath of up to 1,500-miles (2,500-km) wide. The data are either transmitted to ground receiving stations in real time or stored for playback when the satellite is within range of a ground receiving station .32 33

A third generation of polar-orbiting satellites, the Tires-N series, is now operational. The series consists of two satellites in orbit: *Tiros-N* and *NOAA -6. Tiros-N*, the NASA prototype and the first of this series, was launched October 13, 1978. NOAA-6, formerly *NOAA-A*, **was** launched in April 1979, as the first operational satellite of this series. A third satellite, *NOAA -7, is* scheduled for orbit in 1981.

The satellites carry four primary instruments: a Tires operational vertical sounder (TOVS), an advanced very high-resolution radiometer, a space environment monitor, and a data collec-

[32] U. s. Department of Commerce, National Oceanic and Atmospheric Administration, "Summary of Actions Leading to Establishment of the National Operational Meteorological System (NOMSS) in Department of Commerce, " background paper, received from G. Ludwig, Director of Satellite Operations, NESS, Oct. 24, 1973,

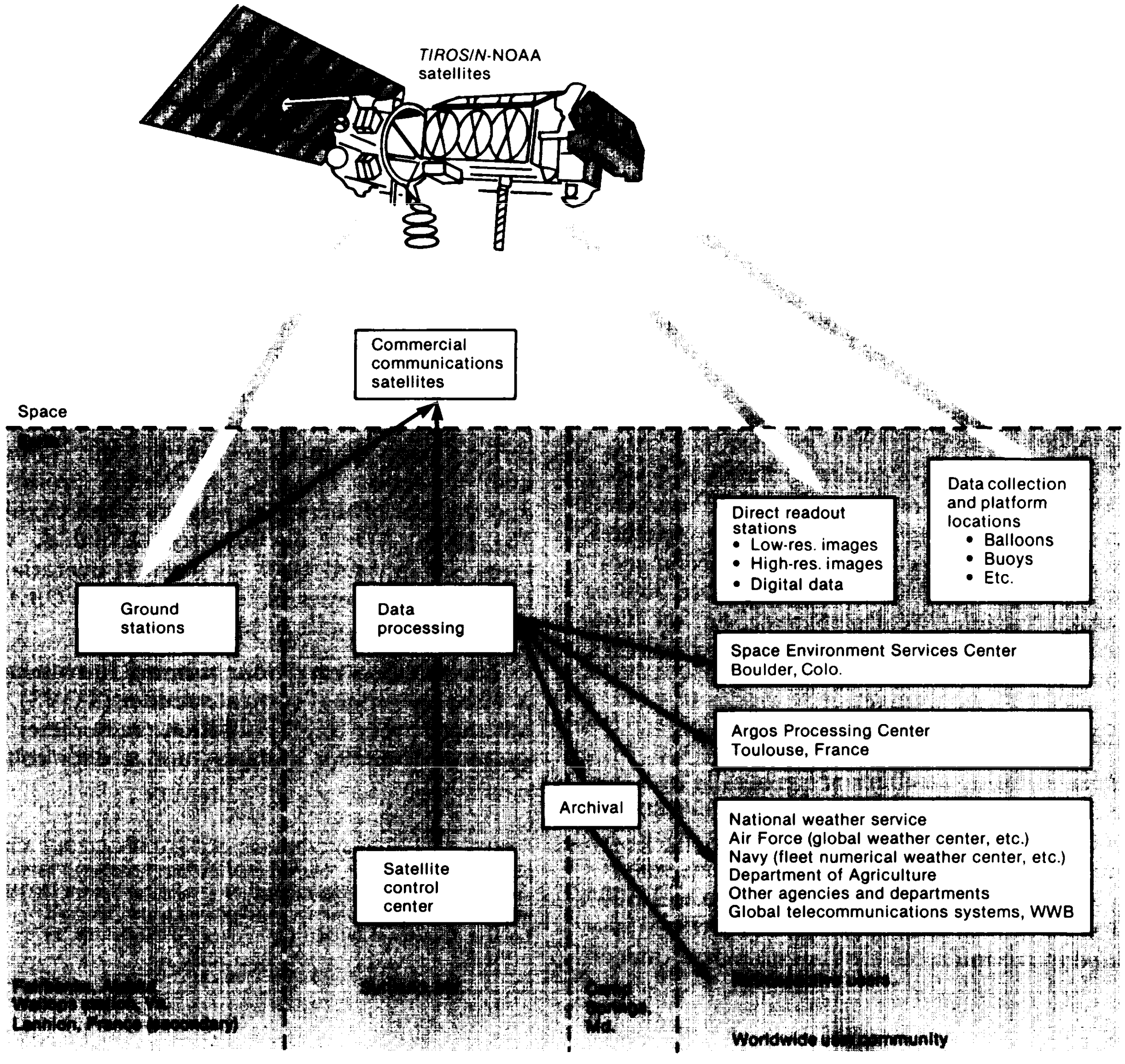
[33] Ibid.

tion and platform location system called ARGOS (fig. 9).

France is furnishing the ARGOS system and will also do the platform location analysis in the operational system. The United Kingdom is providing the stratospheric sounding unit (a component instrument of TOVS). Major improvements in Tires will be higher accuracy and resolution of atmospheric temperature and water vapor soundings, increased radiometric data providing more accurate seasurface temperature mapping and plotting of snow and ice cover and the additional ability to monitor solar spectral disturbances. 34

[34] U. S. Department of Commerce, National Oceanic and Atmospheric Administration, *Oceanic and Related Atmospheric Phenomena as Viewed From Environmental Satellites,* Washington, D. C., April 1979.

**Figure 9.—Polar-Orbiting Satellite Subsystem**




SOURCE. National Oceanic and Atmospheric Administration

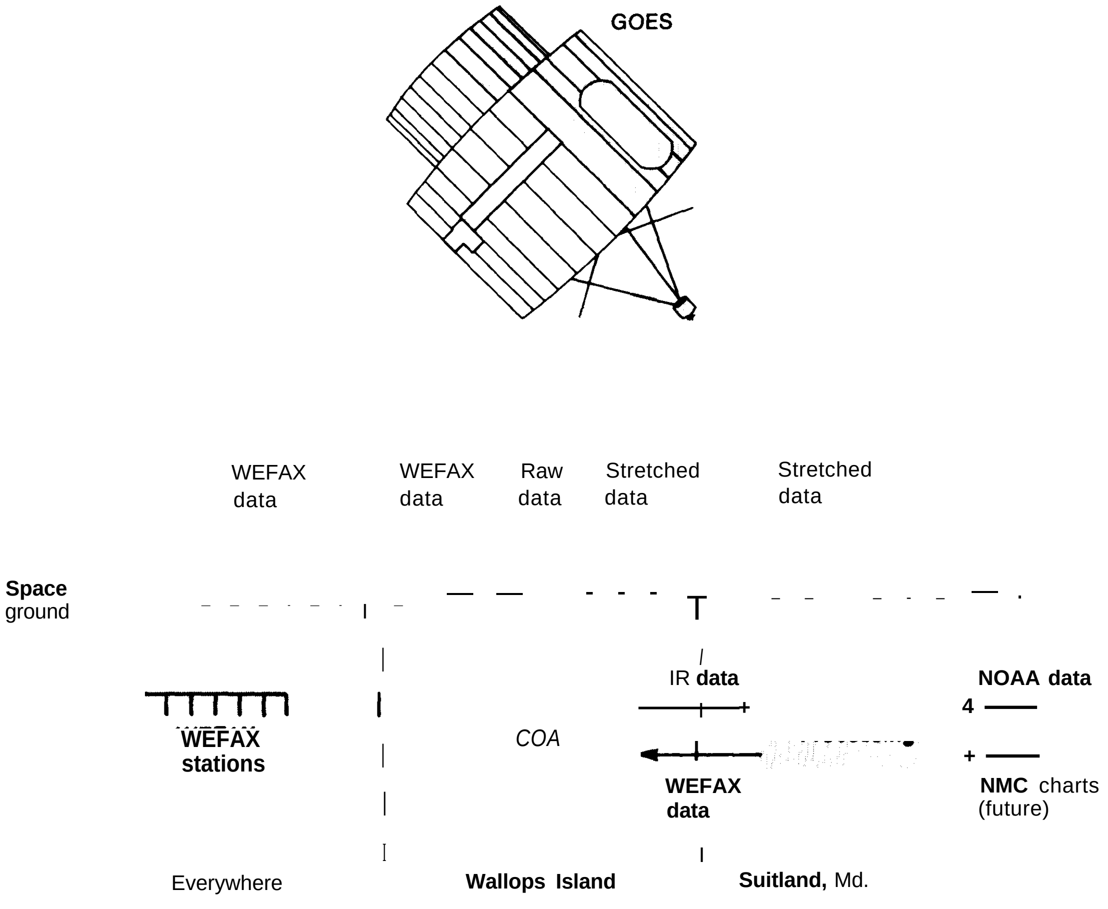
Because of the extremely large volume of digital data delivered by these satellites, it was necessary to install a new ground system which was completed in June 1978. The system is functionally divided into two subsystems called the Data Acquisition and Control Subsystem (DACS) and the Data Processing and Service Subsystem (DPSS). The DACS equipment is located at Wallops Island, Va., Gilmore Creek, Alaska, San Francisco, Calif., Suitland, Md., and Lannion, France. Satellite data acquired at the Wallops and Gilmore Creek sites are relayed to the NESS Suitland, Md., facility via a domestic commercial communications satellite. The DPSS, located in Suitland, preprocesses and conditions the data for archiving and storage and directs it to the NOAA Central Computer Facility. Products are then developed and distributed to the users. The data are archived in a mass-storage system and retained by NOAA's Environmental Data and Information Service (NOAA/EDIS).

### Geostationary Satellites

Geostationary satellites are parked in orbit about 22,000 miles (36,000 km) above the surface. At this altitude, they remain above the same point on Earth, thus being geosynchronous or geostationary. The satellites' sensors collect a complete Earth-disk image of about 25 percent of the globe once every 30 minutes (fig. 10).

NOAA operates the Geostationary Operational Environmental Satellite (GOES) system, consisting of predominantly land and marine

**Figure 10.–Geostationary Satellite System (GOES)**




SOURCE National Oceanic and Atmospheric Administration weather observation units with remote data-transmission links. This system includes three operating satellites (SMS-2, GOES-2, and GOES-3), two partially operating satellites in standby duty (SMS-1 and GOES-I), a recently launched satellite (GOES-4) that is still being checked out, the data acquisition system, and a centralized data distribution system. The first satellite in this system, NASA's Synchronous Meteorological Satellite (SMS-1), a prototype for GOES, was launched May 17, 1974.

There are now approximately six functional geostationary satellites in space. Positioned over the Equator, SMS-2 operates at longitude 750 W., GOES-3 operates at longitude 1350 W. and GOES-2 operates at longitude 1050 W. to re-transmit weather map data to Government and private users.

The European Space Agency operates its own geostationary satellite, *Meteosat*, at *00* longitude, and Japan's National Space Development Agency operates a satellite at 1400 longitude.

In addition, the standby satellites, SMS-1 and GOES-I, are located at longitude 300 W. and longitude 1290 W. respectively. Other potential satellites include GOES-4, launched in September 1980 and positioned at longitude 980 W. for trial, and GOES-5, scheduled for orbit in 1981.

The primary instrument carried by SMS and GOES satellites is the visible and infrared spin-scan radiometer (VISSR). VISSR provides a full-disk view of the Earth every 30 minutes. More frequent images can be obtained at the sacrifice of spatial coverage. The visible channel provides high resolution (about 1 km) daytime images; the infrared channel provides lower resolution (about 8 km) day and night images.

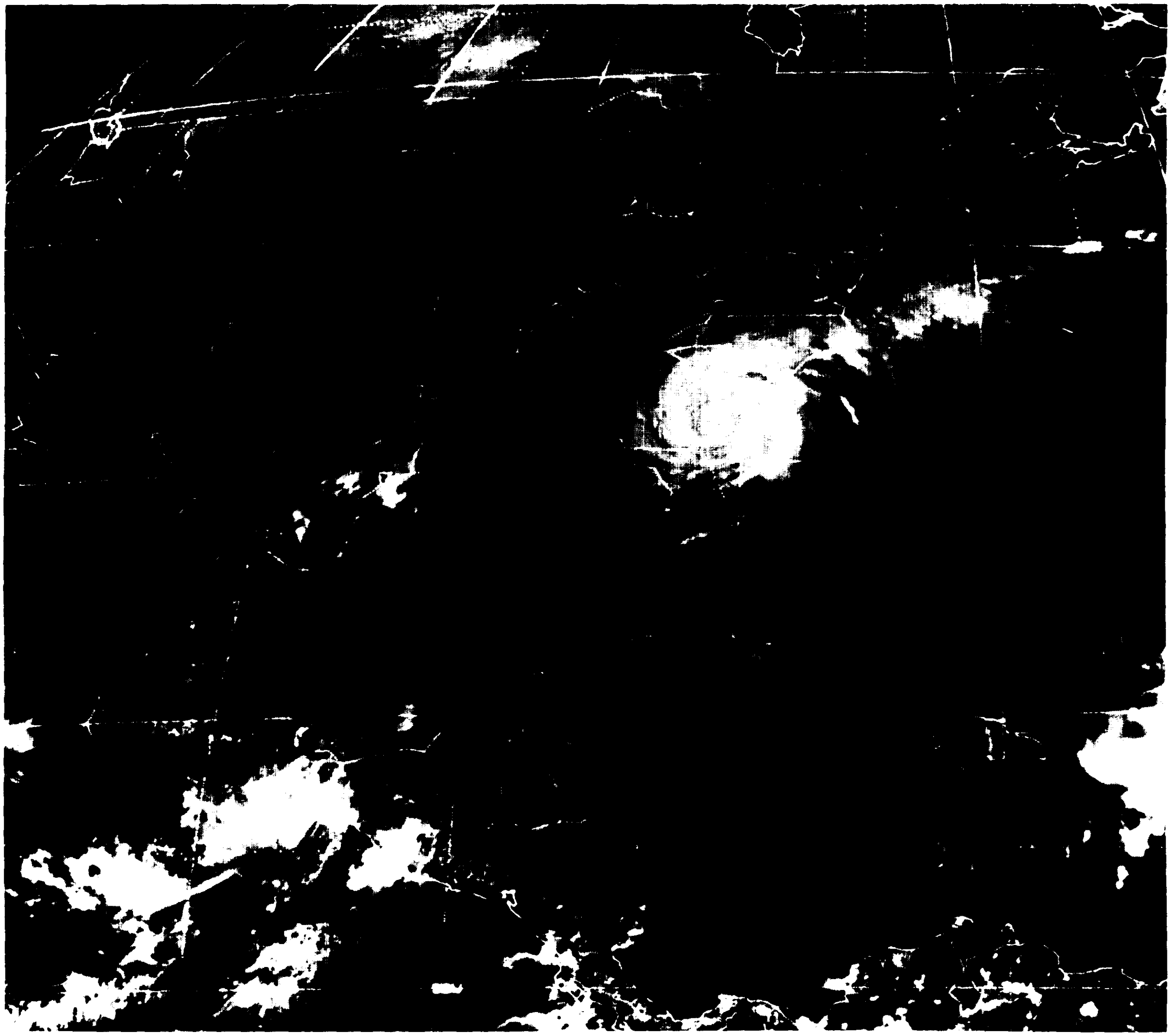
SMS/GOES satellites also carry a space environment monitor for observing solar radiation and the Earth's magnetic field and a data-collection system for collecting and relaying environmental data from remote observing platforms on the Earth's surface. Such sensing devices include river and rain gages, seismometers, tide gages, and instruments on buoys, ships, aircraft, and automatic weather stations. Each operational GOES spacecraft can accommodate data from more than 10,000 platforms every 6 hours. Data may also be transmitted under emergency conditions in which the platform transmitter is triggered whenever an observed parameter exceeds a predetermined threshold value. About 500 platforms have now been certified in the GOES Data Collection System to provide environmental data to users in the United States and Canada.

VISSR images are processed through the NESS Central Data Distribution Facility, either as a full-disk image or a section thereof, and routed to Satellite Field Services Stations (SFSS) for analysis and further routing to National Weather Service forecast offices and other users (fig. 10). Each SFSS provides regional analysis, interpretation, and distribution of the VISSR images to meet a wide variety of environmental needs. One of these important services is the near-continuous viewing of the development and movement of severe weather systems, such as hurricanes and thunderstorms.[35]

An extension of the GOES image-distribution service is the "GOES-TAP" system. Instituted by NESS in 1975, "GOES-TAP" now allows Federal, State, and local agencies, television stations, universities, and industry to receive a limited inventory of GOES satellite images directly from the nearest field service station. In addition, GOES satellites broadcast weather data to remote locations using the Weather Facsimile System.

As a result of the international cooperation and participation within the World Meteorological Organization, a future global geostationary observation system is being developed. Japan, the European Space Research Organization (ESRO), and the U.S.S.R. are each planning to launch their own geostationary environmental satellites within this decade. All except the U.S.S.R. spacecraft will be launched by the United States aboard a Delta launch vehicle from Cape Kennedy, Fla. Figure 11 shows the approximate spacecraft locations for the proposed global system. Each spacecraft will be spaced about 700 apart around the world —one over the western Pacific (Japan), one over the eastern Atlantic (ESRO), and one over the Indian Ocean

[35] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *Geostationary Operational Environmental Satellite/Data Collection System*, NOAA technical report NESS 78, July 1979.



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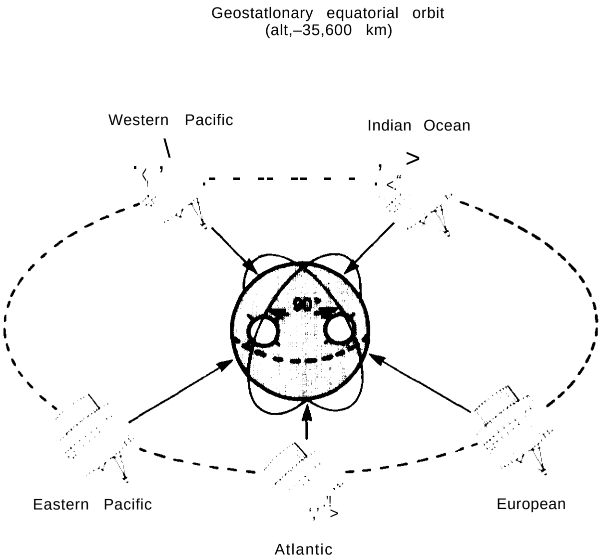
## *Recent Satellıte Developments*

Tw h p g m *S* *A* d
*Nimbus* h b p h
g ph mm w h h p

*S* w h NASA pp
d d m m d
m d g d *Nimbus* pp
nm m n g p d
n nd m ph m m B h
*S* nd *Nimbus* w d g d d h d
b NASA

NOAA p d p m wh h
d w wh h d w d b

**Figure 11.—Proposed Global Geostationary Satellite System**




SOURCE: National Oceanic and Atmospheric Administratlon

compared with *Seasat-A* and *Nimbus-7* overflight observations. Localized experiments would form elements of surface-truth data for comparison with satellite data. For example, surface-wind data could be obtained from aircraft and surface platforms for calibration of *Seasat/Nimbus* data to be used in support of the global weather experiment.[36]

The Nimbus series was originally conceived as meteorological satellites to provide atmospheric data for improved weather forecasting; but as increasingly sophisticated sensors became available, the series grew into a major program studying earth sciences. The U.S. Navy has used *Nimbus* data for planning operations in the Arctic and Antarctic. Satellite images showing the location and movement of ice masses enables naval ships to operate in these areas for an additional several months.

### *Nimbus-7*

The disciplinary areas of *Nimbus-7*, the most recent of the series (and the only one now operating), are pollution, oceanography, weather, and climate. Like its six predecessors, it is a Sun-synchronous, polar-orbiting spacecraft carrying atmospheric sounders, scanning mappers, and Earth radiation-balance sensors. Oceanographic parameters include sea-surface temperature, sea-ice coverage, waveheight, surface winds, and rain rate. In addition, an imaging instrument called the coastal zone color scanner (CZCS) provides six channels of visible and infrared color picture transmissions. The CZCS is designed to detect and interpret ocean color, suspended sediment and chlorophyll concentrations, and ocean pollutants. *Nimbus-7* carries a microwave identical to SMMR (scanning multichannel microwave radiometer); however, it provides no real-time data. *Nimbus-7* will go out of service in 1981.

### *Seasat-A*

*Seasat-A* was the first dedicated oceanographic satellite. Launched in June 1978 by NASA, it pioneered new microwave and remote sensing for oceanography. It was originally planned to collect data for about one year but the spacecraft failed 3 months after launch. The experiment cost about $100 million. About once every 36 hours, *Seasat* completely scanned the globe, providing high-resolution geophysical data in continuous real time for ocean-surface winds and temperature, waveheight, ice conditions, ocean topography, and coastal and open-ocean storms.

The general characteristics and a summary of the instrumentation of *Seasat* are defined in table 27. The *Seasat-A* sensor complement (fig. 12) was comprised of three active radars: a radar altimeter (ALT), a synthetic aperture radar (SAR), a radar scatterometer system (SCATT), and a passive SMMR. The geophysical oceanographic measurement capability of *Seasat-A* as shown in table 27 can be compared to user requirements in table 25.

The *SeaSat* sensors, which were turned on for operation on the 10th day, operated at maximum capacity until the end of the mission. The microwave scatterometer (SASS) and SMMR operated continuously throughout the mission. ALT and the visual and infrared radiometer (VIRR) experienced specific problems, but still produced

[36] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite Service, "Program Development Plan for *Seasat-A* Research and Applications," March 1977.

**Table 27.—Geophysical Oceanographic Measurement Design Capabilities for Seasat-A**

| Measurement | | Sensor | Range | Precision /accuracy | Resolution, km |
|---|---|---|---|---|---|
| Topography | Geoid | Altimeter | 5cm-200m | * 20cm | 1.6-12 |
| | Currents, surges, etc. | | IOcm-10m | | |
| Surface winds | Amplitude | Microwave radiometer | 7-50m/s | +/- 2m/s OR +/- 10%' | 50 |
| | | Scatterometer | 3-25 | +/- 2m/s OR 10% | 50 |
| | Direction | | O-360° | * 200 | |
| Gravity waves | Height | Altimeter | 0.5-25m | +/- ().5 TO 1.0m OR* I0% | 1.6-12 |
| | Length | Imaging radar | 50-100m | +/- 10% | 50m |
| | Direction | | 0-360" | * 150/o | |
| Surface temperature | Relative | V & IR radiometer | -2-35" C Clear weather | 1 .5° | - 5 |
| | Absolute | | | 2° | |
| | Relative | Microwave radiometer | -2-35° C All weather | 1° | 100 |
| | Absolute | | | 1 .5° | |
| Sea ice | Extent | V & IR radiometer | | - 5km | - 5 |
| | | Microwave radiometer | | 10-1 5km | 10-15 |
| | | Imaging radar | | +/- 25m | 25m |
| | Leads | | 50m | +/- 25m | 25m |
| | Icebergs | | 25m | +/- 25m | 25m |
| Ocean features | Shores, clouds islands | V & IR radiometer | | - 5km | - 5 |
| | Shoals, currents | Imaging radar | | +/- 25m | 25m |
| Atmospheric correct ions | Water vapor & liquid | Microwave radiometer | | +/- 25m | 50 |

SOURCE. National Oceanic and Atmospheric Administration.

excellent data sets. VIRR was not operational at the time the data transmissions stopped.

*Seasat* completed 1,503 revolutions of the Earth during its period of operation. SAR completed about 480 passes of 2- to 20-minutes duration each over receiving stations accumulating over 14,000, 100m X 100m image frames.

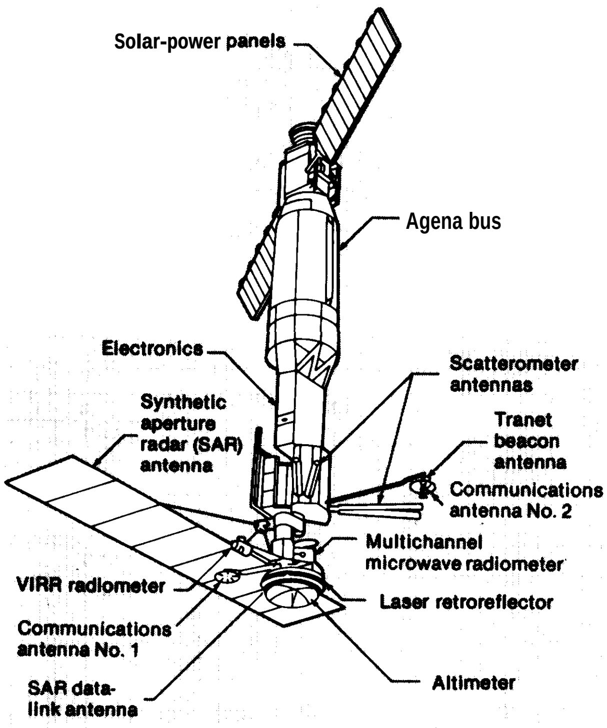
Two major surface experiments were conducted during the mission. The first of these was the multinational Joint Air-Sea Interaction Experiment (JASIN), which was conducted in the eastern Atlantic near Scotland. Planned and conducted by a group of European and American scientists, JASIN was an intensive study of the marine boundary layer and air-sea energy transfer. Some 200 *Seasat* passes were made over the JASIN area during the experiment period. A NASA C-130 aircraft, equipped with a *Seasat* underflight scatterometer, also participated, along with several European and American research aircraft, [37] [38]

Another *Seasat* ground-truth experiment was conducted in September 1978 in the Gulf of Alaska. Termed the Gulf of Alaska *Seasat* Experiment (GOASEX), this activity was planned and conducted by NOAA and included NOAA's Pacific Marine Environmental Laboratory, NESS, the Atlantic Oceanographic and Meteorological Laboratory, the Wave Propagation Laboratory, and NDBO. The principal research facility deployed during GOASEX was NOAA's research vessel, *Oceanographer*. The Canadian weather ships, *Quadra* and *Vancouver*, alternating at Ocean Weather Station PAPA, also obtained special data on satellite overpassage times. Selected research vessels of USGS and of the University of Alaska also made special weather observations during satellite overpass of their positions. Participating aircraft included an Ames Research Center's CV-990, equipped with an airborne version of the SMMR; the Johnson Space Center's NC-130B with the Seasat underflight scatterometer; the Naval Research Laboratory's RP-3A, equipped with meteorological and microwave radiometer instrumentation, and the Canadian CV-580A aircraft, carrying the Environmental Research Institute of Michigan's

[37] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite Service, "Satellite Activities of NOAA 1977" April 1978.

[38] Jet Propulsion Laboratory, California Institute of Technology, *Seasat Log*, vol. Z, Jan. 25, 1979.

**Figure 12.—The Seasat-A Spacecraft**




SOURCE: National Aeronautics and Space Administration.

synthetic aperture radar system. This experiment was also supported by nine NOAA data buoys moored in the Gulf of Alaska. A comprehensive data set was collected, corresponding to some 60 satellite overpassages, including more than a dozen SAR passes. A coordinated study of this data set is underway as a key element in the early evaluation activity. 39

NASA states that *Seasat-A* was a success in its "proof-of-concept" mission despite its short life and mechanical failure of the spacecraft. Recent evaluations by NASA conclude that certain *Seasat* instruments have been proven to the extent that they can be used on a next phase or prototype mission. ALT performed better than expected (+/- 7 cm), the SCATT measured winds within +/- 2 m per second; the CZCS made measurements of chlorophyll within a factor of 2; and the SMRRs provided sea-surface temperature data to 1.50 C in selected cases. Although only a limited number of the planned experiments were actually carried out, interagency recommendations have proceeded for the development of NOSS's limited operational demonstration.

[39] Jet Propulsion Laboratory, California Institute of Technology, *Seasat Gulf of Alaska Workshop Report (Preliminary)*, Pasadena, Calif., February 1979.

# AIRCRAFT

Aircraft are used only to a limited extent for oceanographic research and survey work. Like satellites, they permit a synoptic overview of ocean-surface conditions that cannot be obtained from shipboard surveys.[40] Typically, long-range aircraft such as those described in table 28 by NASA are used for survey work. When equipped with appropriate remote or airdropped, radio-linked oceanographic and acoustic sensors, they provide an efficient means of acquiring data over broad ocean areas on a near real-time basis. The Federal agencies which use aircraft and helicopters most for oceanographic research and survey are Coast Guard, NASA, NOAA, and Navy.

One major disadvantage of aircraft is that they are grounded in adverse weather conditions. Although some flights are made for surveillance and medical evacuations in the face of hurricanes, most flights are not conducted during conditions of low visibility, heavy ice accretion, or low ceiling.

## Federal Agency Operatiom

The U.S. Coast Guard employs the equivalent of three aircraft specifically for oceanographic survey, ice patrol, and oilspill response. These aircraft are not always the same. The rest of the extensive Coast Guard flight time is devoted to operations, and the overlap with research is sometimes difficult to define.

[40] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Oceanic and Atmospheric Services, *User and Measurement Requirements for an Integrated Ocean Oriented Observing System*, July 25, 1979.

**Table 28.—Aircraft and Sensors**

| Aircraft (typical) | Altitude, km (typical) | Sensor | Spectral range | Spatial resolution (at Nadir) m | Swath width, km |
|---|---|---|---|---|---|
| Aircraft and sensor characteristics | | | | | |
| i - 2 | 197 | OCS | VIS, NIR | 75 | 25 |
| | | Cameras | VIS, NIR | 10 | 25 |
| C-130 | 3 0 | M2S | VIS, NIR | 8 | 8 5 |
| | | | TIR | 8 | 8.5 |
| | | cameras | VIS, NIR | 0.5 | 4.5 |
| c-54 | 14 | MWR | MW | 500 | 500m (+-1) (Line) |
| Helicopter. | 003 | Alope | VIs | 50 | 0. 3m (Line) |

VIS Visible O 307 pm (typical)
NIR Near IR 0 711 pm (typical)
TIR Thermal IR 105 12 5 pm (typical)
MW L and S bands

SOURCE National Oceanic and Atmospheric Administration

Some Coast Guard aircraft fly about 3 days per month with a portable sensor — a passive infrared instrument to measure sea-surface temperature –between Cape Hatteras and Cape Cod. The data collected are used by 600 to 700 fishermen to locate certain species of fish that tend to school in waters having a fairly narrow temperature range. The aircraft data are accurate to +/- 0.50 C, compared to the +/- 10 C-accuracy of satellites.

One Coast Guard aircraft is used by the International Ice Patrol to search and track icebergs. This plane is based in Newfoundland for the ice patrol season, usually between February and July. To augment the present visual search method, new imaging radar is being developed for the aircraft. Also, buoys are now deployed from the plane to measure sea currents in an effort to predict with computer modeling the trajectories of icebergs. These buoys communicate directly with the Tiros-N satellite.

The U.S. Coast Guard also operates an Aircraft Oil Surveillance System (AOSS) using the *C-130 Hercules*. Currently scheduled for delivery is a Falcon twin-engine jet aircraft, known as Aireye, that will have a side-scanning radar, a passive IR, a UV line scanner, a passive microwave, and a camera. The main function of the Aireye system is to detect oilspills in the ocean and to trace the oil to the ship or tanker causing the spill. AOSS and Aireye are capable of night and day operations.

NASA has a program to develop remote-sensing capabilities for use by aircraft (and satellites) involved in four aspects of physical and biological oceanographic research: sediment transport, transport and fate of marine pollution, phytoplankton dynamics, and ocean dumping,

Some ocean-dumping projects may be best handled by aircraft because some dumping material that must be studied has a short surface-of-the-ocean life (4 to 8 hours), and a satellite might not be in the proper position in time for monitoring.[41]

The National Marine Fisheries Service (NMFS) charters several planes from private companies for a variety of projects. The bulk of NMFS airtime is devoted to working with the Coast Guard to enforce the fisheries law. One of its related ongoing tasks is to count the porpoises in the area from South Carolina to Central America. In two major surveys (1977 and 1979) to count porpoises, both vessels and aircraft were used. It was discovered that visual search by trained observers from aircraft was the most effective counting method. Results of the surveys have not yet been fully evaluated, but these efforts undoubtedly constitute the major attempt thus far to count marine mammals from the air. It has been reasonably well-established that mammal survey work cannot be done by photography, it requires visual search by trained observers.

Another NMFS project uses 50 to 60 days per year to measure sea-surface temperatures for sport fishermen. A spotter in a plane over the Gulf of Mexico, e.g., uses a low-light-level TV to search for schools of menhaden, which tend to congregate near the ocean's surface and shore in the morning and to move to deeper water in the heat of the afternoon.

In two experiments NMFS studied the total suspended solids and chlorophyll concentrations in the ocean. In 1977, NMFS began such a study in the New York Bight. In April 1979, NMFS, in cooperation with NASA, started the Large Area Marine Productivity Experiment in which chlorophyll, over a large shelf area, was measured from a U-2 or C-230 aircraft. Until this project, data were taken periodically, and only from ships .42

NOAA uses aircraft in a variety of ways. Its Research Facilities Center (RFC) in Miami, Fla.,

Photo credit National Space Technology Laboratories

Air-droppable instruments are used to collect ocean and geophysical data

provides instrumented aircraft in support of a variety of environmental research programs. RFC operates three four-engine turboprop aircraft, two *WP-3D Orions*, and one *WC-130B Hercules*, equipped with sophisticated research systems capable of measuring a wide range of atmospheric and oceanic parameters. In addition, RFC operates four helicopters in the conduct of the Outer Continental Shelf Environmental Assessment Program. NOAA's National Ocean Survey operates two other aircraft to flightcheck aircraft charts; one of these aircraft is used to support National Weather Service snow studies.

Another NOAA project involves the installations of the Aircraft-to-Satellite Data Relay for weather forecasting on 17 *Boeing 747's* owned by various airlines. Data on air temperature and wind velocity are collected every 71A minutes, stored, and broadcast once an hour. With the addition of a microprocessor to this system, the possibility of recording and transmitting additional atmospheric observations by scheduled airliner and ship traffic is increased. Normally, a *Boeing 747*, records pressure altitude, radio altitude, air temperature, humidity, and air velocity with respect to the aircraft and with respect to the ground. These data are used by onboard computers to provide needed information for aircraft operations. 43 NOAA is currently collecting this

[41] Robert W. Johnson and Craig W. Ohlhorst, *Application of Remote Sensing to Monitoring and Studying Dispersion in Ocean Dumping*, First International Ocean Du-mping Symposium, Kingston, R. I., Oct. 10-13, 1978.

[42] U. S. Department of Commerce, National Oceanic and Atmospheric Administration/National Marine Fisheries Services, Northeast Fisheries Service, *LAMPEX (Large Area Marine Productivity Experiment, Sea- Truth Data Report, Apr 17-19, 1979, Sandy* Hook Laboratory, report No. SHL - 19-28, July 1979.

[43] Erik Mollo-Christensen, Department of Meteorology, Massachusetts Institute of Technology, letter to OTA, Sept. 1, 1979.

data from 100 *Boeing 747's* as part of the World Weather Experiment. The data are presently stored on an aircraft tape recorder which must later be removed from the aircraft. An alternative to collecting these data would be to interrogate the aircraft from communications satellites and to retransmit the data to a ground station.

Navy uses three oceanographic survey aircraft (RP-3A) assigned to the Oceanographic Development Squadron (VXN-F), located at the Patuxent River Naval Air Station, Patuxent, Md. , to conduct oceanographic, acoustic, sea ice, and magnetic surveys and other research experiments. These aircraft provide some direct support to the fleet for Arctic and antisubmarine warfare operations, but their major function is to collect ocean and geophysical data to meet various high-priority requirements — for both operational and research and development needs. In addition, Navy uses the ship *Chauvenet* and its workboats, to engage in nearly full-time bathymetric measurements covering about 20,000 linear miles, at a cost of $7.5 million, annually. About 200 times this coverage would be desirable. To increase the areal coverage, Navy intends to let a contract for a pulsed, scanning, blue-green laser of about 350 kW to be installed on a helicopter. In daylight hours, this laser would measure ocean depths to 20m and in typical coastal waters should cover at least one-third more area than the *Chauvenet*. At an expected cost of $2.5 million, delivery should be in fiscal year 1983.

The Defense Mapping Agency has a modest development program for using lasers for bathymetry in coastal waters. The lasers will be installed on aircraft rather than on satellites in order to maximize accuracy and to minimize the chance of personal injury from the laser. The National Ocean Survey, Navy, and NASA are jointly supporting development of the helicopter-mounted laser-depth measuring system.

## Aircraft v. Spacecraft

NASA has conducted a comparison of costs for dedicated airplane and spacecraft missions for remote water-monitoring of U.S. coastal zones .[44] NASA initially considered large, well-instrumented aircraft because they provide large payload capacity at long range with adequate speed. It found, however, that large aircraft such as the RP-3 and C-130 cannot compete with small business airplanes such as the Falcon twin-engine jet. The twin-engine business jet provides reasonable dependability, is readily adaptable for carrying remote sensors, and does not require extensive airport support facilities nor long runways. Furthermore, it has low operating and purchase costs.

Compared to a satellite, an aircraft provides more site-viewing opportunities, at less cost; however, an aircraft becomes 2 to 3 times more costly than a spacecraft as the variable path coverage is increased and as the mission duration goes beyond 3 years.

Moreover, aircraft have particular problems with data management. Unlike satellite programs such as Landsat and SMS/GOES that have established, sophisticated ground-process systems, the routine processing of aircraft gathered data is plagued with problems from flight-path errors, altitude variations along the flightpath, and altitude changes. In addition, data cannot be retrieved easily without having to write a letter to the agency in charge of past flights in order to get the data in a computer-compatible format. This approach applies, e.g., to the Gulf Stream overflights carried out by Coast Guard for which the resultant data appear as printed maps of tracks and roughly interpolated isotherms. Modern technology can certainly ameliorate this situation but Coast Guard may not have the inhouse technological capability to do this at present.

Aircraft cover large areas more rapidly than ships can and with better spatial resolution than satellites can. They are also capable of covering a small area intensively over a short time. The optimum approach suggested in the NASA study would be to use satellites for large area, long-

[44] Wayne L. Darnell, *Comparison of Capabilities and Costs of Dedicated Airplane and Spacecraft Missions for Remote Water Monitoring of U S. Coastal Zones,* **NASA Technical Memorandum No. 74046, December 1977.**

term coverage and to use aircraft for complementary coverage in high-pollution coastal areas.

## *Helicopters*

Helicopters are in limited use aboard oceanographic research vessels. Three of Navy's ships, two ships of NOAA, and five of the seven Coast Guard vessels are equipped for helicopters. Helicopters are used more extensively for commercial transportation and for industrial operations in coastal waters.

Commercial helicopter operations include inspection, crew change, medical and emergency evacuation, and ice surveillance. Navy uses helicopters extensively for antisubmarine warfare operations where instrumentation arrays are lowered into the water and towed at a much higher rate of speed than when towed by ship. Also, military helicopters are equipped with thermal scanners for measurement of infrared signature of aircraft and ships. Oceanographic research and operational use by the military has been limited to testing new instrumentation systems. Like aircraft, helicopters have dropped buoys and XBTs and have received data from them on wave measurements and water and air temperature. NOAA has used helicopters in the conduct of the Outer Continental Shelf Environmental Assessment Program.

# OCEAN DATA SYSTEMS

Rapidly developing computer and communications technologies have resulted in the generation of large quantities of remotely sensed data that will soon overload the present oceanic data archives unless the same technology is applied to data inventory, processing, and distribution. Much of the data generated is not conveniently available outside of the major Federal agency offices. Thus, the growing need for more near real-time data for status and forecast information, coastal zone management, fisheries management, monitoring of marine pollution, and the investigation of many other oceanic problems is not being met.

For data to be of value to a variety of users, program planners must plan not only for the collection of data, but also for the distribution and storage of data. Designing for user needs cuts across agency missions and requires consideration of various industrial, institutional, and individual capabilities to handle data. One major consideration is whether to provide real-time data, retrospective data, or both. Another consideration is how to standardize data formats in order to store data in archive centers and to ensure their easy availability to a large community of users.

## *Data Archival Centers*

Environmental Data and Information Service

In the context of data management, the archival centers outlive individual projects. Thus, it becomes exceedingly important that they are well-managed and provide the function of receiving and distributing data with convenience and reasonable cost to the user.

Although many agencies and institutions are involved in the collection of oceanographic data, NOAA's EDIS is the primary Federal organization specifically created to manage environmental data and information for use by Federal, State, and local agencies, and the general public. To carry out this mission, EDIS operates a network of specialized data centers that include:[45]

[45] *Federal Register*, vol. 44, No. 184, Sept. 20, 1979.

- *National Climatic Center*– acquires, archives, and disseminates climatological data. It is not only the collection center and custodian of all U.S. weather records but also the largest of EDIS centers as well as the largest climate center in the world. It includes the Satellite Data Services Division.
- *Satellite Data Services Division (SDSD)* –provides environmental and Earth resources satellite data and products derived from the data to its users after the original collection purpose is complete.
- *National Oceanographic Data Center* (NODC)–acquires, archives, and distributes oceanographic data. It houses the world's largest usable collection of marine data. NODC operates EDIS' multidisciplinary Environmental Data Index (ENDEX) which provides over 14,000 referral listings to data files held by NOAA, other Federal agencies, State and local governments, universities, and private industry. This referral capability greatly enhances EDIS archival capabilities.
- *National Geophysical and Solar- Terrestrial Data Center*– acquires, archives, and disseminates solid earth and marine geological and geophysical data. Maintains separate archives for special data sets from programs such as International Decade of Ocean Exploration.
- *Environmental Science and Information Center– is* NOAA's information specialist, librarian, and publishing branch. It provides computerized literature searches from over 100 automated bibliographic data bases.
- *Center for Environmental Assessment Serv*ices — designs projects and services to provide national decisionmakers with data, analysis, assessments, and interpretations.

Discussion of Two EDIS Centers

The National Oceanographic Data Center. –Through a series of policy agreements negotiated with NOAA, many agencies (NSF, DOD, USGS, BLM) encourage or require their programs and contractors to follow EDIS data management procedures. Some people specify that selected oceanic data be archived at NODC. All data received by NODC are requested to be accompanied by full documentation and instructions for this documentation are widely distributed. Much of the data archived at NODC is in the form of averages made over large regions and at irregular time intervals. This averaged data is inadequate for studying many dynamic ocean processes. In addition, data at NODC are stored in many other forms, much of it just as it is received; accuracy and calibration information is often missing from data files. Guidelines for data format submissions could be improved, and managers of programs could be required to take data management and archival needs into consideration during project planning.

Since NODC is and will remain the primary data bank for archiving oceanographic data and since instrumentation and data-distribution technology is changing rapidly, a review of NODC practices seems necessary in order to provide faster access and wider public distribution of data from Federal programs.

Centralizing all oceanographic data in a single data center may not offer the specialized advantages of using distributed data storage methods. ENDEX and the Oceanic and Atmospheric Scientific Information System have been established by NOAA to provide users with a computerized referral to available environmental data files and published data in the environmental sciences and marine and coastal resources, respectively. This centralization is a natural first step in establishing distributed archival centers both on a data content and regional basis available on dial-up computer terminals.

Satellite Data Services Division. –Satellite data services from NOAA's SDSD of EDIS are colocated with NESS' operations center. Each day SDSD receives hundreds of satellite images in a variety of forms — negatives, film loops, and magnetic tapes. NOAA's archive, present since 1974, contains several million images from the earliest meteorological satellites of the 1960's through those from the most recent geostationary and orbiting spacecraft.[46 47]

Satellite data are most often received in the form of photographic imagery. The quantitative information that can be derived from a photograph is limited. Analysis of satellite data requires data that are available in computer-compatible formats. To accomplish this task, formatting must be considered on a user basis during satellite design. Normally, natural formats are used that optimize acquisition. In such cases, there is a need to develop standards for reformatted "exchange formats" for users.

Since January 1980, all digital data from satellites have been archived permanently. Questions about exchanging formats to provide compatibility of these data to users needs must be answered. Some have suggested that part of the budget for satellite efforts should be devoted to making data more readily usable by non-Government organizations. This would force data management planning, including distribution and archiving, on the agencies that now produce satellite data so that the data is available in compatible formats. This will also prevent satellite projects from being solely based on in-house science and users and would require the input of data management ideas from the outside in an effective manner .48

Files at SDSD contain imagery from many operational and experimental spacecraft. In addition to the visible light images, infrared images are available from Nimbus, NOAA, and SMS/GOES satellite series. The imagery from experimental, polar-orbiting satellites is in great demand by investigators around the world, and constitutes one of the archive's most active holdings.

[46] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, "Environmental Satellite Data from NOAA," publication No. PA-75021, 1976.

[47] U.S. Department of Commerce, National Environmental Satellite Service, "Satellite Data Users Bulletin," vol. 1, No. 2, August 1979.

[48] "COMSAT Auditions for Television," New York *Times*, Jan. 6, 1980.

In SDSD archives, the Tiros-lV data are cataloged in the form of composite pictures of the Northern and Southern Hemispheres made upon mosaics of Tires imagery. The catalog is issued monthly, typically 6 months after the data have been obtained. The photographic images are not corrected for viewing angle nor arranged in geographical coordinates, and the navigational data have to be figured out from orbital information if there are no landmarks visible. Since there are no landmarks in the ocean, it is often difficult to interpret the data.

The current archives are increasingly unable to handle the present digital data system, and new satellite programs will exacerbate the problem. Large data-base management systems will be needed to properly archive and retrieve data and to coordinate activities of the various NOAA data centers in the future.

### Data Acquisition

There are three categories of oceanographic data that are collected. The first includes in situ measurements provided in various formats by either research investigators or survey groups. The second is surface data transmitted from monitoring stations such as ice stations or ocean-data buoys. The third is data from remote sensors, including directly transmitted satellite data, and recorded data, like that from aircraft.

Data from all categories are being fed into the data centers at increasing rates. Large-scale projects are providing large new bases of category 1 data. The National Ocean Data Buoy program is providing category 2 unattended surface data; and the various satellites are furnishing a downpour of category 3 data. Very few of these programs were reviewed at their inception with respect to data archival needs/requirements.

To handle the increased data rates so that data from ships, satellites, and buoys can be compared, processed, and analyzed together, it may be necessary to equip some oceanographic ships with compatible data systems that label all data in a consistent manner and that produce information for the national file as soon as possible after data have been taken. Such an acquisition system could also collect auxiliary data, such as water temperature and salinity, windspeed, barometric pressure, depth of water, navigation data, and other variables. With compatible ship data-logging systems, there would be an incentive to standardize the interfaces between instruments and data loggers. Moreover, if academic ship operations are centralized into regional centers, the ship data system could be the responsibility of the regional center. For NOAA's fleet, it may also be advantageous to centralize the data and ship instrumentation activity.

If the automatic means of acquiring the data and then transmitting the data via satellites is achieved, significant new data bases may result. Present satellite data have been discussed fairly extensively. However, future satellite systems will each introduce new problems of acquisition by the data centers.

### Data Distribution

Conventional distribution of data from archives is accomplished by the physical transmittal of the data media, e.g., by mail. Data distribution via communication satellite will also become important, thus entailing data distribution from central computerized storage to distant analysis laboratories. Automatic data retrieval systems, transmitters, receiving systems, and methods for data request and charging must be developed by NASA and NOAA.

***Landsat*** and ***Seasat:*** Two Recent Data Distribution Examples. — The Landsat program, after 9 years of successful operation, is improving its distribution system by making available dial-up inquiry of inventory. This service will indicate the data available by display on a computer terminal. This combination of easy access to inventory listing and the mailing of data tapes for use on the user's computers probably represents the best present compromise between economy and convenience.

*Seasat-A* was the first ocean research satellite. Its data were initially furnished to the various investigators whose participation was selected by prior proposal reviews and acceptance. However, data from *Seasat-A* are of special interest to many oceanographers. During its operation, *Seasat-A* collected a unique combination of simultaneous data on sea-surface temperature, roughness, elevation, and waves.

NOAA/EDIS has started to distribute 70 mm copies of quarter-width swaths of the synthetic aperture radar data from *Seasat;* however, the different swaths are not assembled or combined, the navigational and time information is not readily available, and no combined data sets from all sensors are readily available. Only limited data are available in digital form outside of the Federal agencies and there has been no concerted effort to make the data available to the outside scientific community.

The *Seasat* failure reduced the urgency of devising a data distribution operation. However, some of the *Seasat* sensors were innovative and have provided data challenging to interpret.

Direct Satellite Data Receivers.-–EDIS cannot meet the needs of direct readout users of large volumes of satellite data. These users must use their own receiving antennas, which can be quite simple for low-resolution data, such as that used by TV stations to obtain data for weather forecasting. Many users have elaborate ground systems since they process the data qualitatively for operational or research purposes. At NASA, data from the geosynchronous meteorological satellites (GOES) are transmitted to NASA's ground station, are processed and reformatted, and are sent back to NOAA/GOES satellites for reformatted retransmission to the ground stations of data users.

For small volume, nonscientific users, data can be received from EDIS or other sources by direct communication links. The simplest system for display and some analysis of reformatted data for the skilled user is a microcomputer equipped with a tape recorder (and a video monitor) to enter data. This system will display data and enhance contrasts, but will be unable to do more than rudimentary analysis and data combination. Such a system may be useful for ship operators, weather forecasters, and limited scientific and educational purposes.

An example of a large volume scientific user is The Scripps Institution of Oceanography (S1O) which has a ground station for receiving raw (unprocessed) sensor data and computer facilities for handling the algorithms necessary to convert the data to scientific and engineering units. The system costs (about $700,000) were borne by NASA and Navy. Operating costs are being shared by NASA, Navy, and NSF. Utilization of the system is running at about 18 hours a day, 7 days a week, using data from Tiros-N, *Nimbus*, and *NOAA -6*. The system is being used not only for scientific purposes, but also, more importantly, to educate oceanographers in the use of satellite data. Investigators from other organizations besides SIO (such as the Fisheries Center of NOAA) are using the system.

A group of university and Government laboratories in New England have proposed to establish a regional satellite remote-sensing data center.[49] [50] The center would have antennas for receiving data from several satellites and would provide data processing, storage, and analysis. A significant part of the cost of such a system would be its operations, since a system which acquires data on a routine basis will have to be staffed to meet data requests as well as to handle data acquisition. However, many institutions could be served economically by one center because the total cost of data systems is small compared to the cost of data stations and their operation. In fact, the cost will, as technology advances, possibly decrease.

## Data Management

The Federal agencies responsible for handling and distributing oceanic data must improve their data management systems. The present approach to data management will not be adequate

[49] U.S. Department of commerce, National Oceanic and Atmospheric Administration, Proposed Regional Remote Sensing, Receiving and Processing Center, *New England Remote Sensing Notes, No.* 1, February 1980.

[50] Joseph P. Mahoney, General Services Administration, letter to Paul F. Twitchell, Office of Naval Research, Attachment "Regional Satellite Receiving Station, " Mar. 3, 1980.

in the future, particularly when new satellite systems begin to acquire very large amounts of data.

The costs of collecting environmental satellite data can only be justified by effective use of the data for national purposes. Weather and climatology prediction and assessment, ocean climate and productivity research, and direct use by shipping, fisheries, and other economically vital activities are examples of such use.

For all large data-collection programs, using satellites or ships or combinations of stations, it appears important that data management plans be prepared for both real-time and retrospective data users. The data archiving centers such as EDIS should be part of those plans but may not be the only part. The centers, however, must be concerned with overall Federal capabilities in making data available to suit user needs.

In order to ensure that environmental satellite technology programs serve the intended user community and deliver the data products that justified the satellite, plans for satellite and other remote environmental-sensing programs should include specific plans for data distribution, including methods for quality control, formats of data products, near real-time and retrospective data distribution, cataloging and storage. Without such a plan, a remote-sensing program will be incomplete and its benefits uncertain.

Because one cannot predict all future uses of data, data formats need to provide a complete documentation of the data so that data from different sources can readily be used in the same context and combined and compared. The logical format for Earth sensor data would be based on geographical coordinates and time. Satellite data should be available in geographical coordinates, corrected for viewing angle, spacecraft position, and altitude.

While communications and data processing technology is available for environmental data dissemination, there is a need for a policy and a plan to prevent expensive duplication and the possible establishment of duplicative and incompatible systems. This can be done by deciding on a few general rules for data availability and formats, and by describing general features of a data dissemination system.

# MANAGING TECHNOLOGY DEVELOPMENT

Whether the foregoing assemblage of ocean technology, and the related National capabilities, will be adequately maintained or improved in the future depends on Federal agency management efforts.

The planning for research and development takes many forms, some formal and some quite casual. The more technologically oriented agencies, such as Navy and Coast Guard, have very formal procedures. Others, such as NOAA, have not developed formal documentation procedures for planning. It is sometimes argued that the formal planning procedures give rise to too great a paper load, that too many documents are generated, and that no one knows how to use the documents generated. The purpose of most planning documents does not lie in the document itself but in the process that it forces the planner to use. The process includes determining the benefits of a program, coordinating multi-programs, determining schedules, and determining the facilities and the technology to be developed. The need for coordination between programs within an agency and with those of other agencies has necessitated the designation of lead agencies for particular programs.

The technology development programs within the Federal ocean agencies have been reviewed and critiqued by a number of study groups over the past few years. As a result, it is generally claimed that the existing organizations do not have adequate management and technical capabilities in technology development and that improvements are needed.[51 52 53]

Government agencies having ocean missions make use of many related ocean technology disciplines, using Government organizations as well as contractors to accomplish tasks. The size and organization of ocean technology groups and projects within the agencies vary greatly. Some agencies that support major ocean programs have very little expertise within their staffs, while others have a long history in ocean engineering.

To a large extent, the structure and organizational positions of engineering groups within an agency depend upon the characteristics of the agency and the relative role that engineering plays in accomplishing agency missions. For example, Navy is heavily technology-based, and its capability of " fulfilling many missions in the future depends on technology advances; thus, the research, development, and testing aspects of Navy's support organizations are accented. On the other hand, most of the activities of EPA are either scientific or regulatory; relatively little ocean engineering development is supported by this agency.

Coast Guard, like Navy, is heavily dependent on technology advances to accomplish its increasing offshore work. The Arm y Corps of Engineers is likewise technology oriented in both beach erosion and dredging activities. Both Coast Guard and the Corps of Engineers have strong, highly visible engineering organizations.

NASA's engineering activities are very strong in space vehicles and in remote sensing used in oceanographic and other applications. While its activities requiring ocean technology have been limited up to now, there are indications that NASA is increasing its oceanic efforts to gain a greater ground-truth data base for use with aircraft and spacecraft remote-sensor data collection systems.

The Department of the Interior's ocean engineering activities are closely coupled to offshore petroleum leasing and management. USGS is charged with assuring the conservation of resources and the protection of the environment in resource development. Ocean engineering at USGS is accomplished within the geology and conservation divisions, at field verification and inspection offices, and under contract.

The technology developments sponsored by NSF are of three types: ship construction and

[51] Commission of Marine Sciences, Engineering, and Resources, *Our Nation and the Sea* ( Washington, D. C.: U.S. Government Printing Office, January 1969).

[52] U. s. Department of Commerce, National Advisory Committee on Oceans and Atmosphere, *Engineering in the Ocean, Nov.* 15, 1974.

[53] R. E. Bunny, et al. , "The Report on NOAA's Ocean Engineering Baseline Study, " Aug. 22, 1977.

maintenance, oceanographic instrumentation, and deep-sea drilling. All are essentially contracted out in conjunction with the scientific programs. Much ocean engineering development is accomplished by the academic institutions in conjunction with NSF-funded science programs.

The Department of Energy (DOE) has a limited staff concerned with oceanic programs, and its programs are highly technical, e.g. , ocean thermal energy conversion. Consequently, DOE must depend mainly on outside contractors and consultants and on other Government agencies for ocean engineering support. While this approach may have some merit, the internal staff is limited in ocean engineering experience and thus cannot conduct detailed in-depth reviews of its programs.

NOAA's overall engineering efforts are numerous. Most of NOAA's activities depend on technology, and every major subdivision of NOAA has an engineering component, although not necessarily directly related to ocean engineering. Many of the same technologies are used in the weather service, the marine fisheries service, the ocean survey, the climate program, and the environmental laboratories.

Two of NOAA's organizations concerned with engineering, the Office of Ocean Engineering (except for underseas operations)–which was part of Research and Development –and the Office of Marine Technology-–which was part of the National Ocean Survey — have recently been combined into a new organization, the Office of Ocean Technology and Engineering Services (OTES), under the direction of the Administrator for Ocean and Atmospheric Services. OTES is assuming the functions of the replaced organizations. The charter for the new organization is:

- to provide basic ocean engineering support and to develop advanced technologies to improve NOAA's products, services, and observations of the atmospheric and oceanic conditions from marine stations; and
- to provide technological support of selected national programs, such as ocean energy development (under DOE programs), resource management, and others. 54

Assuming transfer of personnel and funds from the former activities, the new OTES division will have a staff of about 138 people of which 72 will be engineers. Work locations will be at NOAA headquarters and at least three field laboratories.

The types of projects that this new division will have, based on the projects contained within its predecessor organizations, include:

- bathymetric swath survey system;
- shipboard acoustic current-profiling system;
- underway towed water-sampling system;
- tidal height-measuring system;
- coastal ocean dynamics application radar for current measurements;
- data buoy development and operations;
- advanced digital side-looking sonar (with NASA);
- continuous in situ sediment analyzer;
- ocean thermal energy conversion (support to DOE); and
- analysis of ocean-pollution observation systems.

While the merging of NOAA's engineering offices into OTES may solve some of NOAA's engineering management problems by using more engineers to support NOAA ocean programs, it appears that other management problems must still be addressed. NOAA engineering groups are scattered throughout the many components of NOAA (65 engineers and technicians are located at various NOAA marine centers). The overall engineering capability of the scattered components will depend on how communications are established.

While NOAA's organization management does not show engineering within EDIS, it is apparent that emphasis within that organization on engi-

[54] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *Ocean Engineering Programs in the National Oceanic and Atmospheric Administration*, Washington, D. C., Mar. 31, 1980.

neering aspects could aid in the archiving and management of data.

For the newly formed OTES to gain a credible capability, it must gain a stronger and broader base of engineering expertise, provide communication channels and exchange of skills between engineers throughout NOAA, provide a direct line of engineering advice to the Administrator of NOAA, and initiate more cost-effective engineering solutions to NOAA's engineering-related problems.

One of the most important goals is to gain a stronger base of expertise. The central office for technology development at NOAA must have adequate authority and capability to address the important technology problems in oceanography and in NOAA. Otherwise, the routine engineering-support tasks could better be done in the laboratories and in other field operations.

Technology management capability within the agencies varies quite considerably, some being weak and others being strong. Some agencies, such as DOE with large technological programs (OTEC) have little ocean engineering management capability. Others, such as Navy, have continuing strong technological needs and have staffed accordingly. Still others such as NOAA have considerable technological efforts buried in their agency programs but have not provided a strong technological focus within the agency. Programs to advance the ocean engineering technological base do not get strong support outside Navy. The concept of an institute, such as that proposed by the National Advisory Committee on Oceans and Atmosphere, for providing a strong support to the civil sector has not been undertaken by any of the agencies, and it appears that most Federal efforts in ocean engineering will remain as scattered and diffuse as the programs and research needs are now.

# Chapter 4

# Selected National Programs

# Contents



**TABLES**



FIGURES

# Chapter 4
# Selected National Programs

Four national programs are presented in detail in this chapter because they represent the institutional and technological opportunities and problems facing Federal efforts in oceanography today.

Two of the programs are major new ocean program initiatives that will depend on the development of large, new technology systems. The Ocean Margin Drilling Program (OMDP) is a scientific endeavor unique for its private industry support. The National Oceanic Satellite System (NOSS) combines civilian and military operational goals with related scientific investigations.

The remaining two programs will incorporate a mixture of conventional technology already in use plus advanced technologies tailored to research needs. Both programs have been mandated by Congress. The Federal program in fisheries and other living resources has been in existence for some time, but has recently been directed to focus its research more directly on resource management problems. The Federal program in climate research, when fully operational, will attempt to provide climate information and prediction services.

# OCEAN MARGIN DRILLING PROGRAM (OMDP)

A program of new marine geologic investigations to gain knowledge of the nature and origin of the Earth began detailed planning in fiscal year 1981. Undertaken by the National Science Foundation (NSF), this $693 million, 10-year drilling program is a new thrust to investigate the geology of continental margins and ocean crust using deep-ocean drilling. (Some of the margin regions, which are the borders between continental shelves and the deep ocean, could contain substantial oil and gas resources in addition to valuable geologic information; but very little evidence of this possibility has yet to be collected.) Major ocean technology development, particularly in the early stages of the program, will be necessary to develop the deep-drilling equipment and techniques for accomplishing the OMDP science goals.

In some ways, OMDP is an extension of NSF's Deep Sea Drilling Project (DSDP), that has been in effect since 1968. That program, which may be terminated in fiscal year 1982, has resulted in considerable scientific accomplishments. The many boreholes that were drilled have yielded major scientific knowledge about the nature of the surface features of the Earth, the chronology of tectonic and environmental events, the nature of natural disasters, and the geological framework in which economic concentrations of resources are located. Equally important are the technological advances made in the recovery of soft sediments from the ocean floor. A hydraulically driven piston-coring device (the Hydraulic Piston Corer) was developed that has successfully recovered continuous sequences, hundreds of meters long, of undisturbed ocean-floor sediment. This device could open the way to a whole new series of studies on the:

- evolution of global climate, measured on time scales of a decade to millions of years;
- evolutionary development of marine plankton during the last 10 to 15 million years;
- sedimentary structure of deep-sea fan deposits, which are the most probable reservoirs of any deepwater hydrocarbons; and
- suitability of various types of deep-sea deposits as repositories for nuclear waste.

OMDP itself has resulted from years of planning by Government-sponsored committees. Planning began in 1973 and continued through several conferences and NSF reviews in the late 1970's. Finally, at an NSF-sponsored meeting in Houston, Tex., during March 1980, scientists and engineers from academic institutions, petroleum companies, and Government agencies developed an initial plan for a model ocean margin drilling program. That plan is the principal basis for NSF's present OMDP.[1]

## *Program Plan*

Scientific objectives stated in the plan are to investigate:

- passive and active continental margins;
- the Earth's crust beneath the deep ocean; and
- the deep-sea sediments which could yield historic environmental information on the Earth, especially those at the opening of the Atlantic Ocean and the Gulf of Mexico.

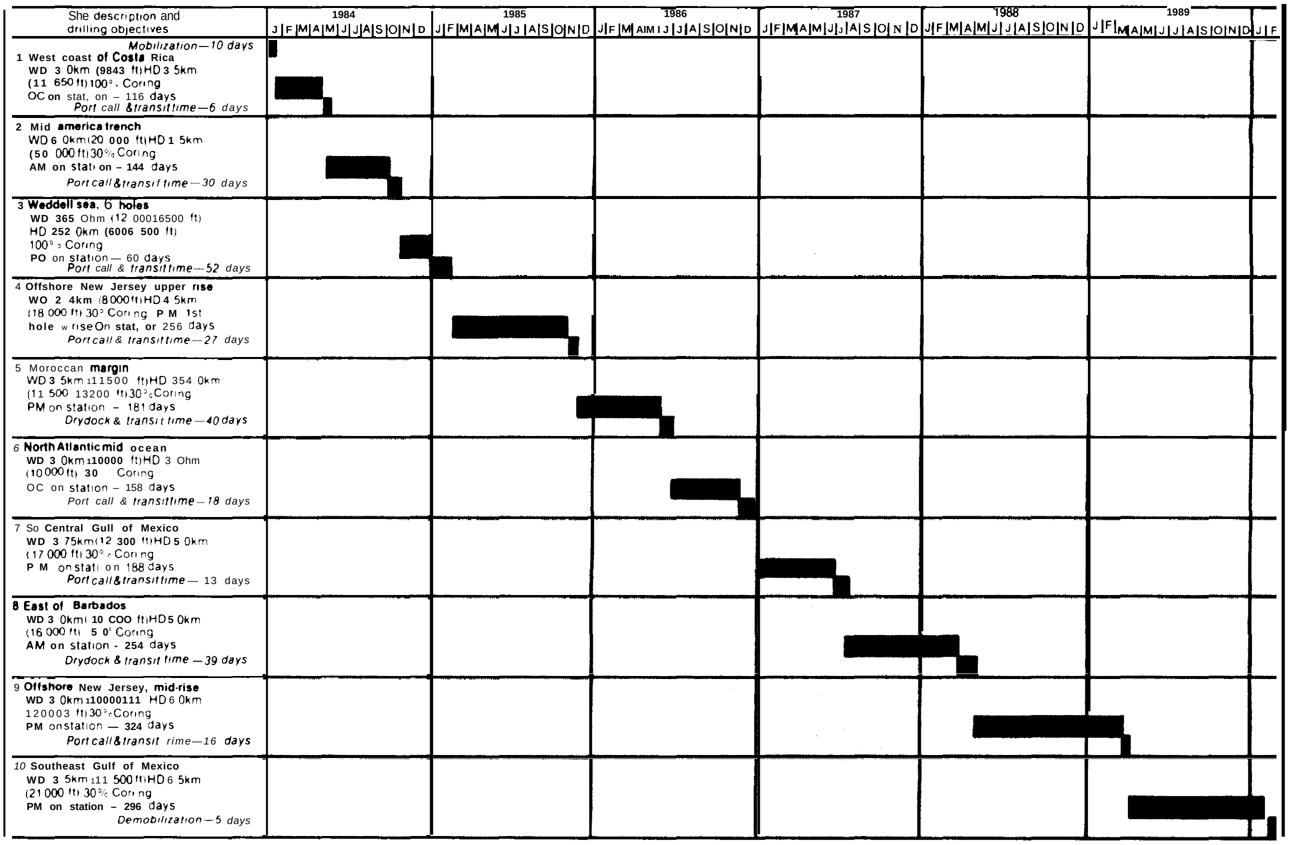
Meeting these objectives involves drilling 15 holes at 10 sites (fig. 13). Two sites will be in the Pacific Ocean; one will be in Antarctica's Weddell Sea, and the rest will be in the Atlantic Ocean and the Gulf of Mexico. The deepest hole (in the southeast Gulf of Mexico) in the model program will be about 21,000-ft below the sea floor in about 11,000 ft of water. OMDP's plan allots 4 years for drilling preparation and 6 years for actual drilling. Furthermore, it presents an initial estimate of operational and program-site costs.

## *Technology*

The technology plans include the conversion of the Government -owned *Glomar Explorer* to a deep-drilling ship and the development of a riser

[1]For a detailed discussion and analysis of the Ocean Margin Drilling Program and all references to other reports, see OTA technical memorandum, *Ocean Margin Drilling*, May 1980.

**Figure 13.—Ocean Margin Drilling Program Plan**




Notes. WD-water depth HD-hole depth below sea floor. OC-ocean crust objectives, AM-active margin objectives, PO-paleo oceanography objectives, PM-passive margin objectives Coring percentages shown are for hole depths below ZO.inch casing "

SOURCE OMDP overview, NSF, June 30, 1980

system* (fig. 14) for controlled drilling in up to 13,000 ft of water and down to 20,000-ft below the sea floor.

Since this drilling technology has not been developed, OMDP requires a significant element of technology development. The 12, 300-ft riser pipe required for the deepest margin sites is about twice the depth of existing technology, therefore, a major effort will be needed to develop the riser and the entire deep-drilling and well-control system. Basic designs of the system, to be prepared during fiscal year 1981, will need careful evaluation.

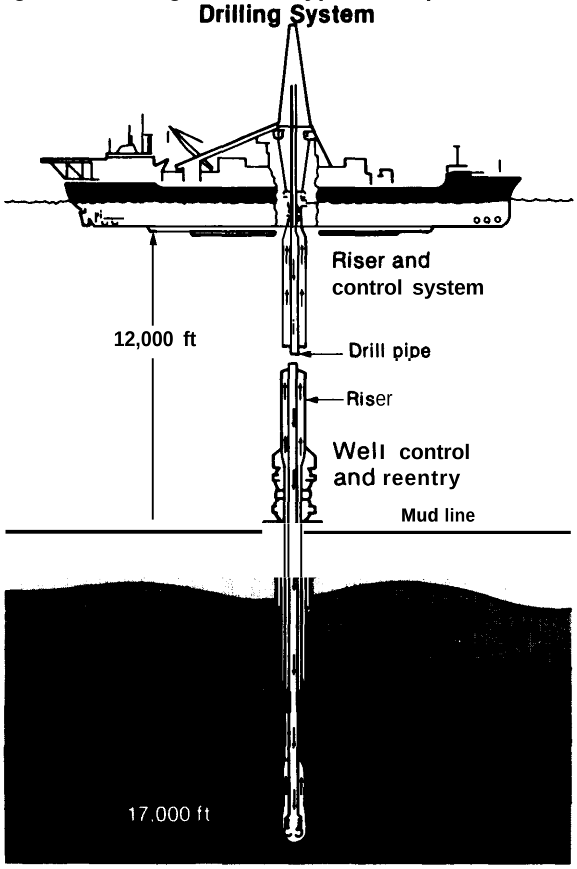
* **A riser is a large-diameter pipe. extending from the sea floor to the dri II ing ship on the surface, through which the drill pipe is inserted. The riser acts as a conduit for drilling fluid, which, after being pum ped down the pipe flows back up to the ship between the pipe and the riser. The riser is also used to help control pressure in the wel I and to su pport blowout prevention.**

Since the technology is uncertain, so are the cost estimates. Because extremely deep holes are very costly, the sites must be selected with great care and attention to engineering conditions as well as to scientific objectives.

## Budget

It is planned that the program will be jointly funded by the Federal Government (NSF) and the petroleum industry, each sharing 50 percent of the cost over the 10-year period. By November 1980, eight major petroleum companies had agreed to participate and support the first year's efforts. The total budget for the 10-year program is now estimated at $693 million with the Federal Government share at $346.5 million.

**Figure 14.—Diagram of a Typical Deep-Water Riser Drilling System**




SOURCE Project Contributions Program Review for Director. NSF. presented Apr 3, 1978 Deep-Sea Drilling Project, IPOD

Table 29 illustrates the proposed budget from fiscal year 1981 to fiscal year 1990 for the program and divides it into major components of ship conversion, vessel operation, ship operation management, scientific operations, advisory and management support, systems support, and science programs. The budget includes a 10 percent per year inflation factor for each year beyond fiscal year 1981; thus a considerable portion of the $693 million total budget is for inflation. During fiscal year 1981 the total program budget will be refined, based on system designs and plans to be prepared. A major commitment will be made with approval of the fiscal year 1982 budget because that is when the ship conversion and large expenditures will begin (see fig. 15 for major program milestones). Since the ship conversion and riser-development cost estimates could escalate substantially when a final design is completed, they must be evaluated prior to the decision to proceed with hardware contracts. During 1980 some cost estimates for the ship and riser were made that were almost double the budget figures. These discrepancies have not yet been reconciled by NSF, so the status of budget changes, or tradeoffs if one component cost escalates, is now uncertain.

**Table 29.—Proposed Ocean Margin Drilling Program Budget—Fiscal Year 1981-90 August 1,1980 (million of dollars)**

| Activity | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ship conversion and riser development. . . . | $ 2.0 | $20.5 | $46.0 | $36.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | $104.5 |
| Vessel operations. . . . . | 0.0 | 0.0 | 0.0 | 24.0 | $48.3 | $53.2 | $58.4 | $64.2 | $70.5 | $ 2.0 | 320.6 |
| Management of ship operations. . . . . . . . . . | 0.0 | 0.0 | 0.0 | 5.0 | 9.9 | 10.9 | 12.0 | 13.4 | 14.8 | 1.0 | 67.0 |
| Scientific operations . . | 0.0 | 0.0 | 0.6 | 3.0 | 5.5 | 6.1 | 6.7 | 7.3 | 8.0 | 2.7 | 39.9 |
| Advisory and management support. | 1.5 | 1.5 | 1.4 | | | 1.6 | 1.8 | 1.9 | 2.1 | 2.3 | 16.9 |
| System support contractors . . . . . . . . . | 2.0 | 2.0 | 2.0 | 2.4 | 2.7 | 2.9 | 3.2 | 3.5 | 2.4 | 2.0 | 25.1 |
| Science programs. . . . . | 4.5 | 8.0 | 10.0 | 11.0 | 12.1 | 13.3 | 14.6 | 16.1 | 19.2 | 10.0 | 118.8 |
| Total. . . . . . . . . . . . | $10.0 | $32.0 | $60.0 | $82.7 | $80.0 | $88.0 | $96.7 | $106.4 | $117.0 | $20.0 | $692.8 |

NOTES: This August 1, 1960 budget reflects:
a) A start-up or orientation of the SIC in late fiscal year 1961.
b) Mainly a design effort by the SIC in fiscal year 1982—long-lead hardware procurement limited to approximately $12 million.
c)Ship completion date, April 1964.
d) Fiscal year 1961 Government funding $5 million and 1962 Government funding $16 million.

SOURCE: National Science Foundation.

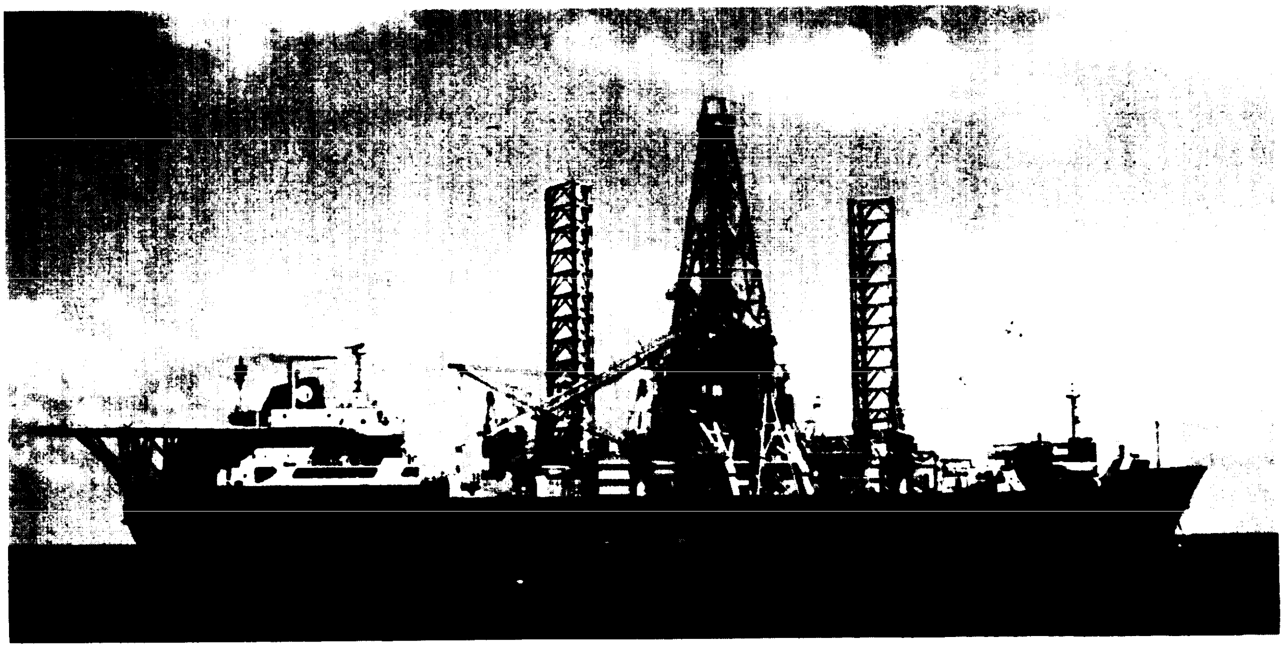


Photo credit' U.S. Navy

*Glomar Explorer,* a 52,000-ton, 620-f t-long ship, originally built by the Central Intelligence Agency to recover a Russian submarine, is proposed to be converted for the Ocean Margin Drilling Program

## Program Management

NSF has successfully directed DSDP for the past 10 years, using oceanographic institutions to manage the scientific effort. The proposed management structure for OMDP relies on DSDP staff, a systems support contractor, science support contracts with Joint Oceanographic Institutions (JO I), Inc., and a future systems integration contractor. The systems integration contractor will be selected after the program has been specified in sufficient detail and formal invitations to bid are evaluated. This contractor will have major project responsibility, including the design, construction, and operation of the drilling system.

In addition to the basic program management, NSF plans to establish outside groups to advise both the director and the OMDP team. A program advisory committee will be comprised of representatives from industry (40 percent), academia (40 percent), and the public sector (20 percent). The Marine Board of the National Research Council has already selected a smaller advisory group from among those who served on its deep-ocean drilling, 1978-79 committee. Navy will be called on for its expertise in ship conversion inspection and supervision. Additional consultants from Government and industry will be used as required to assist various facets of the program as it develops.

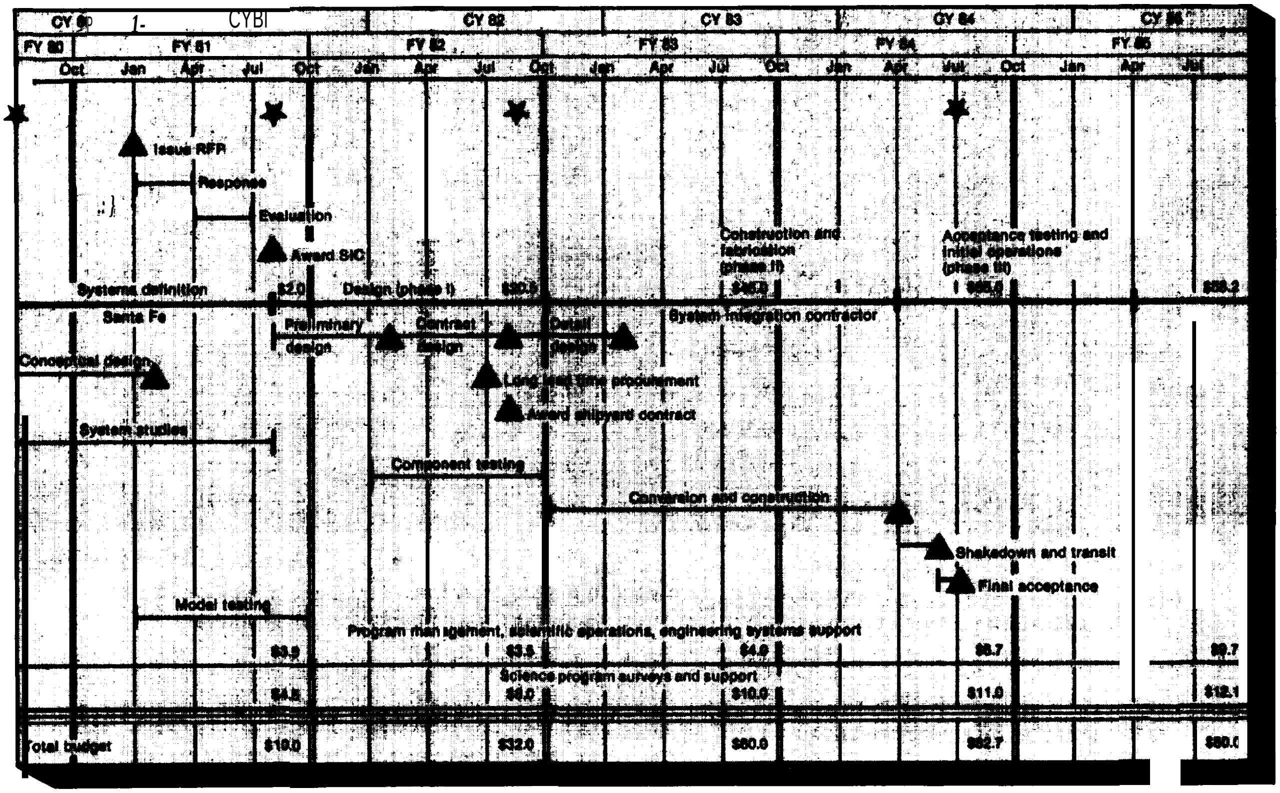
## Analysis of OMDP

### Objectives

Many scientists believe that the recently developed plan contains many worthwhile scientific objectives and that the chosen drilling plan and sites encompass significant scientific investigations that are in keeping with past committees' recommendations. Whether scientific objectives can be achieved from the holes drilled and information collected will depend, in large part, on the capabilities of the technology developed. Engineers have estimated a 50-percent probability of completing all the planned holes. However, some deep holes may not be completed as planned because of the uncertainty associated with deep-drilling in as yet untried geologic envi-

**Figure 15.—Major Program Milestones and Budget—Proposed Ocean Margin Drilling Program, National Science Foundation**

15 August *1980*




★ - Major program decision points

SOURCE National Science Foundation

ronments. As the technology is developed, better estimates of success probabilities for each hole can be made, but it is likely that some deep-drilling goals will not be reached.

## Program Plan

Many scientists agree that the present OMDP is probably the broadest scientific program that could be put together using the *Glomar Explorer* in an industry -academia-Government cooperative venture and is worthy of complete support. They believe that the scientific objectives are of high priority and that if the petroleum industry provides 50 percent of the funds, the program will be a bargain for science. Some claim that even allowing for the predicted chances of technological failure, each hole or site will offer partial answers to many of the questions asked. They also note that much of the success of past deep-sea drilling has been from unanticipated results.

However, many scientists believe that OMDP may not be the best, the most appropriate, nor the most important scientific program that could be proposed for exploring the ocean floor.

There is wide agreement, even among those who support the present program, that more emphasis on geophysical surveys is needed. While funds are reserved for such surveys and support, a detailed plan for a science program is still in the planning stage. The plans are under development by JOI, Inc., who has an established scientific advisory committee and several planning advisory committees to consider the outstanding scientific problems and necessary studies. The committees are analyzing all existing geologic

Photo credit Woods Ho/e Oceanographic /nsfItut/on

Core samples from deep-sea drilling

and geophysical data available in order to recommend where new surveys are most critical.

Because scientists disagree on the program's goals and scope, it is important that the future peer review process for the scientific program be more explicitly defined. This process is now being developed by NSF. Since the holes, sites, and objectives are likely to change as the technology and plans are developed, additional review will be necessary to assure broad support and proper attention to high-priority scientific problems.

In addition, the most advanced state-of-the-art geophysical surveying methods and experiments will eventually be needed. The National Academy of Sciences (NAS) report, "Continental Margins Geological and Geophysical Research Needs and Problems" (known as the "Bally" report), recommended that academic institutions have at least one modern, thoroughly equipped, state-of-the-art geophysical surveying vessel, as well as supplementary equipment aboard existing oceanographic ships for conducting multiship surveys. Such technology is not now included in OMDP and will probably need to be funded from other sources.

Until the Explorer is ready to begin drilling, the selection of sites and holes will remain flexible. The drilling plan proposed during March 1980 was based on existing knowledge. Additional surveying, both within and without this program, will change concepts and drilling sites. To this end, the primary scientific task for fiscal year 1981 will be the synthesis of existing geological and geophysical data in 11 geographic regions targeted as candidate drilling areas. These regional syntheses will form the foundation on which the science" program will be developed. However, the capabilities of the *Explorer* technology and the funds available will have the major influences on any changes to the science program.

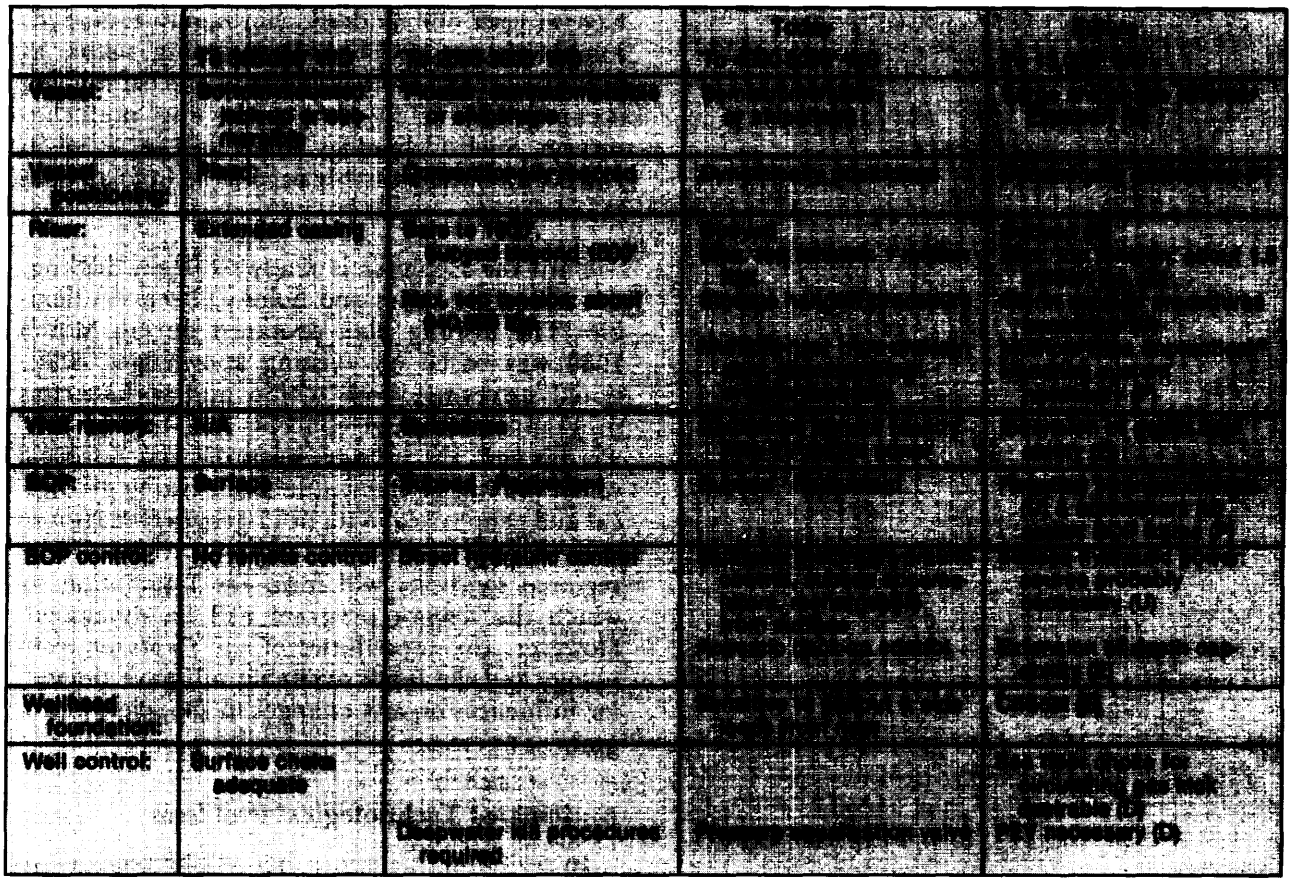
## Anticipated Technological Problems

In reviewing the effort that will be required to develop the technology for meeting the present OMDP goals, heavy reliance was placed by OTA on an April 1980 report entitled "Engineering for Deep-Sea Drilling for Scientific Purposes, " by the Marine Board of the National Research Council. That report and the OTA technical memorandum on ocean margin drilling may be referred to for more detailed evaluations of future problems associated with OMDP.

An effective drilling system for the ocean margins will include a large number of complex and interrelated components. Most system elements will probably require some modification from present practice to perform at the extreme water depth and penetration goals of the program. Problems caused by drilling in unknown environments with untried technology may cause engineers and scientists to compromise as the program proceeds, thus lowering OMDP scientific objectives. Figure 16 outlines the extent of

80-710 0 - 81 - 9

**Figure 16.—Deepwater Drilling Technology/Water Depth Spectrum**




Key: U - Undeveloped; D - Developed but not field tested; E - Extension of existing technology; F - Field tested.
.Solution dependent on casing program and feasibility of extending drilling shallow hole without riser.

SOURCE. National Academv of Sciences, Marine Board, National Resource Council, "Engineeri Q for Deep Sea Drillinq for Scientific Purposes," Washington, D C "1980

present development for major equipment and indicates future technology development needs.

Some petroleum company participants in OMDP are concerned that the cost estimates are too low or that the chances of reaching all the deep holes are not good. It appears, in general, that industry participants will force future decisions on realistic technology development goals and cost estimates.

### Industry Participation

The potential of oil and gas resources in the continental margins is subject to much speculation, but competent geologists claim that these areas hold significant promise. OMDP would help establish better scientific information on which to base further speculation on hydrocarbon resources. In fact, the U.S. Geological Survey (USGS) expects to benefit from OMDP in its efforts to evaluate long-range oil and gas potential in offshore regions. As designed, however, OMDP falls short of a logical oil and gas exploration program. Some petroleum companies claim that they are not participating in the program because it is not directed more toward assessing commercial resources.

Eight out of seventeen petroleum companies that were invited to sign an agreement to support the first-year OMDP efforts have agreed to do so. While there will not be a severe financial burden on these participating companies during the first year, greater industry participation will be needed in subsequent years when a much higher level of funding is necessary. A concern of some industry participants is the manner in which most companies commit funds to the program. In general, the funds that each of the companies would commit would be funds reprogrammed from present industry R&D budgets. Thus, there is concern that participation in the NSF program would preclude other research and exploration projects. Some nonparticipating companies are keeping close watch over the program; and, if the program benefits change, they may decide to join.

The companies that OTA surveyed expressed a variety of reasons for participating. Some that did not have extensive technology development programs themselves felt that technology developments would be the principal benefits. Some foresaw benefits related to the science of sedimentary geology. Very few felt that there were specific, substantial benefits to industry; however, they felt that there would be long-term intangible benefits, similar to those from DSDP, from new ideas generated by program results. None of the companies felt that information on potential commercial resources would be a great benefit.

### Program Management

OMDP is a major increase in funds and complexity from previous efforts, and thus the capability and appropriateness of NSF to manage it is subject to question. Several concerns that have been noted include: whether NSF can effectively manage the considerable technology development work, whether the extra funds needed for technology would be taken from other needed programs, whether the possibility of finding oil and gas resources should involve the Department of Energy (DOE) or USGS more directly, and whether technology needs overshadow science needs.

Three major aspects in managing the program are operations, science, and technology development. Scientists are concerned about the current emphasis on the operational and technology development aspects. The initial plan developed in March 1980 did not win wide support from the basic research community. One reason may be that earlier expectations cannot be met within the financial, time, and engineering constraints faced by the project. A more detailed, overall management plan for science, which spells out the responsibilities and authority of NSF, industry, JOI, Inc., and the panels, may answer some of these concerns.

### Alternatives to the Present OMDP Plan

In April 1980, OTA convened an advisory panel of academic scientists to explore possible alternatives to the present OMDP plan. Most alternatives suggested by the panel focused on the scientific efforts and recommend a delay in developing the technology, and thus the very deep drilling. While these alternatives lack the scientific variety of the present plan, they suggest focusing on a few principal areas of research. Most advocate using the NAS Bally report, which is broadly supported as addressing important problems, for initiating a program. Some advocate making a direct connection between specific science goals and national needs for future oil and gas resources.

The principal elements in an alternative approach with a greater science focus would be to:

- plan and conduct extensive geophysical surveys as the initial effort and to delay decisions on the technology and operations for very deep drilling;
- identify targets that are within the capability of existing technology for the early drilling efforts;
- define the goals of the very deep-drilling phase after the initial work is completed, assuming that substantially improved technology is developed by that time by industry; and
- seek broad scientific support before each phase of the program for specific program plans commensurate with the size of the effort.

Although some of the petroleum companies may be more willing to support this alternative approach, others may not – particularly if drilling is proposed in water depths of less than 6,000 ft. Some companies prefer that only industry exploratory drilling be permitted in water depths that are within existing oil and gas leasing regions.

With the above alternative approach, technology would be developed at a dower pace to minimize risks at each step; thus, also making it possible to estimate more accurately the cost at each phase. Less funding would be required in the early years of the program, and the decision to spend more money for a drilling ship might be delayed. Furthermore, more emphasis would be placed on geophysical studies and less on developing hardware.

Industry and some academic scientists advocate the need for a greater understanding of potential hydrocarbon resources in offshore continental margins. The present OMDP offers very little opportunity for assessing commercial resources. Although some petroleum companies want the Government to refrain from direct participation in oil and gas exploration, there is some support for an alternative program that would include some Government and industry cooperation in assessing commercial resources.

Thus, a second alternative approach would probably contain the following elements:

- The petroleum industry would take the lead in planning and conducting a program to assess the commercial resources on the U.S. Continental margins.
- The Government would offer incentives to allow industry funding of the program.
- Scientific studies would be conducted both as an adjunct to the industry program and separately in those areas not covered by industry.

With such an approach, a new science plan would have to be developed in conjunction with an industry plan. Industry would then probably assume the large financial risks and the responsibility for developing the advanced drilling and well-control technology. The budget and technology development of the Government in OMDP would thus be substantially reduced. It is not certain whether the *Glomar Explorer* would be the appropriate vessel for this approach. This approach would also require substantial changes to the existing offshore oil and gas leasing practices, including the probable offer of very large lease-blocks for commercial exploration and development.

# NATIONAL OCEANIC SATELLITE SYSTEM (NOSS)

A major new effort in satellite oceanography, NOSS, was scheduled to begin in fiscal year 1981 and continue to fiscal year 1991. The new administration has recommended a substantial budget cut and delay. Jointly sponsored and funded by the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), and Navy, NOSS consists of an orbiting spacecraft and dedicated ground control and data processing systems that will collect and deliver remotely sensed data about the global ocean to Navy and NOAA centers. Although primarily an operational demonstration satellite, NOSS will allocate 25 percent of its payload for research experiments. Therefore the satellite will be both a prototype for a future operational system and a station for some ocean research and experimentation.

Satellite systems like NOSS could become important tools for oceanography because satellites can provide wide-area coverage of the ocean surface in a single observation and can observe areas that are infrequently attended by other stations. At present, meteorological satellites provide only limited capability to measure the ocean. One research satellite that has some ocean research capabilities within its mission is *Nimbus-7,* which was designed for experiments in both pollution-monitoring and oceanography and has pioneered technologies for all -weather coverage. However, more experimentation will be necessary to determine the utility of such satellite data for specific ocean research programs.

NOSS follows several early satellite missions that provided oceanic data *(Skylab* and GEOS-3). However, these data were usually outside of the main purpose of the missions. The first satellite with a specific ocean research mission was *Seasat-A*. *Seasat-A* was dedicated to pioneering new microwave and radar remote sensing for oceanography, and was launched in June 1978 with a sensor complement that included one passive and three active radars: a radar altimeter, a synthetic aperture radar, a radar scatterometer system, and a passive scanning multichannel microwave radiometer. These sensor systems acquired real-time data for ocean-surface winds and temperatures, waveheights, ice conditions, ocean topography, and coastal storms. The spacecraft completed a scan of the globe about once every 36 hours, providing extremely high-resolution geophysical data. *Seasat-A* failed prematurely in October 1978 due to mechanical problems, after completing 31A months of a projected 1 -year research mission.[2] The cost of the *Seasat-A* experiment was about $100 million. This included no provision for a ground-based data system to process data at the rate it was acquired aboard the spacecraft.

In early 1978 some planning studies were conducted by NASA to define a *Seasat-B* follow-on research spacecraft to *Seasat-A*. However, NASA, Navy, and NOAA concluded that there were fundamental flaws in the design of the *Seasat-A* data processing system and in the spacecraft itself. They could not immediately agree on requirements for a follow-on ocean-oriented research satellite beyond those originally submitted for *Seasat-A*, *Nimbus-G*, *Tiros-N*, and *Landsat*. Planning continued throughout 1977 and early 1978, but no funding proposals for a new start for an oceanographic satellite were requested until requirements for NOSS were defined. [3]

## *NOSS Program*

The NOSS program is currently in the planning stage. The three agencies that support the program are working together at all levels. During 1980, the Office of Management and Budget (OMB) approved a resource apportionment among the three agencies as follows: Navy (50 percent), NOAA (25 percent), NASA (25 percent). A reassessment of the levels of participation will be made by the three agencies prior to the decision to proceed beyond the alternate-concept-study phase now underway.

Launch of the first NOSS spacecraft by the spaceshuttle was originally scheduled for the

[2]U .S. Department of Commerce, National Aeronautics and Space Administration, Department of Defense, *NOSS, National Oceanic Satellite System*, Washington, D. C., Mar. 23,1979.

[3]S. W. McCandless,"An Analysis of the National Oceanic Satellite System, " discussion paper prepared for OTA, April 1980.

third quarter, fiscal year 1986. Once the spacecraft and ground systems are operational, a second satellite will be launched (within approximately 6 to 12 months). A fully operational system would presumably follow if the demonstration program proves successful.

### Budget

NOSS program budget estimates submitted to Congress in 1980 included the costs for the development of the prototype, the launch of two satellites, and the continuing operations through a 5-year demonstration period from fiscal year 1986 to fiscal year 1991. The flight segment of the program will cost an estimated $240 million to $350 million. Additional funds budgeted for instrument development ($125 million to $150 million), ground support ($175 million to $210 million), and science evaluation and other support ($40 million to $50 million) bring the total to $700 million to $900 million.[4] These costs do not include costs for secondary data distribution and for satellite communication such as a Western Union TDRSS (Tracking and Data Relay Satellite System) satellite data link, needed for the current concept. All of these estimates are in current (fiscal year 1981 ) dollars and contain no allowance for inflation. If inflation at the rate of 10 percent per year were added to the above, NASA estimates the cost would increase to $1 billion to $1.4 billion. Table 30 provides a fiscal year 1981 estimate of program costs. Table 31 provides an NOSS-funding profile by agency by fiscal year.

[4] U.S. Congress, House Committee on Science and Technology, Subcommittee on Space, Science, and Applications, *NASA Fiscal Year 81 Authorization*, 96th Cong., 2d sess., February 1980.

**Table 30.—NOSS Program Cost Estimates (in millions of dollars)**

| | | |
|---|---|---|
| Base program | | $580-760 |
| Flight segment | (240-350) | |
| Instruments | (125-150) | |
| Ground segment | (175-210) | |
| Science and evaluation | (20-30) | |
| Support (shuttle) | (20-20) | |
| STS tariff | | 75-85 |
| Management and other support | | 45-55 |
| **Total**[a] | | $700-900 |

[a] Excludes funding for TDRSS services.

SOURCE: National Aeronautics and Space Administration, 1980

### Mission Goals

Principal goals for NOSS include the attainment of global, all-weather coverage and near-real-time processing and distribution of oceanic data for diverse but important activities such as weather forecasting, climate research, sea-ice forecasting, ocean-wave forecasting, and ocean acoustic-propagation predictions. The most important data products from NOSS will describe the following oceanic parameters:

- *Global Winds.* – Measurements of all-weather, near-surface windfields are necessary for nearly all operational ocean activities (weather forecasts, fisheries monitoring, military operations). These data provide a basis for waveheight-prediction models and will be useful for climate-prediction purposes.
- *Waveheights.* –These data will be useful for correcting wind/wave models and for making direct sea-condition predictions. In turn, these data can be used for real-time ship routing and for selection of optimum conditions for undersea missile launching.
- *Sea-Surface Temperature.* – All-weather measurements of sea-surface temperature can be used to locate ocean frontal zones for antisubmarine warfare, fisheries, and long-range weather forecasting.
- *Chlorophyll Concentrations and Optical Coefficients.* — Measurements of surface chlorophyll concentrations may allow observation of plankton and assist in pollution research. Optical properties of the near-surface water and atmosphere may provide visibility correction factors useful for military operations.

## NOSS Users and User Needs

The primary use of the data collected by NOSS will be for Federal agencies with operational missions. Secondary uses of the data will be for Federal research, and for scientific and commercial applications. A TriAgency Mission Needs Statement has been written that identifies requirements of each funding agency for global oceanographic data; sufficient oceanographic data within the territorial waters of the United

**Table 31.—Funding Profile by Agency by Fiscal Year[a] (fiscal year 1981 dollars in millions)**

| | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988-91 | Total |
|---|---|---|---|---|---|---|---|---|---|
| NASA | 6 | 34 | 47 | 43 | 30 | 19 | — | | 179 |
| NOAA | 4 | 11 | 29 | 49 | 48 | 32 | 16 | 28 | 217 |
| DOD | 12 | 40 | 7 | 89 | 77 | 50 | 16 | 29 | 386 |
| Total | 22 | 85 | 149 | 181 | 155 | 101 | 32 | 57 | 782 |

[a]Preliminary planning estimates only —TDRSS charges not included

SOURCE National Aeronautics and Space Administration

States; and a capability for real-time, rapid high-volume processing and distribution of remotely sensed oceanographic data.[5]

Navy needs global monitoring of oceanographic conditions in real-time to provide timely, accurate oceanographic predictions on a global basis to its operational fleet of surface ships, submarines, and aircraft. NOAA justifies its need for satellite oceanic data to support its four major missions in fisheries management; coastal zone management; mapping and charting; and, most significantly, weather services which will benefit directly from the data to be collected. NASA's interest in NOSS relates to NASA's role in the expansion of global environmental knowledge, in its studies of space activities for peaceful and scientific purposes, and in the useful application of space science and technology.

Civilian considerations, economic benefits, and operational data requirements are also claimed as major justifications for NOSS. Proof-of-concept and research demonstrations from NASA's Seasat project and from other Government projects (Defense Meteorological Satellite Program, Tires, Nimbus, GEOS, and Landsat) have shown applications for civilian users that include offshore oil and gas developers, the fishing industry, the maritime industry, and the oceanographic research community.

Even though civil-sector needs are widely referred to in NOSS program justifications, civilian users have only recently been asked to contribute suggestions. This fact has spurred these users to organize and state their focused interests in NOSS. Although major benefits are attributed to civilian users, the Federal agencies managing NOSS cannot be as responsive to research and commercial users as the users would like when civil user needs conflict with agency mission needs.

During 1980, NOAA held a series of five 1-day regional conferences around the United States to inform potential users about NOSS and to encourage their participation in the development of the program. The conference objectives were to obtain comments from users on priorities and requirements for NOSS data and to develop methods of participation. The participants in the workshops expressed the following concerns in a NOAA draft report of the workshop results:

- Support in the user community for NOSS is tempered by previous experience with existing satellites. Specifically, the length of time to receive data and information has been too long, and the data are not consistent in format and quality.
- A data distribution system that works should be in place prior to launching NOSS. Availability of *Nimbus-7* sensor data in conjunction with ongoing marine experiments would significantly enhance NOSS statements on the capabilities and validity of satellite-derived data.
- Suggestions were made to include near-real-time wind, wave, ice, and water-mass data from NOSS on a time base comparable to that of data available from other environmental satellites.
- There should be "focused points of contact" in NOAA with whom users can interact in lieu of the present system in which five different NOAA components have responsibilities and information.
- Before investing in equipment necessary for using NOSS, certain users want assurances

[5]National Oceanic Satellite System Steering Committee, *Major System Acquisition Tri-Agency Mission Need Statement, National Oceanic Satellite System*, Washington, D. C., Aug. 20, 1979.

that similar satellite systems will operate after NOSS.

- The research users are concerned with the lack of sufficient computer capabilities to support planned NOSS research. At present, no facility can handle the large volume of data sets that will be generated. A national facility for interactive processing of NOSS data is a high-priority requirement among research and development users.[6]

NASA, which has been most sensitive to civil-sector needs in the past, has been assigned responsibility to foster scientific interest in NOSS. This role may be difficult because some scientific interests are in conflict with certain operational objectives. Payload space reserved for science and archival data files can and will be used for scientific purposes; however, it is not likely that basic orbital parameters and design configurations will be changed to accommodate science needs. It may be difficult to protect and preserve even the payload reserved for research if overruns occur and if payload, volume, and power needs grow.

Moreover, concern has been expressed by those who are not a part of the triagency team that a single NOSS demonstration project will not satisfy all of their needs. As a result, NASA is studying various supplements and alternatives to NOSS, including other research satellite projects which, if funded, would provide more comprehensive data. These project proposals are described later in this report.

## Key Features of NOSS

NOSS includes two spacecraft and a complete ground system for receiving and processing data from each satellite sensor and for supplying that data to primary networks for handling and storage in both Navy and NOAA. This ground system is at least 25 percent of the total system cost and a major portion of the program's hardware. The entire NOSS system will be designed with at least a 5-year lifetime so that replacement and repair will be minimal.

[6] U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Earth Satellite Service, *Report of the Conference On the National Oceanic Satellite System*, September 1980.

The sensors that have been proposed for the NOSS satellite are based on operational needs identified by Navy and NOAA with special consideration to those sensors that have had successful previous development and testing. The following NOSS sensors, that have had varying amounts of testing on previous satellites, will be used:

- ***radar altimeter (ALT).*** — Developed and tested on *Seasat-A, GEOS-3;*
- ***coastal zone color scanner (CZCS).*** — Developed and tested on *Nimbus-7;*
- ***large antenna multichannel microwave radiometer (LAMMR).*** — Adapted from the scanning microwave radiometer that was used on *Nimbus-7, GEOS-?;* and
- ***radar scatterometer (SCATT).*** — Developed and tested on *Seasat-A.*

A variety of orbits for a satellite such as NOSS can be chosen, including polar, near-polar (Sun-synchronous), and low-inclination orbits. The orbit inclination angle to the Equator can vary, depending on the satellite's altitude, the desired instrumentation swath, the sensor suite, and the mission objectives. The nominal inclinations for each kind of orbit and the logical orbit selection as a function of the primary mission measurements are summarized in table 32. For instance, if monitoring ocean color is a primary mission requirement, a Sun-synchronous orbit must be used to provide constant Sun-angle light reflections. On the other hand, if polar ice coverage is of primary importance, a polar orbit is required for optimum coverage.

A near-polar, Sun-synchronous orbit has been selected for NOSS spacecraft. This orbit is a compromise based on an evaluation of the most important operational needs for ocean coverage and the optimum operating conditions for all of the sensors. The indications are that while useful data coverage of ice conditions can be made from the near-polar Sun-synchronous orbit selected for NOSS, open-ocean circulation will definitely require a satellite in a low-inclination orbit like that of *Seasat-A.*[7]

[7] National Aeronautics and Space Administration, *National Oceanic Satellite System (NOSS) Orbit Selection and Coverage Study Report*, Washington, D.C., Aug. 14, 1980.

**Table 32.—Comparison of Orbit Selections—Oceanographic Satellites**

| Measured parameter | Polar 87 °-93” | Near-polar Sun-synchronous 970-990 (NOSS planned orbit) | Low inclination 105°- 1150 (Seasat orbit) |
|---|---|---|---|
| | | Inclination to Equator | |
| Winds | x | x ‘-” | x |
| Waves | x | x | x |
| Sea-surface temperature | x | x | |
| Ice edge | x | | (a) |
| Polar ice dynamics | x | (a) | — |
| Color (chlorophyll) coastal area | — | | |
| Circulation (deep ocean) | – | (a) | (b) |

x = optimum coverage
[a]Less than complete coverage
[b]Requires a large spacecraft for Optimum coverage

SOURCE Off Ice of Technology Assessment

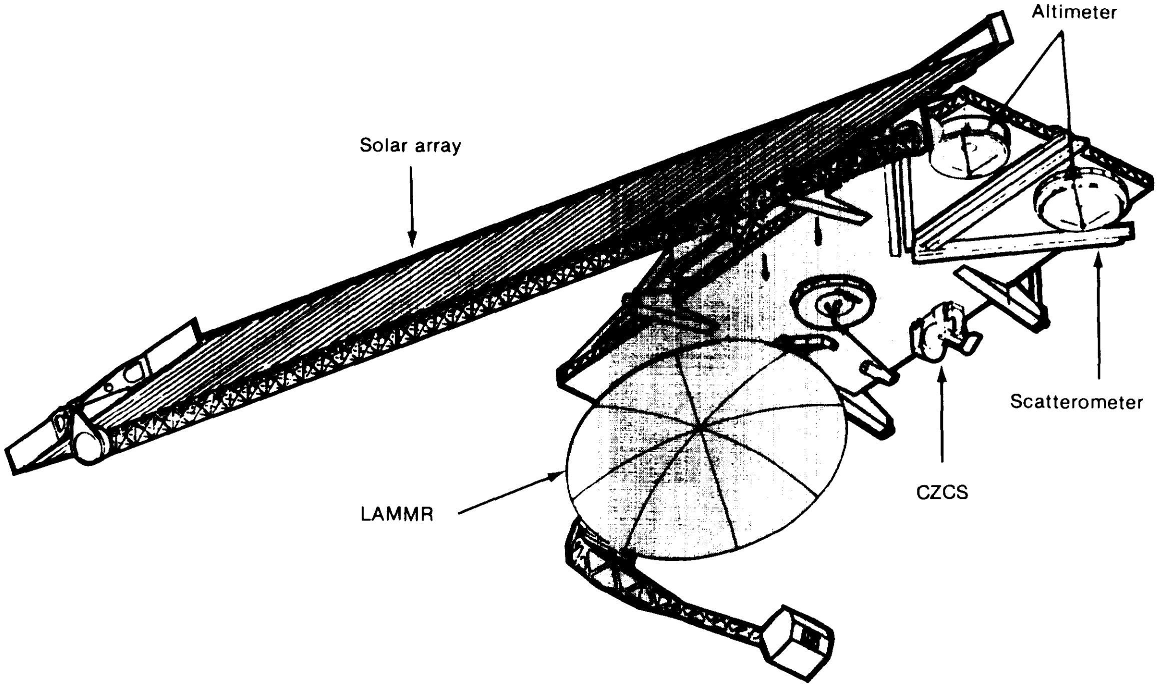
**System** Description

A series of studies of alternative concepts and configuration are now being performed by contractors to define the final NOSS design. Elements under consideration in these concept studies include the optimum use and deployment of ground systems (including the location of the primary processing facility) and the methods to accomplish a 5-year systems lifetime having a greater than 95-percent availability. The selection of the orbit and sensors, fixed prior to initiation of these studies, will not be part of the alternative concepts to be evaluated. [8]

Figure 17 illustrates the NASA/Goddard Space Flight Center conception of the NOSS

[8]U. S. Department of Commerce, National Aeronautics and Space Administration, Department of Defense, *NOSS, National Ocean Satellite System*, Washington, D. C., Mar. 23, 1979.

**Figure 17.—Goddard Concept of NOSS Spacecraft**



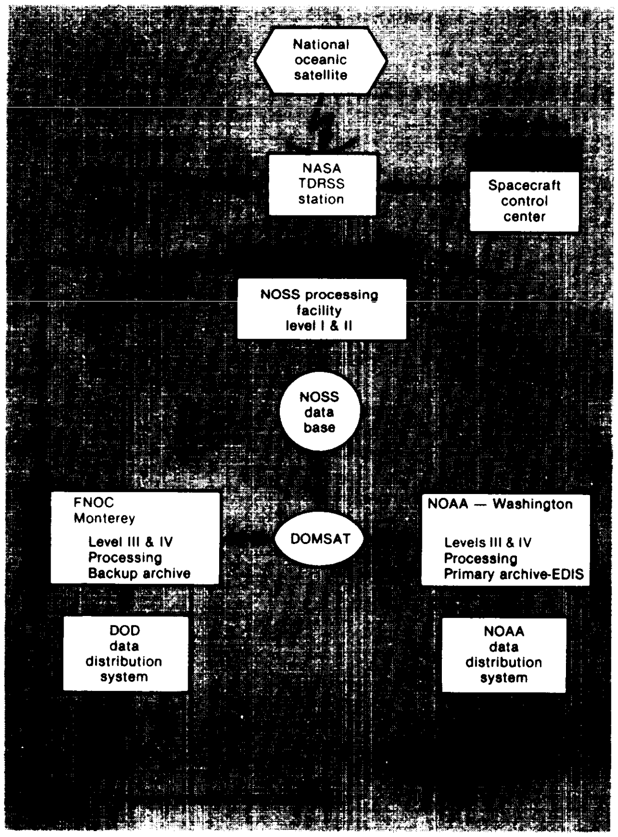

SOURCE National Aeronautics and Space Artmlnistratlon spacecraft. The spacecraft sensors and the shuttle launch and retrieval are considered part of this package.

The basic elements of the ground segment, shown in figures 18 and 19, will include system control, data processing, and distribution. System control is where all major spacecraft and data decisions are made and where complete information on the status of the entire system is available.

An important functional part of the ground system is the ability to perform near-real-time processing. Such processing of raw NOSS data will take place initially in the primary processing facility, which will:

- *ingest raw output* data from all sensors and tracking aids, such as positioning and timing information, and engineering data important to sensor calibrations (level O);

**Figure 18.—NOSS Functional Diagram**




SOURCE National Aeronautics and Space Administrat!on

- create preprocessed sensor data records (level I); and
- *create geophysical* data records (level II).

The computer programs (algorithm specifications) necessary to convert the raw sensor data to geophysical quantities such as windspeed, waveheights, and surface temperatures will be provided by the Government to the mission contractor who will operate the primary processing facility. Distribution of level I and II NOSS data from the primary processing facility will be restricted to the primary users — NOAA and Navy. Further data dissemination will be implemented by NOAA, but is not designated as part of the NOSS program per se.

From Navy and NOAA, NOSS outputs will then be sent to facilities for storage and for further processing and distribution (respectively level III and IV). The archival subsystem will be responsible for the storage, production, and maintenance of all data and data products and for a current data directory.

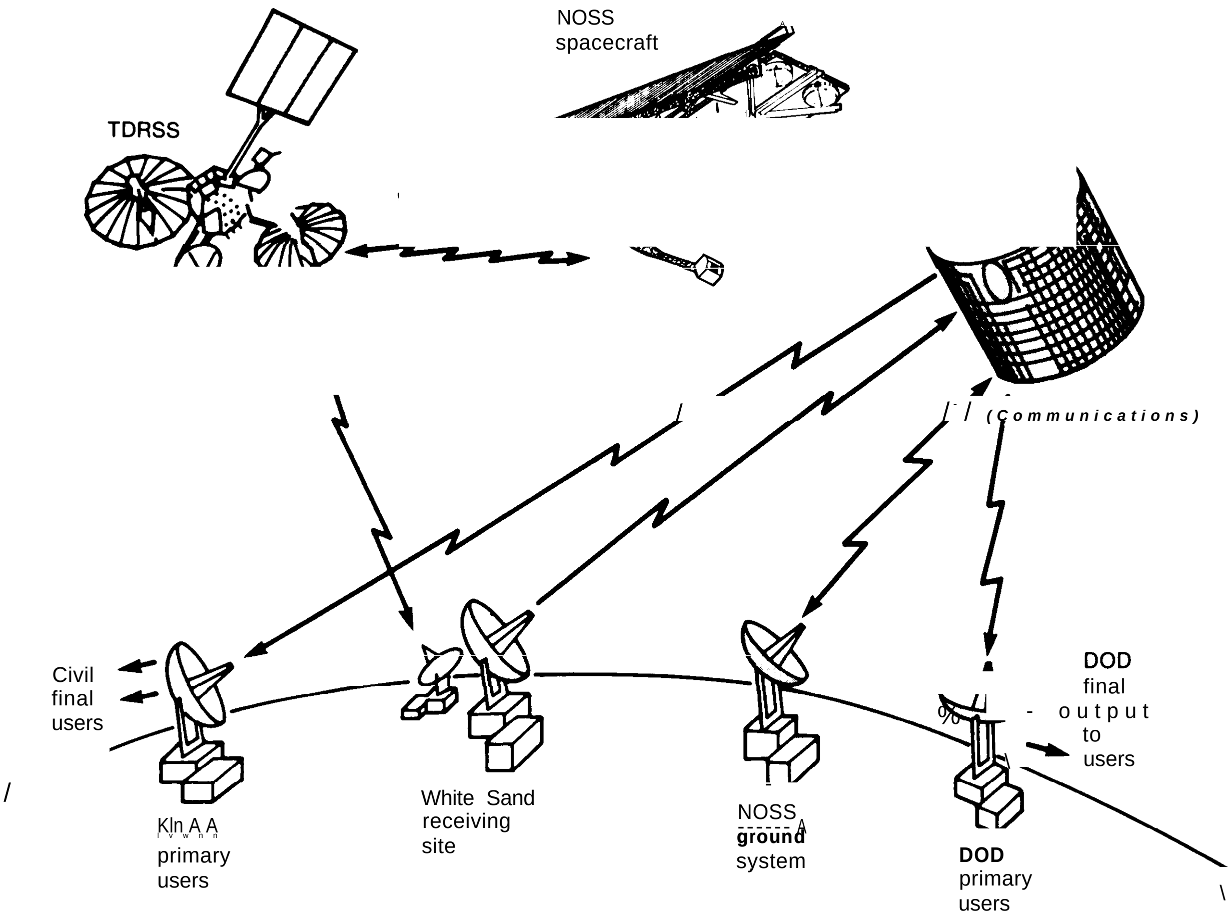
## *NOSS Status*

Planning for NOSS began in the fall of 1977 when NASA, Navy, and NOAA met to discuss the need for operational remote sensing of the ocean environment. These three groups formed a triagency program management group to which there have been few changes in composition and structure since its inception. When this structure was originally conceived, the Jet Propulsion Laboratory (JPL) continued its *Seasat* role as project manager, however, this assignment was shifted by NASA management in early 1979 to the Goddard Space Flight Center because of the Center's operational experience and involvement with the Tires weather satellites.

The following is a brief listing of NOSS program milestones that have already occurred:

1. *January 1978:* program structure established.
2. *March 2978:* objectives defined and approved.
3. *April-June 1978: NOSS* working group in place at JPL, conducting feasibility analyses.

**Figure 19.—NOSS End-to-End System**




SOURCE National Aeronautics and Space Administration

4. *June 2978:* study results presented to steering committee.
5. *July-September 1978:* revisions to and finalization of four-volume set of study results; synthetic aperture radar removed from NOSS payload.
6. *March 1979:* Goddard Space Flight Center chosen as lead NASA center for NOSS.
7. *August 1979:* release of Request for Proposal (RFP) to begin a major procurement for the total NOSS.
8. *January 1980: six* contractors responded to the NOSS' RFP to perform concept-definition studies.
9. *August 2980:* four contractors selected for concept definition.

A total systems procurement for NOSS is proceeding within the three funding agencies. The general OMB policy that has been applied to NOSS procurement is to contract for missions, not equipment, thereby encouraging innovation and conceptual competition to promote exploration of alternative flight and ground systems that will be compatible with Government-furnished sensors. The major objective of this type of procurement is to foster competition between concepts throughout the entire acquisition process, ensuring that a range of appropriate tradeoffs of performance, cost, risk, and schedule are considered.

Needs and objectives require a mission contractor to:

- furnish a NOSS flight segment, except for sensors, including satellite systems and spaceshuttle interface and checkout system;

- furnish a NOSS ground segment from communications interface to primary users;
- provide overall systems operation for 1 year; and
- furnish plans for the following 4 years of operation.

Original plans called for a total systems procurement for NOSS to be initiated during 1981 and a contractor selected by 1982.

Concurrent with the main contractor's effort, procurement of the four NOSS sensors would begin. NOSS sensors will be provided as Government-furnished equipment to the NOSS contractor selected. Three of the four sensors, ALT, CZCS, and SCATT, will be sole-source procurements because they are nearly identical to the *Seasat* and *Nimbus* instruments and they are being purchased from the same contractors. LAMMR, the longest lead-time sensor, will be competitively procured.

The program milestones that follow the concept-definition studies span 10 years: 5 years until the launch of the first satellite system and 5 years of planned system operation.

## Analysis of NOSS Program

At present, satellites appear to be a promising, but limited, research tool for oceanography. Because past oceanic satellite observations have been inconsistent in quality and inadequate in coverage, the merged, high-quality oceanic data sets with long-time histories required for some research are deficient. The measurement capabilities to be provided by NOSS will only partially solve this problem.

### Measurement Goals and Expected Performance

The performance goals and present estimates of system capability for NOSS are shown in table 33. NOSS will meet many but not all of the stated goals that were established as long-range goals for an operational system. Some of the goals will require multiple satellites performing simultaneously in complementary orbits to achieve the temporal coverage indicated, as well as sensor technology advances to achieve the accuracies noted.

Based on the *Seasat-A* and *Nimbus-7* results, NOSS capabilities appear to be reasonable and achievable, with the possible exception of LAMMR performance. This sensor has not yet demonstrated its capability. Figures 20 through 23 describe the performance and capabilities of each NOSS sensor.

System/Mission Design. –The potential contribution of NOSS to operational needs is significant. The contribution to research will depend on many factors. NASA has concluded that no single system can satisfy all the requirements for satellite oceanography. Combining data from various satellites with in situ data will be necessary. To handle data from both operational and research satellite systems as well as from many other stations will require a cooperative program with participation from the oceanographic community and NOAA. More than just archival services will be required. The data management system must be capable of extracting and combining data from several sources, thus preventing a possible problem in data handling and formatting in addition to requiring funding for satellite hardware.

A concern of the oceanographic research community and commercial users is that NOSS may be the only oceanographic satellite authorized as a new start in this decade. The research payload for NOSS has not been defined at this time. The academic community has some concern that a loss of research payload will result from inflationary costs and weight-budget overruns during NOSS program development. Research needs that require hardware systems other than NOSS may not be met until the 1990's. Two major experiments — e.g., the Ice and Climate Experiment (ICEX) and the Topography Experiment (TOPEX), that require new hardware or platforms have been proposed by NASA and the research community, but budgets for these experiments have not been submitted to Congress for authorization.

ICEX Science Applications Working Group was established in February 1979 to consider research needs for the mid- 1980's in satellite sens-

**Table 33.—NOSS Operational Geophysical Measurements**

| | Goals | | Expected NOSS system capability | | |
|---|---|---|---|---|---|
| Parameter | Accuracy | Resolution | Accuracy | Resolution | Instrument |
| *Wind* | | | | | |
| Speed | 2m/s | 25km | +/- 2m/s or +/- 10% | 17km | LAMMR |
| Speed | | | +/- 2m/s or +/- 10% | 50km | SCATT |
| Speed (Nadir only) | | | +/- 2m/s or +/-10% | 12km | ALT |
| Direction | 10° | 50km | +/- 20 | 50km | SCATT |
| Sea-surface *temperature* | | | | | |
| Global | 1.00 c | 25km | +/- 1 .5" c | 25km | LAMMR |
| Local | 0.5° c | IOkm | * 2.00 c | 1.Okm | CzcsIII |
| Waves (sea state) | | | | | |
| Significant wave height | 0.3m | 25km | +/- 0.5m or 10% | IOkm | ALT |
| Direction | 10° | 25km | — | — | — |
| Ice | | | | | |
| Cover | 150/0 | 20km | & 150/0 | 9km | LAMMR |
| Thickness | 2m | 50km | 2 2m | 9km | LAMMR |
| Age | New, 1st yr, multiyear | 20km | 1st yr, multiyear | 9km | LAMM R |
| Sheet height | 0.5m+/-2m change | IOkm | +/- 2m change | 10km | ALT |
| *Water-mass definition* | | | | | |
| Chlorophyll | Within factor of 2 | 0.4km | Within factor of 2 | 1.Okm | CZCS/ll |
| Turbidity | Low, medium, high | 0.4km | Within factor of 2 | 1.Okm | Czcs/II |
| *Horizontal* **surface** *currents* | | | | | |
| Speed | 5cm/s | 20km | +/- 15cm/s | 50km | ALT |
| Direction | 10° | 20km | +/- **20°** | 50km | ALT |

SOURCE: Off Ice of Technology Assessment

ing of ice parameters for ice processes research, climate studies, resource extraction, and polar ocean operations. The study group responded with a satellite concept similar to NOSS that would be flown in a polar orbit within 30 of the pole. The satellite system would include special altimetry and radar systems to map ice elevation as well as telemetry links for locating and transmitting buoy data. It is not clear yet whether NASA will propose a new start for ICEX or will try to accommodate these needs in an operational NOSS.

TOPEX is an experimental spacecraft concept that is being developed to determine global geostrophic (density balancing) circulation of the oceans. NOSS will not be capable of providing the proper altimetry coverage from a Sun-synchronous orbit to perform the precision ocean-surface topography needed for TOPEX. To obtain accurate orbit and geoid information required for making precision altimetry measurements, TOPEX may use an orbit inclination (105 °to 1150, similar to that of *Seasat*. TOPEX is being proposed as a new start in fiscal year 1983 for launch in fiscal year 1986 by NASA.[9]

Orbit Selection Tradeoffs. –A report prepared by NOSS' program office in August 1980 details how the satellite orbit was selected. The analysis was based on each funding agency's stated needs or measurement goals (as shown in table 33) and on the requirements of the four basic sensors selected. The analysis does not consider major variations and deep-ocean circulation measurements, nor does it consider any alternatives in sensor complement.

NOSS' orbit was selected on the basis of operational user needs (the Federal TriAgency Team), with secondary consideration for other scientific research and commercial applications. The need for a Sun-synchronous orbit for NOSS

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'National Aeronaut ics and Space Adm inistrat ion, *Oceanic Processes Progra m Stat us Report Fiscal Year 1980*, Washington, D. C., July 1980.

[10]Nat iona] Aeronautic-s and Space Adm i n ist ra t ion, *National Oceanic Satellite System (.%'0.7S) Orbit Selection and Coverage Study Report*, Washington, DC., Aug. 14, 1980.

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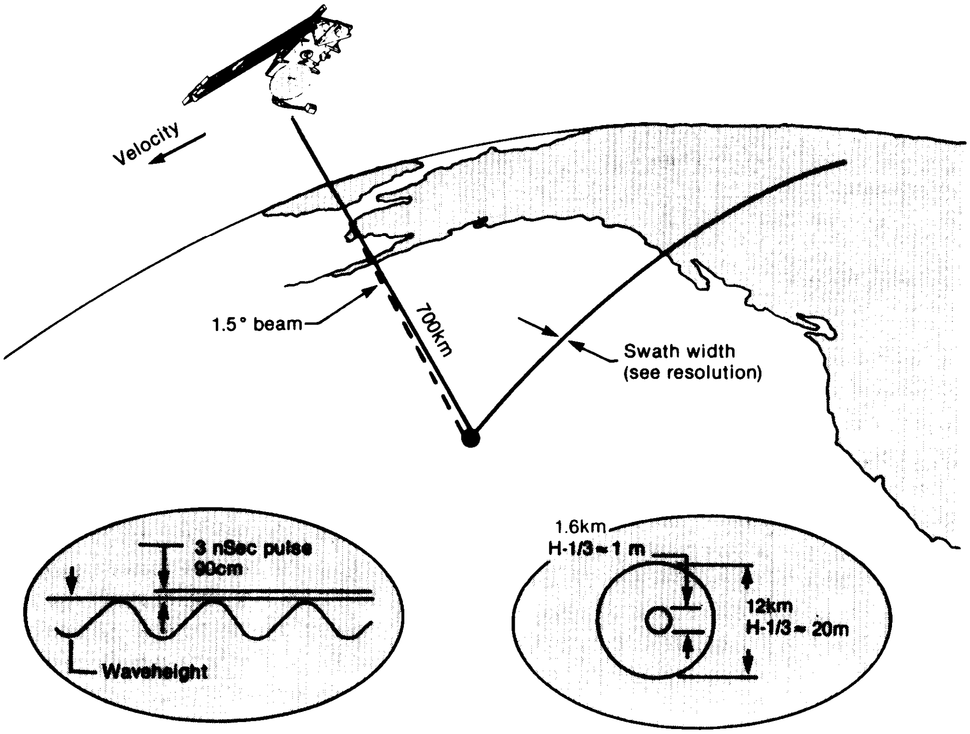
**Figure 20.– NOSS Altimeter**

The NOSS altimeter (ALT) is a short-pulse, fixed-beam active microwave **sensor that operates at 13.5** GHz. It **makes precision measurements of significant waveheight in the range 1-20m. ALT surface topography data can be processed to derive ocean-surface current and icesheet height along the satellite ground track.**

**Predicted altimeter capability**

| Parameter | Range | Accuracy | Resolution |
|---|---|---|---|
| Satellite altitude | 700km +/- 15km | 10cm | — |
| Ocean waveheight | 1 to 20m | 0.5m | < 10km |
| Surface currents | 15 to 250cm/s | 15cm/s | < 10km |
| | O to 3600 | 20” | |




Waveheight measurement

Foot print

SOURCE. National Aeronautics and Space Admlnlstratlon

was partially driven by the requirement for a CZCS. CZCS is the one sensor that can operate only in visible-light bands and thus requires a Sun-synchronous orbit (97 °to 990 inclinations). Other NOSS sensors do not require a Sun-synchronous orbit because they use all-weather microwave radiometers. The NOSS ALT, for instance, works best in orbit inclinations that improve geodetic information (66 °to 1080, by permitting north-south and east-west component derivations.

Data taken in a Sun-synchronous orbit will not have a diurnal variation because only conditions at a single local time will be observed. This result can be good or bad depending on the user’s point of view. Moreover, this orbit renders some of the sensors less than optimally effective. In coastal

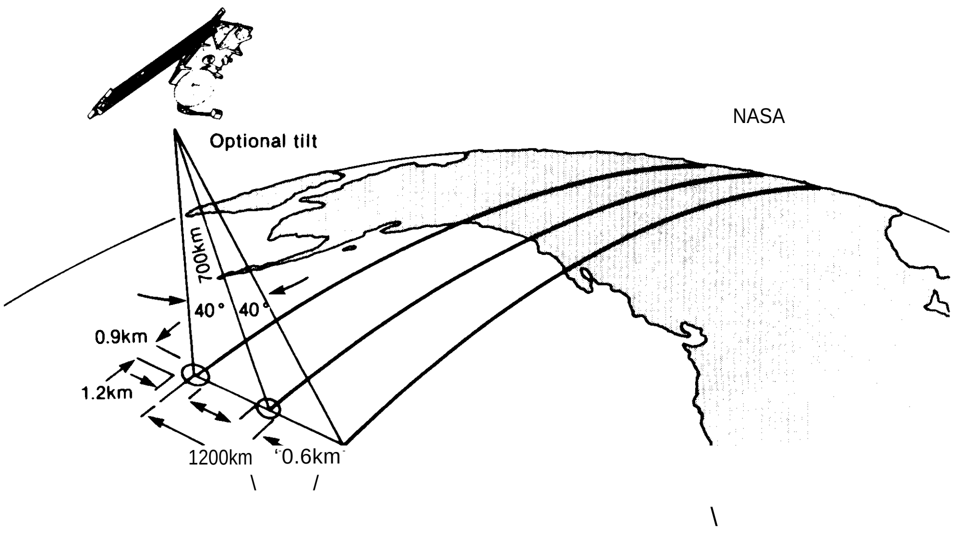
**Figure 21.–NOSS Coastal Zone Color Scanner/2 (CZCS/2)**

**The purpose of the CZCS/2 is to measure the abundance or density of chlorophyll at or near the sea surface. This will reveal the abundance of phytoplankton or planktonic plants which contain chlorophyll and are at the bottom of the oceanic food chain. The CZCS/2 maps the location and measures the density of the plankton on a temporal or time scale, providing information to marine biologists and the fishing industry.**

**Additional objectives of the CZCS/2 are the measurement of sediment in coastal waters, diffuse attenuation coefficient, and the measurement of sea-surface temperature. The temperature measurements can detect cold water upwelling, which frequently provides the nutrient necessary for plankton "blooms."**

**Predicted NOSS system capability**

| Sea-surface temp. | Sensitivity | Range | Accuracy | Resolution |
|---|---|---|---|---|
| Local | 1.00 C | – 2 to 35° C | 2.0° c | 0.8km |
| Water-mass definition | | | | |
| Chlorophyll | 10% (mg/m$^3$) | 0.1 to IOOmg/m$^3$ | Within factor of 2 | 0.8km |
| Diffuse attenuation Coefficient (K) | O. Olin-' | O to 6m$^{-1}$ | Within factor of 2 | 0.8km |




SOURCE National Aeronautics and Space Administration

areas, the signal strength will be marginal. The signal bandwidth of chlorophyll and sediment measurements by CZCS overlap causing interpretation difficulties. Moreover, algorithms to map concentrations of chlorophyll are not yet fully developed. Therefore, even if the concentrations can be measured, NOAA, the primary user of the data, has not demonstrated how the measurements will be effectively used to support its operational programs.

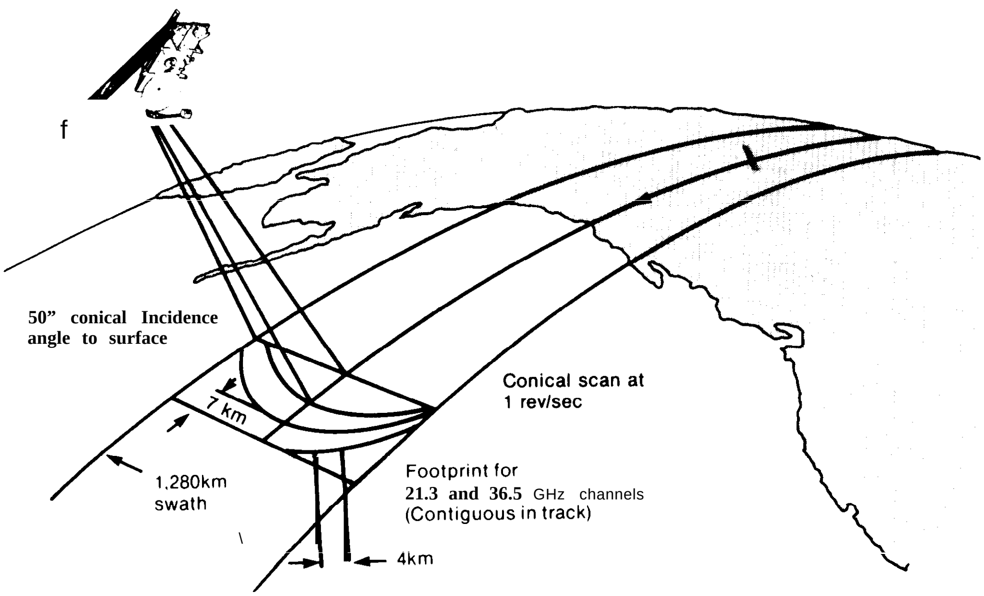
Selection of a Sun-synchronous orbit has some benefits, however, NOSS will require less time-correction of data to aline with the format of meteorological data products from both Navy and NOAA because it will use the same standard

**Figure 22.–NOSS Large Antenna Multifrequency Microwave Radiometer (LAMMR)**

The LAMMR is a passive multichannel microwave radiometer that provides high-resolution radiometric brightness temperature maps of the Earth's surface and atmosphere at multiple frequencies in verical and horizontal polarization.

Predicted LAMMR capability

| Parameter | Range | Accuracy | Resolution |
|---|---|---|---|
| Sea-surface temp. | – 2 to 35° c | 1 .5° C | 25km |
| Sea-surface temp. | – 2 to 35° c | 2.5° C | 16km |
| Oceanic windspeed | O to 50m/s | 2m/s | 20km |
| Sea-ice coverage | o to 1000/0 | 15 "/0 | 9km |
| | New to multiyear | New, 1 yr., multiyear. | |
| Water vapor-integrated | | | |
| Atmosphere water-vapor content | O to 6gms/cm² | 0.2gm/cm² | 9km |
| Liquid water | O to 100mg/cm² | 4mg/cm² | 9km |




SOURCE National Aeronautics and Space Administration

worldwide reference based on Greenwich Mean Time. Another benefit is that the near-polar NOSS orbit ensures better ice coverage than does a low-inclination orbit similar to that of *Seasat.*

Technology Readiness/Sensors. –The effectiveness of the entire NOSS depends substantially on the capability of the sensors to produce accurate and reliable oceanic measurements. In general, the sensor technology is well-founded, with a few exceptions.

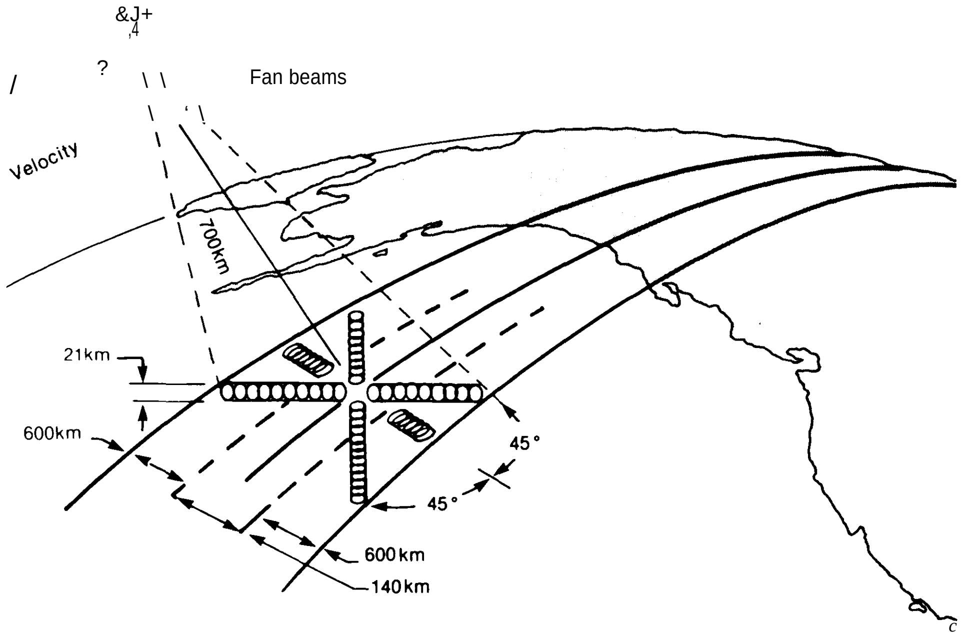
Of the four primary sensors on the NOSS spacecraft, LAMMR is classed as a major new sensor development, while the three remaining sensors are modifications of prototype sensors that were flown either on *Seasat-A* or on *Nimbus-7.* Thus, LAMMR does not have a concrete performance history at the same level as that of the other NOSS sensors. It is an improved version of the scanning microwave radiometer on *Seasat* and *Nimbus* that provided data with up to 1.50 C accuracy.

**Figure 23.–NOSS Scatterometer (SCATT)**

The NOSS Scatterometer (SCATT) is a long-pulse scanning active microwave radar at 13 to 14 GHz that provides measurements of radar backscatter coefficient from which the synoptic scale, ocean-surface vector winds are inferred. The physical basis for this technique is the Bragg scattering of microwaves from centimeter length capillary ocean waves.

**Predicted NOSS/SCATT capability**

| Wind | Sensitivity | Range | Accuracy | Horizontal resolution |
|---|---|---|---|---|
| Speed | 1.5m/s | O to 50m/s | 2m/s | 50km |
| Direction | 200 | 0° to 360° | 20° | 50km |




SOURCE National Aeronautics and Space Administration

The synthetic aperture radar (SAR) was removed from the NOSS program by NASA in the fall of 1978. The reasons given for its removal were that its high data rate and experimental nature prevented its operational use and that its cost would be too high. Recently, completion of *Seasat* studies have shown that while resolution of the open-ocean data from the SAR is good, lack of sea-truth and inadequate position information make it very difficult to interpret SAR output. Those who disagree with the agency decision to shelve SAR point out that all of these problems could be solved. Thus, although NASA has indicated research needs for an ocean-observing SAR sensor in a near-polar orbit, it stresses that improved interpretation of SAR imagery and near-real-time data distribution would be prerequisites for SAR use. SAR is proposed as part of NASA's 15-year objectives and may eventually be launched in a civilian oceanographic satellite.

Recent development has indicated that the use of multiple sensors, possibly on multiple satellites, to estimate one parameter could substantially improve the capability of remote-sensing systems. Significant improvement of some measurements, such as sea-surface temperature, will require in situ measurements in conjunction with satellite measurements.

Technology Readiness/Ground System. – The most important concern about NOSS' ground system is the acquisition, management, and distribution of the acquired data. The processing and communication transfer and the archiving of data is not limited by technology. NOSS civilian-user data distribution plans are currently being developed by NOAA.

Because of the concerns of many potential satellite data users, NOAA is now planning for the development of a data system to process and handle NOSS data for end-users, both inside and outside of the Federal agencies. This system will not be part of NOSS' program as such, but will be designed to make NOSS measurements widely available and to produce useful products for Government research labs, universities, private industry, and the oceanographic community in general.

The two general classes of distribution systems that may be utilized are systems of distribution to standard user terminals and of distribution to other computer installations. One class is that of data distribution to NOSS user terminals via standard dial-up or permanently connected commercial telecommunications services. The second class of data distribution is a computer-to-computer service that can be tailored to support the transfer of data between NOAA and end-user computer installations.

The Navy Fleet Numerical Oceanography Center (FNOC) in Monterey, Calif., is making progress with the problem of processing and distributing oceanic data from satellites that will be directly transferrable to the NOSS program. FNOC along with NASA operates a satellite data distribution system demonstration project for commercial users in accordance with a memorandum of agreement between NASA and the Department of Defense. Likewise, NOAA is handling sea-surface temperature data from *Tiros-N*. The amount and complexity of the coded NOSS datastream, however, require a much bigger processing effort than that of any current effort. This aspect of the NOSS program will be the responsibility of NOAA.

Nearly two decades of environmental satellite missions and technology has produced some valuable data. However, information of value to many users has been difficult, if not impossible, to obtain in the past. In the regional NOSS user conferences conducted by NOAA, users expressed the opinion that a major success for the NOSS program may lie not in creating NOSS, but rather in creating a national oceanic data system with compatible data formats from various stations.

NASA has also identified the high-priority need for an oceanic data system, not now part of the NOSS program, that could foster research associated with remotely sensed parameters from many data sources, including NOSS, *Seasat*, *Nimbus*, *Tiros*, and GOES. Data would be far more useful and usable by scientific and commercial users if it were processed in both a near-real-time as well as a retrospective mode, with data products and data links available on-line from a computer rather than through hard copy only.

# FISHERIES AND LIVING RESOURCES RESEARCH PROGRAM

The Federal Government has an ongoing, sizable investment in programs and supporting technology designed to study and manage living marine resources. The technology required for the programs is unique and is a mixture of conventional systems which have been in use for a long time and new developments which could significantly advance future research.

OTA's study of both programs and technology includes a comprehensive analysis of marine fishery management, fishery research, and stock assessment. In addition, it covers specific problems associated with the krill fishery* in the Antarctic[11] and with the implementation of the Marine Mammal Protection Act (MM PA) of 1974.

OTA study highlights are presented here, more detailed information is available in the complete study version, being issued by OTA as a working paper. [12]

## *The Fishery Conservation and Management Act*

Most of the coastal countries of the world have asserted authority over fisheries within a 200-mile-wide exclusive economic zone bordering their coasts. This action was taken in the United States by means of Public Law 94-265, The Fishery Conservation and Management Act (FCMA) of 1976.13 Under FCMA, which became effective March 1, 1977, a clear Federal authority was established over a fishery conservation zone defined as the area between the outer limit of State authority (usually 3 miles) and 200 miles from the coast. Foreign fishing is now allowed in the zone only under permit and in accordance with management plans. To monitor compliance with the Act, observers are often placed onboard foreign vessels, and frequent radio reports of foreign catches are gathered. However, to what extent the United States should allow foreign fishing inside its 200-mile zone continues to be a subject of debate, and recent proposed legislation calls for gradually phasing out foreign fishing in the U.S. 200-mile zone.

With FCMA, the United States brought under its management about 10 percent of the conventional ocean fishery resources of the world. This decision caused a dramatic increase in U.S. commercial catches that had remained about level for the preceding three decades. In 1970, for instance, the world commercial catch totaled 59.7 million tonnes; 7.4 million tonnes of this amount were caught within the U.S. 200-mile coastal zone 1imit by both U.S. and foreign fishermen. The U.S. commercial catch alone in 1970 was 2.9 million tonnes. [15] By 1980 the U.S. catch had increased to 3.5 million tonnes, reflecting both the restraints placed on foreign fishing and the increased opportunities for U.S. fishermen to seek stocks which had been almost exclusively fished by foreign fishermen. [16]

In addition to extending U.S. fishing opportunities, FCMA established principles of fishery management and a system of Regional Fishery Management Councils to meet the demand for

* Krill are shrimp-like crustaceans, 4- to 6-cm long, which are widely distributed around Anarctica and inhabit an area about 5,300,000 square nautical miles. In contrast, the U.S. Continental Shelf fishing area is about 800,000 square miles. In part of the area, krill form dense aggregates called "super swarms, " which are the object of the fishery. Krill are the major food source for baleen whales and other marine mammals, fish, and birds in the region.

[11] Takeyuki Doi, Takehiko Kawakami, "The Estimation of Krill Abundance in the Antarctic by Analysis of Echogram," *Biomass* 2(5): 1.11, 1980,

[12] College of Fisheries of the Universit, of Washington, OTA Working Paper on "Fishery Research Technology, " including manuscripts from a conference, Seattle, Wash., Apr. 21.24, 1980.

[13] US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, *The United States Marine Fishery Resource, Marmap Contribution No. f,* John P. Wise (cd, ) (Washington, DC.: U.S. Government Printing Office, 1 974).

[14] U.S. Congress, Senate, *American Fisheries Promotion Act,* H. R. 7039, 96th Cong., 2d sess. (Washington, DC.: U.S. Government Printing Office, 1980).

[15] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, *The United States Marine Fishery Resource, Marmap Contribution No. J,* John P. Wise (cd. ) (Washington, D. C.: U.S. Government Printing Office, 1 974).

[16] US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, *Fisheries of the United States, 1979,* April 1980.

better information on which to base the management of both U.S. and foreign fisheries. This demand was the result of research findings that previous management was not as effective as possible. The Act required the regional councils to develop management plans according to the following requirements:

- Each fishery in the United States that comes under the purview of the law must be managed for optimum yield, defined as that amount of fish "which will provide the greatest overall benefit to the Nation, with particular reference to food production and recreational opportunities."
- Optimum yield must be calculated by first calculating maximum sustainable yield and then modifying that figure by ". . . any relevant economic, social, or ecological factor."
- Planning for the attainment of optimum yield must be specified in a fishery management plan.
- Fishery management plans must contain:
  — specifications of conservation and management measures applicable to the fishery;
  — a description of the fishery, including number of vessels, type and quantity of gear, the species of fish involved and their location, management costs, actual and potential revenues from the fishery, recreational interests, and extent of foreign fishing and Indian treaty fishing rights;
  — an analysis of present and probable conditions of maximum sustainable yield and optimum yield and a summary of information to make such a specification;
  — the capacity of U.S. fishing vessels; and
  — various specific data from the fishery.
- The acceptability of a plan must be tested against national standards that specify that the plan be consistent with:
  —preventing overfishing while sustaining optimum yield;
  — using the best scientific information available;
  — management of stocks throughout their ranges and in close coordination with interrelated stocks;
  — conservation and management measures that promote efficiency in utilization of fish;
  — conservation and management measures that consider variations and contingencies among fisheries, fisheries resources, and catches; and
  — conservation and management measures that minimize costs and prevent duplication.

## *Fishery Management*

Prior to FCMA, any management of domestic U.S. fisheries was primarily handled by the States. Few of these States had the data on offshore stocks needed to support management of these fisheries, and yield concepts were not widely accepted. A review in the early 1970's of U.S. ocean fishery resources and management revealed that many of the 31 most important fish species or species groups, most of which comprised many stocks, were being managed inadequately. Of those groups that were being managed, few were managed with a yield objective, with the exception of those subject to an international agreement.

Now, the task of managing the domestic ocean fisheries is a very large one. The fishing area adjacent to the United States consists of the Outer Continental Shelf and the upper part of the continental slope out to a depth of 300 fathoms. This area, almost all of which is within the 200-mile zone, amounts to about 800,000-square nautical miles, or an equivalent of about 30 percent of the land area of the United States.

A review that was made just after FCMA was passed listed species that were thought to be overfished or in danger of being overfished in the U.S. fishing area. Those species endangered primarily by foreign fishing totaled 15; by a combination of foreign and domestic fishing, 12; and by domestic fishing alone, 7.[17]

[17] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *Report to the Congress on Ocean Pollution, Overfishing, and Offshore Development, July 1974 through June 1976*, 1976.

The development of fishery management plans to prevent such overfishing is a lengthy process, requiring from 14 to 32 months to complete.[18] If a Fishery Management Council is amending a previous plan –and amendments of at least a minor nature may be expected annually — it is necessary to restart part or evaluate all of the planning process. In the plans not only the requirements of FCMA must be met but also those of the Endangered Species Act, the National Environmental Policy Act, MMPA, the Coastal Zone Management Act, and various other administrative directives.

Not the least of the problems of developing the management plans is the requirement for information based on research. Special demands on the research base occur when the councils consider all of the alternative regulations of quota, gear, area, season, and size of fish. A further demand is the preparation of the environmental impact statement required for each fishery management plan under the National Environmental Policy Act of 1973. As a result, the 76 plans that were in some stage of development by the end of 1979, only 12 were implemented by the end of 1980, and of these, 7 are plans that involved foreign fishing.[19] Furthermore, each plan that has been implemented is subject to annual review and revision, a lengthy process that will probably continue.

## *Fishery Research and Stock Assessment*

Much fishery research is directed at the problems of managing fisheries, of managing human use of the aquatic environment in which fish live, and of growing fish as a domesticated crop. Now, because of the present capability of overfishing almost any valuable and unmanaged fishery resource, the demand for research to guide management decisions is increasing. Such research includes biological, physical, chemical, mathematical, oceanographic, economic, and other studies as may be necessary.

Photo credit National Ocean/c and Atmospheric Administration

Monitoring of commercial catches is an important factor in fishery stock assessment and in developing fishery management plans

Many management successes have occurred with fish stocks that were top predators in their ecological niche or with stocks that did not have a strong interaction with other stocks. In such cases if the fishery harvests a good portion of the stock each year, the relationship between the size of the stock and the amount of fishing is satisfactorily predictable. With stocks that are major prey species, fishing may cause only a minor part of the mortality and have an unpredictable relationship to the size of the stock. This assumption is also true of stocks that are short-lived and subject to highly variable survival because of environmental changes.

Particularly important to successful management is fishery stock assessment that includes studies that describe the stocks, assess their abundance, and measure the impact of the fishery on them. Out of a total research budget of about $44 million in fiscal year 1979, the National

[18] U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, *Operational Guideline for the Fishery Management Plan Process*, 1979.

[19] U. S, Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, council memorandum, vol. 3, No. 12, December 1979.

Marine Fisheries Service (NMFS) allocated about $32 million to such stock assessment activities. Added to this was about $10 million for the operation of the fishery research vessels by the National Ocean Survey in support of the stock assessment activity. These amounts have probably not changed much in fiscal year 1980 or fiscal year 1981 except for adjustments for inflation.[20]

To assess a fishery stock, the stock must first be defined. A stock, defined in FCMA as "a species, subspecies, geographic grouping, or other category of fish capable of management as a unit, " is ideally an intermingling group of one species, but many fisheries catch mixed species, and it is the activity of a fishery that must be managed.

After being defined, the stock is described according to where it lives, where it migrates; if and how it schools; when, where, and how it spawns; how fast it grows; how old it gets; and other aspects of its biology. Such information provides a base for management plans and estimates of abundance. Given the abundance and the amount of fishing effort over a period of time, it is possible to estimate the mortality rate. Given the growth rate, it is possible to estimate not only the effects of fishing on the stock, but also the level of sustainable yield.

Assessing fish stocks involves evaluating fish at all growth stages. Especially critical to the size of a fish stock is the environment of larvae. Normally, fish eggs are produced by the hundreds of thousands or millions by each female, and the larvae have a high mortality rate. Because larvae of most commercial species are freely drifting animals only 4- to 7-mm long (about 1/4 inch), measuring deviations from the norm that will eventually change the size of the stock is exceedingly difficult.

Many other variables also make measuring fish stocks a challenging task. Most fish are distributed in a patchy way over wide areas and migrate seasonally between spawning and feeding grounds. Many behave differently in different hours or seasons. Since the fish population can vary in size and location as well as from human influences, it is hard to locate and count fish, and it is hard to separate human influences from natural variability. Moreover, all fish change in their vulnerability to fishing or sampling gear as they grow from larvae through the juvenile stage to adults. Any mesh in a net will let small animals go through, and no net can be pulled fast enough to capture all of the swiftest and largest fish. No fishing gear is completely nonselective, no sample. can be completely unbiased.

A consequence of the complexity of these variables is that stock assessment depends not only on rigorous methods, but also on experience and judgment. Predicting the abundance of fish is, in some ways like predicting the weather, political elections, or other mercurial events. The reliability of the prediction is a function of the time between the collection of data and the predicted event.

The basic data for predicting yields must include an estimate of the abundance of the stock and the capability of the fishery to catch it. Estimates of both can be obtained from the fishery data and can be quite accurate for the older age groups in the catches. But the fishery has no prior experience with the age group just being recruited to the fishery, and this group may be a large fraction of the stock. A prediction of the abundance of the recruit group must be made from known relationships and measurable environmental factors, both of which can be highly variable. Data from the catches of special nets used by research vessels or from the spawner-recruit relationship must be used in predicting the fishery catch. Direct measurements of the ratio of recruits to adult fish have been made by acoustics for one species, but it is not clear that such research work could be developed into operational systems by NMFS.

## Technology

The validity of the stock assessment also depends on the quality and quantity of basic data. The most important data source is the fishery fleet itself. It is vital to the whole management process to have information on the catch and fishing effort by time, species, size of fish, area,

[20] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, *Stock Assessment Activities Within the National Marine Fisheries Service*, June 1980.

and gear. Such information provides not only an assessment of the capacity of the stock to sustain the catches, but also an assessment of the capability of the fleet to make the catches.

A complimentary and, in some respects, superior source of information is from surveys by research vessels. Such surveys can provide unique information through the use of special gear and by operation in areas not normally fished by the fleet. The surveys can also provide less biased samples of abundance and a greater opportunity for biological studies of the catch. The surveys are expensive, and they cannot provide the assessment of the capacity of the fleet to make the catches.

Fishery research vessels must be able to handle fishing equipment, the fish that are caught, and oceanographic instruments. Handling large fishing gear such as trawls and seines requires major structural and power arrangements. Handling the catch requires deck space for sorting, laboratory space for studying, and storage space. These requirements mean that other ocean research vessels are usually ill-suited for fishery research; although the navigational equipment, laboratory space, and accommodations may be similar.

The fishery research fleet of nine vessels (with the recent addition of the *Chapman)* is operated for NMFS by the Office of Fleet Operations of the National Ocean Survey of NOAA. The budget for the operation of the fisheries vessels for fiscal year 1981 is about $10.2 million, or about one-fourth of NOAA's fleet budget. This sum provides about 2,000 days of sea time. In addition, NMFS budgets about $2 million for vessel charter and about $250,000 for operations of small vessels. About 90 percent of the ship time supports the resource assessment program.

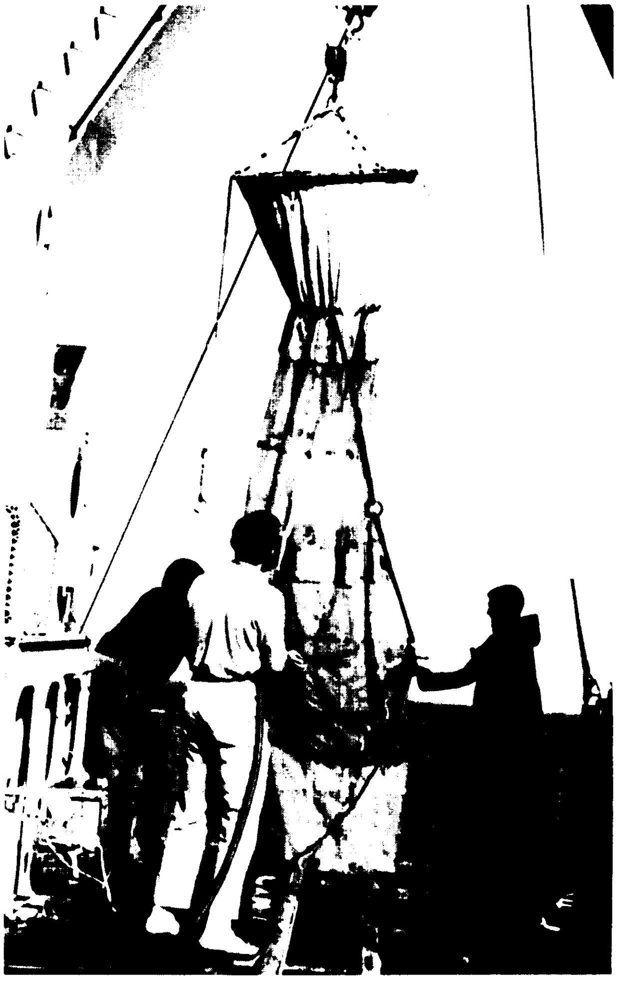


Photo credit Scr/pps /nsfltullon o/ Oceanography

Oceanographers aboard a Scripps research vessel wash down meter net to concentrate marine organisms in the cod end

Photo credit Woods Ho/e Oceanographic /nstltuflon

Scientists bring a sampling net aboard a research vessel. Fisheries surveys require careful sampling of stocks during different stages of growth

Foreign fishery research vessels have recently assisted with stock assessment surveys and have added about 400 sea days to U.S. research-vessel capability. This activity has continued under FCMA because it aids in the determination of catch allocations for foreign nations, but it may

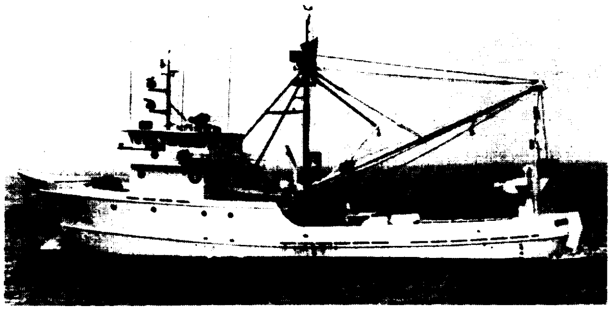


Photo credlf National Oceanic and Atmospheric Administration

National Marine Fisheries Service's 127-ft *Chapman*

not continue much longer. Table 34 lists actual and planned ship days for NMFS research for each ship of NOAA's fleet and for other vessels. Table 35 shows the breakdown of NOAA fleet-support costs by vessel and category for fisheries research in fiscal year 1981.

A method of assessment that is rapidly increasing in effectiveness is acoustic remote sensing from survey ships. Instruments with satisfactory range, sensitivity, and stability have been developed to detect fish to within 1 km from a ship. The instruments cannot identify fish by species, except in certain cases, nor can they assess the abundance of fish very close to the ocean bottom or to the ocean surface. Although acoustic methods have not been widely applied to fishery management problems, such applications are advocated by those in academia and in industry who have studied the problem .21 One benefit of effective acoustic techniques over net-sampling techniques would be a reduction in ship time. It may thus be desirable to invest in such technology development if its benefits appear substantial. The technology development work could be greatly enhanced by encouraging technology transfer from agencies like Navy, which uses acoustics extensively for different problems.

**Table 34.—NMFS Research Sea Days Support—Fiscal Years 1979-81**

| Source | 1979 | 1980 (projected) | 1981 (estimated) |
|---|---|---|---|
| NOAA fleet | | | |
| *Albatross IV* | 213 | 240 | 250 |
| *Delaware II* | 246 | 240 | 250 |
| *Oregon II* | 250 | 235 | 250 |
| *Jordan* | 202 | 232 | 250 |
| *Cromwell* | 242 | 250 | 250 |
| *Freeman* | 138 | 130 | 130 |
| *Cobb* | 166 | 166 | 166 |
| *Oregon* | 196 | 189 | — |
| *Murre II* | 145 | 140 | 140 |
| *Chapman* | — | 100 | 250 |
| *Kelez* | — | 30 | 30 |
| *Other* | 49 | 30 | 30 |
| Charter vessels | 471 | 700 | 700 |
| Foreign ships | 400 | 450 | 450 |
| Program boats | 400 | 400 | 400 |
| Other[a] | 100 | 130 | 150 |
| Totals | 3,218 | 3,662 | 3,696 |

aDonated commercial vessel, research contract, etc

SOURCE. National Marine Fisheries Service

Locating fish through aircraft or satellite observations of ocean-surface conditions such as temperature, currents, salinity, or chlorophyll (which may indicate productivity) has been useful occasionally for locating surface fish, especially certain tunas that follow productive ocean currents or temperature boundaries. This method is not effective for the many fish that live below the surface where conditions are more unpredictable and are different from surface conditions. Another disadvantage is that coastal zones which contain most fisheries also have the most cloud cover, a phenomenon that hinders the effectiveness of many satellite sensors.

The usefulness of satellite or aircraft observations of ocean-surface conditions for the purpose of predicting the abundance of a stock has yet to be demonstrated, but such observations are being used by many researchers as part of their research on the ocean. These observations are especially important for providing nearly simultaneous information on the surface conditions over the entire range of a stock.

## Future Fishery Research and Development

Stock assessment research has been driven and shaped by the needs of the fishery managers. The major need, as noted previously is for better in-

[21]U.S. Department of Commerce, National Oceanic and Atmospheric Administration, "Ocean Acoustic Remote Sensing Workshop, Summary Report, " VOI. 1, March 1980.

**Table 35.—Cost Estimate for NOAA Fleet Support of FCMA-Related Research— Fiscal Year 1981**
**(in thousands of dollars)**

| | Operations | Percent | Maintenance/ repair | Management/ overhead | NMFS total | FCMA[a] (MARMAP) total |
|---|---|---|---|---|---|---|
| *Northwest Region* | | | | | | |
| Freeman (52°/0) | $ 942 | 13.1 | $ 375 | $ 217 | $ 1,534 | $ 1,335 |
| Chapman | 893 | 12.4 | 355 | 205 | 1,453 | 1,264 |
| Cobb | 382 | 5.3 | 151 | 88 | 621 | 540 |
| Murre II | 228 | 3.2 | 91 | 53 | 372 | 324 |
| Subtotal | $2,445 | 34.0 | 972 | 563 | 3,980 | 3,463 |
| *Southwest Region* | | | | | | |
| Cromwell | 880 | 12.2 | 349 | 202 | 1,431 | 1,245 |
| Jordan | 1,046 | 14.6 | 417 | 242 | 1,705 | 1,483 |
| Subtotal | 1,926 | 26.8 | 766 | 444 | 3,136 | 2,728 |
| *Northeast Region* | | | | | | |
| Albatross IV | 1,088 | 15.1 | 432 | 250 | 1,770 | 1,540 |
| Delaware II | 854 | 11.9 | 340 | 197 | 1,391 | 1,210 |
| Subtotal | 1,942 | 27.0 | 772 | 447 | 3,161 | 2,750 |
| *Southeast Region* | | | | | | |
| Oregon II | 876 | 12.2 | 349 | 202 | 1,427 | 1,241 |
| Grand total | $7,189 | 100.0 | $2,859 | $1,656 | $11,704 * | $10,182 |

[a]FCMA (MARMAP) sea days amounted to 87 percent of all NOAA fleet support for NMFS research in fiscal year 1979

SOURCE National Marine Fisheries Service

formation on a large number of stocks that have not been managed as rigorously as required under FCMA. This need for information is ongoing since management plans are reviewed and changed annually. It is an extraordinarily complex need because each stock varies significantly.

Fishery research contributes not only to Federal management, but also to fishery development. FCMA promotes domestic, commercial, and recreational fishing and encourages the development of fisheries, such as that of bottomfish off Alaska, which are currently underutilized by U.S. fishermen.

The stock assessment information, when suitably presented as forecasts, provides the fishing community with indispensable information on the quantity of each stock that may be caught and on the amount of fishing that the stock can tolerate without depletion. In addition, the observations of foreign fishing can provide similar information on the stocks not being fished by U.S. fishermen. Such information is vital for planning the construction and operation of fishing vessels and processing plants.

## Krill Research

Many distant-water fishing nations have shown great interest in Antarctic krill as a major potential source of food for animal and human populations because of its wide distribution, its abundance, and its accessibility, Other nations, including the United States, are interested in the key role krill plays in the Antarctic ecosystem. Because of the speculative nature of information about krill's standing biomass, productivity, and commercial harvest, and because of the issues surrounding the potential impact on the Antarctic ecosystem of an expanded krill fishery, some nations argue for caution in proceeding with commercial development of krill. Under domestic legislation and as party to the Antarctic Treaty and other international agreements, the United States shares a scientific and political interest with other nations in promoting scientific investigations and the conservation and management of krill resources in the southern oceans. [22]

[22]U.S. Department of State, *Final Environmental Impact Statement for a Possible Regime for Conservation for Antarctic Living Marine Resources*, June 1978.

Conventional fishing technology is well-suited to exploit krill's "super swarms. " Over the years, improvements in locating and catching techniques have apparently made it possible to take large catches at moderate costs. The 1979 combined catch was probably over 100,000 tonnes. Projections show a 1985 commercial harvest of 2-million to 4-million tonnes, which will not exceed 50 million tonnes by the turn of the century .23

Although krill are believed to be an immense protein source, U.S. fishermen have not been interested in actively exploiting it. Unlike countries with large, idle, long-range fishing vessels that have pushed for exploitation of krill, the United States does not have such vessels. At present, U.S. fishermen do not see any economic advantage in leaving their domestic fishing operations to fish krill in the Antarctic. The frontrunners of krill exploitation will probably be the Communist bloc countries, Japan, and perhaps, ultimately, Chile,[24] The United States does, however, have an interest in the key role krill plays in the Antarctic ecosystem. Krill, more than any other single species of zooplankton in other ocean ecosystems, is an important link between phytoplankton and higher trophic forms. Whales and other marine mammals, fish, and birds of the area feed on krill. [25]

## The Marine Mammal Program

Protection of marine mammals is addressed in MMPA which declares that stocks of marine mammals should not fall below a level "which will result in the maximum productivity of the population or the species, keeping in mind the optimum carrying capacity of the habitat and the health of the ecosystem of which they form a constituent element."[26] It is difficult not only to define this goal scientifically, but also to obtain enough scientific information about these species to carry out the provisions of MM PA.

Surveying marine mammal populations is difficult because they combine the inaccessibility of most fish populations with the variability in behavior and habitat preference of most terrestrial mammalian species. [27] Surveys often range over large areas and a number of survey techniques must be designed, each with sufficient flexibility to adapt to the particular characteristics of individual species. Some species that concentrate seasonally in dense aggregations (California gray whale and northern fur seal) can be surveyed through efficient sampling devices. Other species (porpoise and harbor seal) that do not aggregate to such an extent require large-scale surveys to assess their population sizes. Although past survey methods have met with some success for a limited number of marine mammalian species, much additional research is needed to develop methodologies capable of satisfying the requirements of MM PA.

### Technology Needs

In addition to the need for improved survey methodologies for marine mammal research is the need for development of new technology and the modification and/or acquisition of current technology.

Photo credit National Marine fisheries Service

Humpback whale

[23] D. L. Alverson, "Tug-of-War for the Antarctic Krill," *Ocean Development and International Law Journal 8(2):* 171-182, 1980.

[24] M. A. McWhinnie and C. J. Denys, *Antarctic Marine Living Resources With Special Reference to Krill, Euphausia Superba: Assessment of Adequacy of Present Knowledge,* report submitted to the National Science Foundation, December 1978.

[25] Scientific Committee on Antarctic Research (SCAR), Scientific Committee on Ocean Research (SCOR), Group of Specialists on Living Resources of the Southern Ocean, SCOR Working Group 54, *Biological Investigations Of Marine Antarctic Systems and Stocks (Biomass), vol.* 1: research proposals, August 1977.

[26] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, *The Marine Mammal Protection Act of 1972 Annual Report,* Apr. 1, 1977 to Mar. 31, 1978.

[27] L. L. Eberhardt, D. G. Chapman, and J. R. Gilbert, "A Review of Marine Mammals Census Methods, " *The Journal Of Wildlife Management, vol. 43, No.* 1, January 1979.

Photo credit Nat/ona/ Mar/ne F/sher/es Serwce

Research on marine mammals has led to development of tuna seine nets that allow porpoises to escape

Virtually all marine mammal surveys require some form of observer platform. Since the number of commercial harvesting vessels has been drastically reduced, a major source of cost-effective platforms has been curtailed. Hence, NMFS must rely more heavily on its own vessels to conduct marine mammal surveys, thus creating a serious need for more and better designed survey ships. Such ships should have long-range capability for operating in remote parts of the world. They should also be capable of visual searching, be equipped to gather both passive and active hydroacoustic data, and be able to accommodate helicopters which can be used to extend and augment surveys. Finally, for Arctic and Antarctic work, survey ships must be ice-strengthened. To date, lack of suitable survey vessels has hampered the Bowhead Whale and Cetacean Tracking programs in the North Pacific Ocean and in the U.S. Antarctic Program.

Aircraft are also needed, especially for large-scale surveys. As with ships, aircraft must have long-range capability. To survey porpoises in the eastern tropical Pacific Ocean, for example, survey planes are used to search as far as 1,500 nautical miles out to sea. Survey aircraft must be maneuverable enough to change altitude and course frequently so that observers can identify species, obtain more accurate counts, and take aerial photographs. Lack of suitable aircraft has, in the past, constrained the Tuna/Porpoise Program in the eastern tropical Pacific Ocean and the Bowhead Whale and Cetacean Tracking programs in the North Pacific Ocean.

In addition to observer platforms, marine mammal surveys require better use of aerial photography. The value of conventional photography has been established, especially for surveying large aggregates of animals, and attempts to employ ultraviolet and infrared photographic techniques have met with some success. Research is needed to improve the accuracy of these techniques and to make them cost effective.

Tracking of radio-equipped animals via aircraft or satellites has not been used to a great extent in marine mammal surveys. However, such techniques show considerable promise and should be addressed by future research.

Finally, updated navigational equipment on survey vessels and aircraft is needed for marine mammal surveys. Since many of these surveys are conducted far from shore, sophisticated navigational equipment is imperative for acquiring accurate distributional information on surveyed populations.

## *Analysis of the Fisheries and Living Resources Research Program*

### Fishery Management, Research, and Development

Although FCMA is obviously the beginning of major changes in fishery management in the United States, domestic fishery management is as yet little changed. It will be first necessary to complete fishery management plans for the many stocks identified as needing management, a task difficult to accomplish while keeping the already implemented plans under annual review and possible amendment. In addition, it is likely that some stocks, not yet identified as needing management, will at some time be more heavily fished and will then require management. Other stocks that are reduced in abundance due to unknown factors may also have to be brought under management quickly but workable techniques to deal with this situation are not yet available.

In addition to these longer range developments, improvements must be made in the current implementation of FCMA. These improvements include collecting better data on biological, social, and economic problems; improving the coordination with the States in regulations and enforcement; improving public participation and understanding; and speeding up the planning process.

Accurate and comprehensive catch data from U.S. fisheries is not now available, but technology does not appear to be the problem. Rather, improvements are needed in the institutional systems that have been established to collect the data, to verify its accuracy, and to provide managers with timely and reliable data-history and forecasts.

Fishery research needs will be met by extending and refining existing theory and technology to hitherto unmanaged stocks as they are brought under management. Generally, fishery research will be relatively routine, directed at monitoring and prediction. But familiar methods have been found wanting when applied to some important bottomfish stocks, which are complex mixtures of species, and to some very large herring and anchovy stocks. In these instances, a better understanding of the nonfishery factors is more essential and can be gained only by researching the ecological production processes. When conducted on a scale adequate to measure the environmental and the interspecies relationships, such research should be expected to be nonroutine, expensive, and lengthy.

## Technology

It does not appear that any significant changes in the fishery research fleet will be necessary in the near future. However, maintenance and upgrading of ship equipment and instrumentation will be important if fishery research capabilities are to be maintained. Also, the present trend toward using more charter vessels to augment the Government fleet may be cost effective in the future. Many commercial fishing vessels have very modern equipment and can be chartered for research surveys during slack seasons.

There are some technology needs that accompany the development of new fisheries to ensure the safety and good quality of new products. Those species that are unfamiliar to U.S. fishermen require different handling and processing procedures. For example, many of these species are small and require different processing machinery and almost all must be prepared in a form suitable for different and highly competitive markets. The successful development of these resources by the United States will require very different technology for fishing and processing than that for the existing fisheries. Such technological development depends heavily on information about flesh quality and its chemistry, toxins, deteriorative processes, and on many other laboratory studies.

## Krill Research

At this time, research on Antarctic krill is basic and exploratory rather than routine assessment. Ongoing multinational krill research efforts include surveys and explorations by the Soviets, Japanese, Poles, West Germans, and Chileans. The United States has not done as much scientific research on krill as these countries have, but could begin by sending more scientists on foreign research vessels. Long-term research programs should be developed, and existing international collaboration in krill research should be further expanded and intensified. Methods of survey techniques, data collection, evaluation, and reporting need to be developed and standardized. This involves collecting comprehensive catch-and-effort statistics and reporting them to the appropriate international agency.

For some purposes better results could be obtained by coordinating research programs with the commercial fisheries on krill than by deploying an independent krill assessment research vessel and program. NOAA claims that while it would be beneficial to coordinate research with commercial vessels to assess krill, a medium-to-large research vessel capable of polar operation will ultimately be needed for basic studies of polar marine life.

## The Marine Mammal Program

Curtailment by MMPA of U.S. harvesting of many marine mammals has drastically reduced direct acquisition data on population sizes and auxiliary characteristics, such as age at maturity, sex and age distribution, fecudity, and survival rates based on catch-effort and mark-recapture procedures. In the absence of harvesting, therefore, marine mammal information must be acquired through scientific expeditions using alternate study methods like mark-resighting, sightings per unit effort, and direct counting. A major drawback to such methods is that often an unknown and inestimable fraction of the population is not visible; indices of abundance are all that can be reliably obtained from many such surveys. A major goal of future methodological research should therefore be to develop corrections for nonvisible population fractions so that estimates of total abundance can be made.

Meeting the research and survey requirements of MMPA will be costly. Funding limitations in the past have generally constrained methodological research and technological development; have slowed the acquisition of data, analysis, and distribution; and have created shortages of necessary equipment and manpower. Most marine mammal survey programs have been severely hampered by these limitations, and it is clear that if these programs are to improve to the extent required, a major increase in financial support is mandatory.

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# THE CLIMATE RESEARCH PROGRAM

Basic understanding of world climate and the ability to predict climate changes do not exist now, but a major new research program to address this subject is urged by the National Climate Program Act of 1978. Such a program would involve major efforts by the oceanographic community in a series of large and definitive experiments, long-term data collection efforts, and theoretical modeling.

The detailed physics of the ocean-atmosphere-cryosphere interaction, now largely unknown, must be understood before reliable models can be constructed for estimating climate variability on seasonal, yearly, and longer time scales.[28 29 30 31 32]

## *The National Climate Program Act of 1978*

The intent of the National Climate Program Act is to strengthen and improve the Federal research efforts to provide useful climate information and long-range forecasts to the public. In the past, climate research consisted of individual programs in agencies such as NSF, NOAA, and DOE whose goals were either to improve basic knowledge or to solve specific problems. The Act focused goals and efforts by calling for the establishment of a National Climate Program Office within NOAA. It called for the preparation of a 5-year plan to define the roles of the agencies and offices involved and to provide for program coordination.

The activities called for by the Act which are relevant to determining ocean effects on climate are:

- Assessments of the effect of climate on the natural environment, agricultural production, energy supply and demand, land and water resources, transportation, human health, and national security.
- Basic and applied research to improve the understanding of climate processes — natural and man-induced — and the social, economic, and political implications of climate change.
- Methods for improving climate forecasts on a monthly, seasonal, yearly, and longer basis.
- Global data collection, monitoring, and analysis activities to provide reliable, -useful, and readily available information on a continuing basis.

The Act also contains specific requirements for the participation by universities, the private sector, and others in applied research and advisory services.

### Climate Program Status

The National Climate Program Office is now established and ongoing programs have been coordinated. During 1980, a 5-year plan[33] was prepared and reviewed by the Climate Research Board of the National Academy of Sciences.[34 35] The ocean research portion of the climate program is now funded at about $10 million annually. A significantly larger and more concerted effort will be needed if any near-term improvements are to be made in understanding world climate and in developing useful forecast abilities. Whether the present small group of ocean research projects develops into a major long-range program in the next several years depends on how clearly a plan can be stated, how specifically certain public benefits can be determined, and how

[28] GARP, *The Physical Basis of Climate and Climate Modelling*, publication No. 16, (Geneva: WMO, 1975).

[29] B. V. Hamon and J. S. Godfrey, "The Role of the Oceans," in *Climate Change and Variability, A Southern Perspective*, A. B. Pittock, et al. (eds.) (Cambridge University Press, 1978).

[30] National Academy of Sciences, Ocean Sciences Committee, *The Ocean's Role in Climate Prediction*, Washington, D. C., 1974.

[31] National Academy of Sciences, *Understa riding Climate Change*, Washington, D. C., 1974.

[32] National Academy of Sciences, Geophysics Study Committee. *Studies in Geophysics Energy and Climate*, Washington, D. C., 1977.

[33] U S Department of Commerce, National Oceanic and Atmospheric Administration, National Climate Program Office, *National Climate Program, Five-Year Plan*, Washington, D. C., 1980.

[34] National Academy of Sciences, Ocean Sciences Board, *The Continuing Quest, Large-Scale Ocean Science for the Future*, Washington, D. C., 1979.

[35] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *An Ocean Climate Research Plan*, Washington, D. C., 1979.

**much funding** will be needed to provide those benefits.

Furthermore, while the 5-year National Climate Program Plan describes goals, experiments, and data needs, the plan has not addressed technology needs to any significant degree. For this major national research program, a strong technology effort is necessary. It will be important to anticipate critical technology needs if significant advancements in climate research are to be made.

Much of the technology (both new techniques as well as applications of existing techniques) to conduct climate experiments and to collect these data is not now in place. Some systems need to be developed, others need to be built and tested, and still others need to be operated and maintained over long time periods. The most critical needs known at this time for measurements are outlined here with their associated major technology needs.

## *Measurement Needs for Climate and Ocean Processes*

### The Heat Budget

The Earth's climate is controlled primarily by the amount of solar heat the planet retains and by the transport of that heat from one region of the globe to another by the ocean and by the atmosphere. The global atmospheric transport of heat is determined principally by the temperature differences between equatorial and polar regions. The oceanic transport of heat is determined in large part by the global distribution of wind stress.

The equatorial ocean regions receive and store a surplus of solar energy which the transport processes mentioned above eventually transmit to the polar regions.[36 37 38] A large portion of the heat which the atmosphere transports poleward is extracted from the ocean in the warmer latitudes through warming of the airmass just above the ocean surface and through exchanges of heat in the evaporation/condensation process. Processes important in the oceanic transport of energy include surface drifts, major polewards currents such as the Gulf Stream and the Kuroshio (off Japan), **deep-return flows** in the **mid-ocean, and** possibly oceanic eddies.

In the polar regions the ice cover affects global climate changes by reflecting a substantial percentage of solar energy and by providing insulation between the relatively warm polar waters and the much colder atmosphere. 39 40 Also, the relationship between solar energy cycles, the heat-transport processes, and icemelt and ice growth, adds further complexity to overall global climate forecasting.

Each of the oceanic processes that is involved in climatic interactions is a component of the ocean heat budget. The technology required for evaluating each of the heat budget components varies widely and ranges from the use of satellites, to the use of drifting ocean buoys, to the use of polar meteorological stations. In the following sections major components of the ocean heat budget are discussed briefly and are linked to the technology required to evaluate the associated oceanic mechanisms.

**Incoming Radiation. –** The energy from the Sun passes mostly through the atmosphere and is stored in the ocean at lower latitudes. In higher latitudes the radiation balance is negative and the Earth loses heat. Simple theoretical climate models suggest that small variations in the incoming radiation can have dramatic effects on the Earth's climate .41 These models also suggest that understanding and predicting climate change will require measurement of incoming radiation to a precision that is only now becoming available. Since such measurements will most

[36] GARP, *The Polar Subprogram*, publication No. 19 (Geneva: WMO, 1978).

[37] D. E. Trenberth, "Mean Annual Poleward Energy Transports by the Oceans in the Southern Hemisphere," forthcoming in *Dynamics of Atmospheres and Oceans*

[38] T. H. Vender Haar and A. H. Oort, "New Estimates of Annual Poleward Energy Transport by Northern Hemisphere Oceans," *J Physical Oceanography 3(2)*, 1973, pp. 169-172.

[39] W. F. Budd, 'antarctic Sea Ice Variations From Satellite Sensing in Relation to Climate," *J Glaciology* 15, 1973, pp. 417-427.

40 National Aeronautics and Space Administration, Goddard Space Flight Center, *Proposed NASA Contribution to the Climate program*, Greenbelt, Md., July 1977.

[41] GARP, *The Physical Basis of Climate and Climate Modelling, publication No 16* (Geneva: WMO, 1975).

likely be made from satellites to avoid the biasing effects of clouds, water vapor, and other factors in the Earth's atmosphere satellite instrumentation must meet extremely stringent requirements.[42] For example, satellite instruments will have to be calibrated repeatedly to high accuracy in order to measure changes in incoming radiation from the Sun that are only a fraction of 1 percent of the total.

Storage of Heat in the Ocean. –The incoming radiation from the Sun is partially reflected by the clouds and by the ocean surface. The radiation energy that is absorbed by the ocean is stored for various lengths of time and is later either extracted locally by the atmosphere or carried by ocean currents to distant areas where it is released from the sea.

The Earth's temperature, on the average, is in equilibrium (about as much energy is radiated over a long period of time as is absorbed). The surplus heat gained in the tropics is carried by the atmosphere and the ocean toward the poles. Recent determinations of the Earth's heat balance from satellite measurements and from upper-air measurements, have shown that the ocean probably transports a large share of the heat needed for global balance.[43] At latitude 200 N., the ocean carries 75 percent of the total heat and the atmosphere carries only 25 percent. The amount of heat carried by the ocean decreases at higher latitudes. In the Southern Hemisphere the sparse data allows only the tentative conclusion that heat transport by the ocean is greater than that of the atmosphere up to latitude 300 S. and remains substantial even to latitude 600 S. 44

Simple measurements of the sea-surface temperature, at best marginal now, can provide fairly good estimates of the temperature throughout the ocean's upper mixed layer. However, the measurement of sea-surface temperature must be coupled with the measurement of the depth of the mixed layer in order to estimate the amount of heat stored. Furthermore, to qualitatively understand heat transport, other properties of the water column such as salinity and density must also be known.

At present, satellites do not yield an accurate measure of sea-surface temperature, and it appears that even in the future they will be unable to measure the depth of the oceanic-mixed layer. Such measurements at present are accomplished from drifting buoys, research ships, survey ships, naval ships, and ships-of-opportunity. New technologies which have been proposed for these measurements include the use of acoustics either from ships or from large arrays (acoustic tomography) and the use of aircraft-mounted laser systems. Expendable instruments that measure not only temperature but also salinity will probably be required for future climate-monitoring programs.

Horizontal Transport of Heat Within the Ocean. –Since heat is transported by ocean currents over relatively large distances, knowledge of currents is vital for determining the ocean's effect on the overlying atmosphere. The kind of current measurements required, however, are not easily made. In general, measurements of currents presently obtained from current meters, hydrographic surveys, and other instruments are point measurements of the currents and do not provide either the time or space coverage required for determining the mass and flow of near-surface ocean currents over time.[45 46 47] (The data do show, however, that there is strong variability of current flow on both the seasonal and interannual time scales. ) New acoustic techniques have been proposed for these measurements, but much development work and experimentation will be necessary to validate these methods. A combination of sensors, including satellite-based radar systems and altimetry systems, coupled with ground-based observing systems (such as drifting buoys), measurements from ships-of-opportunity, island measurements of sea level, and vertical

[42] National Aeronautics and Space Administrate ion, Goddard Space Flight Center, *Proposed NASA Contribution to the Climate Program,* Greenbelt, Md., July 1977.

[43] Report of th, JCC/SCOR Specialists Meeting, *The Role of the Oceans in The Global Heat Budget,* 1978.

[44] D. E. Trenberth, op. cit.

[45] Center for Ocean Management Studies, *Ocean Research in the 1980's* (Kingston, R.1.: University of Rhode Island, 1977).

[46] Federal Coordinating Council for Science, Engineering, and Technology, A *United States Climate Program Plan,* Washington, D.C., 1977.

[47] Roger Revelle, "Presentation of Report on the Pilot Ocean Monitoring Study ( PO MS)," at Joint SCOR ' IOC Committee on Clima tic Changes and the Ocean (CCCO), 11th sess. , Miami, Fla., Oct. 15, 1979.

profiles of temperature and salinity, will be required to measure heat transport in the ocean.

The role of mesoscale eddies in effecting changes in ocean climate is not presently clear, but may be significant. Aside from determining their possible effects on driving the general circulation, it is important to determine the extent that eddy motions effect a net transport of heat in the ocean toward the poles.[48 49] Despite considerable investment in several large U.S. experiments, the role of these eddies in heat transport is not fully understood.

Air/Sea Heat Exchange. – There are several processes by which the ocean and the atmosphere exchange heat:

*Back radiation.* – Infrared radiation from the sea surface is a primary function of sea-surface temperature; however, the actual measurement of this variable, which is generally done by satellite, is influenced by the fact that clouds and water vapor in the atmosphere absorb and eventually reradiate the energy. Knowledge of cloud structure is required to properly estimate the back-radiation from the sea surface worldwide. Although the net radiation leaving the Earth can be determined, the amount of radiation leaving the ocean versus that remaining in the water-vapor field and transported to other parts of the globe can only be estimated.

*Sensible heating.* –Scientists can estimate the exchange of sensible heat (total heat content) between the ocean and atmosphere. To make these estimates, however, requires knowledge of the surface wind as well as that of the air-sea temperature difference (the most difficult of the two estimates because it is generally a small difference between two large numbers). Present satellites cannot determine precisely enough, either the sea-surface temperature or the air temperature in the boundary layer immediately above the ocean's surface. Satellite data may provide an indirect measurement of sensible heating, but the techniques are not yet proven.

*Latent heat transfer.* –To estimate the heat transferred from the ocean to the atmosphere (through evaporation) and from the atmosphere to the ocean (through condensation) requires a knowledge of the wind, the temperature, and the more difficult to measure moisture content of the air just above the sea surface. The technology necessary to carry out surface wind and temperature measurements is just being developed, but the technology to measure moisture content is not currently available. It is absolutely crucial to develop techniques to estimate the moisture content of the lowest 10 m of the atmosphere.

*Precipitation.* –Since the condensation of atmospheric water vapor results in precipitation, measurement of precipitation can indicate a component of the heat budget of the atmosphere. Over land, measurement of precipitation is made at meteorological stations. Over the ocean, there is no satisfactory way to measure precipitation from either existing or planned satellite systems. The best measurement now available is a crude measure by satellite of the rate of precipitation in given regions at given times. However, since most satellites pass a given area only twice a day, a rate measurement becomes of questionable value since the same rate does not apply during the 12 hours between passes.

Ice cover. – The lack of solar heat in the polar regions results in the growth of large volumes of sea ice on a seasonal basis. The resulting ice cover provides insulation which prevents evaporative, latent-heat processes from taking place.

Even satellite observations are inadequate for making polar ice measurements. Ice processes occur over both long- and short-time scales. Earlier *Tiros* satellite imagery and the later finer resolution *Nimbus* and *Landsat* imageries have been of limited use in delineating sea ice extent and morphology and in distinguishing snow from cloud cover. Synoptic data about polar ice can only be obtained with satellites that have nearly polar orbits. No existing satellites meet this need and much improved satellite sensors are needed for any future satellite system.

## Development of a Measuring Strategy

In order to understand and monitor the processes of ocean/atmosphere interaction relevant to climate, it is necessary to carry out specific ex-

[48] Center for Ocean Management Studies, op. cit.
[49] Federal Coordinating Council for Science, Op. cit

Photo credit: Jim Broda, Woods Hole Oceanographic Institution

The ocean and atmosphere continually exchange energy in a way that has a lasting effect on global-weather patterns periments and to do long-term monitoring of critical processes. A major ocean observing system must take into account both the scientific understanding of the ocean's role in the climate system and the rapid changes in technology and in the needs for technology that come as the field develops. 50

A NOAA-sponsored study on the development of a system for ocean-climate monitoring is underway. This study will include technical planning and systems evaluation leading to the development of a global-monitoring system for climate studies. The immediate objective of this effort is the formulation of a strategy for system development that includes an assessment of how emerging technologies can meet monitoring requirements, a projected time-phasing of capabilities, an estimate of the time-phasing of costs, consideration of institutional factors (domestic and international) involved in a comprehensive ocean-monitoring activity, and the coordination with other ocean-monitoring activities.

As currently conceived, the observing system will evolve from existing and projected observational capabilities, including satellites, buoys, ships-of-opportunity, and island stations, into a systematic means of monitoring climatically significant ocean variables. Measured parameters will include surface temperature (air and sea), upper-ocean transport, sea ice extent, and upper- and deep-ocean circulation.

The first phase of this study, which began in earl y 1980, will focus on the problems of measuring the components of the regional heat budgets in the upper levels of the ocean globally in order to describe the annual and interannual variabilities. Supplementary objectives are to assess how to determine the uptake and redistribution of carbon dioxide in the ocean and to monitor the variability of selected key indices in deep water. It is expected that to achieve global coverage at a reasonable cost, the final long-range system will have to be based primarily on remote sensing from space, with in situ measurements and inference from modeling used to fill in gaps and to provide calibration benchmarks. Specific attention will be given to the problem of accurate statistical sampling.

A follow-on phase of the NOAA study will involve systems engineering studies to determine the most effective systems configurations and to perform detailed planning of systems development efforts. It is expected that each phase of the study will take approximately 1 year.

A second phase of planning for ocean monitoring for climate is the Pilot Ocean Monitoring Study (POMS), now in the planning stages.[51] POMS was proposed as part of the World Climate Research Program, which in turn is sponsored by the International Council of Scientific Unions and the World Meteorological Organization. Meetings were held in late 1979 and mid-1 980 by the World Climate Research Program and the Scientific Committee on Oceanic Research to set the goals of POMS. POMS planning meeting recommended that the following activities be carried out:

- Study the feasibility of conducting a basin-scale experiment to evaluate the poleward transport of heat in the atmosphere and ocean using a variety of techniques.
- Explore the feasibility and design of an experiment to determine the global ocean circulation using a combination of hydrographic methods and the geodetic/altimetric satellite techniques under development. A unique opportunity to use these techniques may occur during the latter part of the 1980's when a U.S. satellite, a European satellite, and a Japanese oceanographic satellite orbit simultaneously.
- Designate certain geographic lines in the ocean for continued long-term monitoring by POMS participants.
- Establish a theoretical oceanographic group to assist, interact with, and provide general theoretical expertise to the POMS study as required.
- Take steps to initiate vigorous technical interaction and exchange between laboratories, using buoys to facilitate development of

[50] National Academy of Sciences, Climate Dynamics Panel, U.S. Committee for GARP, *Elements of a Research Strategy for the United States Climate Program*, Washington, D. C., 1978,

[51] Revelle, op. cit.

oceanographically and meteorologically instrumented buoy systems suitable for POMS and corresponding satellite-data transmission links.

At the present time, active planning is going on in the United States, U. S. S. R., Canada, France, Federal Republic of Germany, the United Kingdom, and Japan to prepare for POMS. First studies such as the proposed North Atlantic Heat Flux and Storage Study, have already begun. Some simple monitoring systems such as island stations will also contribute, but they must be maintained and coordinated better than the existing systems.

## Existing Technology for Ocean Experiments and Monitoring

Many technology systems are now in place or available for use in climate research and monitoring programs. Future climate research will be dependent on the following technological advances and continued support for these systems.

Stations. – Existing long-term oceanic data come from relatively few sources: coastal stations, island stations, ocean weather ships, and ships-of-opportunity. Since 1972, organized and expanded ships-of-opportunity programs have been contributors to a description of the climate system because of their good, long-term reliability. Furthermore, they have been used in several of the large-scale, long-term ocean experiments with increasing success. These systems take on greater significance now with the phase-out of the ocean weather ships. Aircraft-of-opportunity and satellites also have substantial potential for some surface measurements, but they have not yet been available on a routine, long-term basis.

Sensors. – Only relatively few types of measurements are available in any abundance or continuity in the climatic data base. One of the most used measurements is sea-surface temperature. Since post-World War II, this variable has generally been measured by ships' injection thermometers. Prior to that, bucket thermometers were used to obtain the data. Sea level, as measured at various tide stations, is another type of measurement that exists in abundance; but more long-term sea-level and bottom-pressure measurements are required to establish a climatic data set. In general, the measurements have been made with standard instrumentation that has not changed dramatically for many years.

There are now some regions of the world's oceans where short and intermittent time series of temperature, salinity, and water velocity as functions of depth can be constructed. These data have come from a variety of measurement techniques, such as measurement by Nansen bottle casts or by continuous-drifting instruments and current meters. The stability of temperature sensors used to collect this data is good, but the salinity sensors tend to drift. Thus, a stable salinity sensor is needed.

The time series referred to above come from point data. There are no good techniques existing now for the measurement of temperature and salinity over large volumes, although acoustical techniques hold promise here. Instruments that measure current velocity accurately over large volumes, especially near the surface and in the presence of wave motion, are another major need.

Other extremely useful measurements taken over the ocean are those pertaining to the windfield. Surface wind, as reported by ships-of- opportunity, is generally not measured from a ship's anemometers, but rather is based on visual estimates — e.g., relating sea state to the Beaufort scale. Nevertheless, these crude estimates have been of great help in a variety of research programs. Information on the wind strength at upper levels comes from standard radiosonde observations taken from islands, ocean and land weather stations, and currently from satellite soundings. The relationship of satellite-measured winds to actual surface winds is still not understood.

Some satellite data sets, extending back to the mid- 1960's, are presently being used in climate research. Among the most important sets are the estimates of cloud cover from reflectance data. The sensors that provide this information have changed considerably since satellites were first launched, and this change can create potential problems. Extensive study of satellite-sensed ocean parameters is required to understand fully how to interpret present satellite measurements, Moreover, satellite estimates of variables such as surface wind, sea-surface temperature, vertical temperature profiles in the atmosphere, upper-level winds, etc., are only just beginning to have the accuracy required to make them useful in long-term climatological studies. Unfortunately, most satellite data is discarded before it can be used in climate studies, a policy that severely hinders research.

**Data Management Systems. –** Most of the data collected by the methods indicated above are organized through different management and reporting structures. Eventually most of the data find their way to the National Climatic Center, where they become available to interested users. The mere mass of the data makes it difficult for the uninitiated to determine what is available.

Generally, the data in the Center are in their natural form. Most researchers would prefer to work with products such as monthly contour maps of the Pacific trade-wind fields. The development of such climatological products is largely the province of the individual researcher. While these products are sometimes available on request, they are not widely disseminated in the oceanographic community.

### New Technologies for the Climate Research Program

The climate studies required by the National Climate Program Act of 1978 will require major new ocean programs that will in turn require new technology. Ocean programs currently planned for the 1980's are designed to meet the need for understanding climate processes, but are generally underfunded in the technology area.

To gain the technological capability to measure climate-related oceanic parameters, an integrated approach may be needed. Such an approach would take into account both national and international climate parameter-measurement capabilities, resources, and research programs. However, particular attention should be addressed to:

- the improvement of remote sensors proposed for the NOSS and other climate-proposed satellites,
- techniques for improving satellite sensor ground-truth,
- innovative, in situ measurement systems to provide integrated heat-flux data,
- techniques for gaining reliable oceanic and meteorological data on a real-time basis from the world fleets of research ships and naval vessels and from ships-of-opportunity, and
- techniques for gaining data from the polar regions.

OTA has identified the following technology needs for future climate research and monitoring of the ocean.

**A Mix of Technologies. –** One of the most important needs is for a variety of technologies to address the climate problem. Since almost all satellite systems sense only the skin of the ocean and cannot measure all quantities at the air-water interface that are required for the determination of the heat budget, it is apparent that space systems are not totally sufficient for studying the ocean's role in climate. Many other technologies must also be used such as instrument packages on ships-of-opportunity to collect surface-transfer measurements and upper-ocean temperature soundings. An expanded and improved ships-of-opportunity program should be developed to gather large-scale and long-time series of ocean data. Drifting buoys can be used to measure currents, sea-level pressure, sea-surface temperature, and other data. Research ships are needed to gather ground-truth data for complex satellite measurements and to perform process experiments. Subsurface moored instruments are required for determining vertical and temporal signals of relevant oceanic variables. Since the technology needs of the climate program are shared by many other oceanographic programs, these programs will also benefit from climate-related technology development.

**Data Management and Computers. –** Present data reporting methods tend to be slow and non-uniform and could be 1argely replaced in the future by a single data-retrieval system. The key to the system would be a reliable, inexpensive satellite data-relay link. With satellites as prime receivers and transmitters of climatological data from ships, islands, or other satellites, it should be possible to develop effectively a single climate datastream. Subsequent production of products for use by operational agencies, researchers, and others would then be a relatively straightforward matter. At present, the huge volume of climate data from satellites and from various other platforms is overwhelming and is poorly managed in available archives. It is critical, therefore, to invest in competent, well-managed data archives that will involve fifth- and sixth-generation computers to manipulate and retrieve the data base. The immense investment in satellites and other technology is wasteful unless the data base can be easily available for scientists and Government managers to use. In fact, many types of users will want access to both in situ and remotely sensed oceanic and atmospheric data. Data formatting, distribution, and management must be considered to provide an effective way by which the research scientist, the governmental climate-product packager, and the ultimate user can have timely access to the data at minimum cost.

A single data-management structure could coordinate and ensure the continuity of the ocean climate-data collection program. A large part of the job in monitoring climate is one of managing a wide variety of resources, institutions, instrumentation, and people. This management structure does not now exist. In addition to developing the management structure, there must be a long-term commitment to carry through the climate-monitoring program. Without this commitment, such long-term measurement programs should not be started.

Specific Major Technologies. – It is essentially impossible now to measure upper (top 100 m) ocean currents with accuracy. Present means of attempting the necessary measurements have serious flaws. Drifting buoys are not accurate due to windage. Line-of-sight radars are very useful only when mounted on land or on ship. Over-the-horizon radar are affected by ionospheric fluctuations which are poorly understood. Current meters are expensive and are unreliable due to wave contamination. Sea-surface slope from satellites yields information on the surface geostrophic components of the currents; but for the total surface current, one must also know the wind-driven component. If a new technology to measure ocean currents with 10-percent accuracy is developed, it will be a major breakthrough for ocean-climate research and for other important problems, such as the fate of pollutants (such as oilspills), fisheries management, rescue-at-sea maneuvers, and numerous military problems.

It is also essential for ocean-climate studies that the windfield be estimated over the ocean on a time scale of at least once a month and on space scales of 200 by 200 km. There are potential satellite systems to accomplish this such as the microwave scatterometer technique. However, the instruments involved have had limited ground-truth verification, and considerable research is required to ensure that their wind-velocity determinations are meaningful.

It is extremely difficult to estimate precipitation, an important part of the energy budget, over the ocean. Rainfall rates have been estimated by observing cloudtop height and density using visible and infrared radiation (on the assumption that thick, dense clouds rain more than thin clouds) and by observing radio energy emitted by liquid water (but not ice) at radio wavelengths near 2 cm. This latter method has an accuracy of around +/- 50 percent, with spatial resolutions on the order of 30 km. The accuracy of the radio technique is limited primarily by inadequate spatial resolution and by the uncertainty in present knowledge of the height of the freezing level and of the distribution of raindrop sizes. (The latter can perhaps be estimated from other satellite data; although this has not yet been done. ) These techniques all require extensive verification. It is highly probable that a new, advanced instrument will be required for estimating precipitation.

It is generally believed that the latent heat flux (evaporation) is several times larger than the sensible heat flux. In order to estimate the latent heat flux, the sea-surface temperature must first be known and then the saturation water content, the windspeed, and the humidity or water content a few meters off the sea surface must be determined. Until reliable technology to measure remotely the humidity of the air near the sea surface is developed, scientists will not be able to calculate balanced heat budgets.

# Acronyms and Abbreviations

AGOR – (Navy classification) oceanographic research ship
ALT – radar altimeter
AOML – Atlantic Oceanographic and Meteorological Laboratory
AOSS – Aircraft Oil Surveillance System (Coast Guard)
ASDAR — aircraft to satellite data relay
AVHRR — advanced very high resolution radiometer
BLM – Bureau of Land Management (DOI)
BT – bathythermograph
CCTV — closed-circuit television
CEAS – Center for Environmental Assessment Services
cm — centimeter
$CO_2$ — carbon dioxide
COSMOS — complementary-summary metal oxide semiconductor
CTD – conductivity-temperature -depth
CZCS — coastal zone color scanner
CZMP – Coastal Zone Management Program (NOAA)
DACS – Data Acquisition and Control Subsystem (NOAA)
DMSP – Defense Meteorological Satellite Program
DMSS – Defense Meteorological Satellite System
DOD – Department of Defense
DOE – Department of Energy
DO I – Department of the Interior
DPSS – Data Processing and Service Subsystem (NOAA)
DSDP – Deep-Sea Drilling Project (NSF)
EDIS – Environmental Data and Information Service (NOAA)
ENDEX – Environmental Data Index (NOAA /EDIS)
EPA – Environmental Protection Agency
ESIC – Environmental Science and Information Center
ESRO – European Space Research Organization
FCMA – Fishery Conservation and Management Act of 1976
FGGE – First GARP Global Experiment
Flip – Floating Instrument Platform
FNOC – Fleet Numerical Oceanography Center (U.S. Navy)
ft – feet
GAO – General Accounting Office
GARP – Global Atmospheric Research Program
GOASEX – Gulf of Alaska *Seasat* Experiment
GOES – Geostationary Operational Environmental Satellite (NASA)
GPS – Global Positioning System
HEBBLE – High Energy Benthic Boundary Layer Experiment
ICEX – Ice and Climate Experiment (NASA)
I POD – International Program of Ocean Drilling
JASIN –Joint Air-Sea Interaction Experiment
JOI –Joint Oceanographic Institutions, Inc.
JPL –Jet Propulsion Laboratory
km – kilometer
LAMMR – large antenna multichannel microwave radiometer
LAMPEX – Large Area Marine Productivity Experiment
LSI – large-scale integrated
m — meter
mm — millimeter
MMPA – Marine Mammal Protection Act of 1974
MODE – Mid-Ocean Dynamics Experiment
NAS – National Academy of Sciences
NASA – National Aeronautics and Space Administration
NASDA – National Space Development Agency
NAVSTAR – navigational system using time and ranging
NCC – National Climatic Center
NDBO – National Data Buoy Office (NOAA)
NESS – National Environmental Satellite Service (NOAA)
NGSDC – National Geophysical and Solar-Terrestrial Data Center
NMFS – National Marine Fisheries Service (NOAA)
NMPA – Marine Mammal Protection Act of 1974
NOAA – National Oceanic and Atmospheric Administration (Department of Commerce)
NODC – National Oceanographic Data Center (NOAA/EDIS)
NOMAD – U.S. Navy Oceanographic Meteorological Automatic Device
NORDA – Naval Oceanographic Research and Development Administration (U.S. Navy)

NORPAX – North Pacific experiment
NOSS – National Oceanic Satellite System
NSF – National Science Foundation
NWS – National Weather Service (NOAA)
OASIS – Oceanic and Atmospheric Scientific Information System
OCS – Outer Continental Shelf
OMB – Office of Management and Budget
OMDP – Ocean Margin Drilling Program (NSF)
ONR – Office of Naval Research (U.S. Navy)
OTEC — ocean thermal energy conversion
OTES – Ocean Technology and Engineering Service (NOAA)
PMEL – Pacific Marine Environmental Laboratory
POMS – Pilot Ocean Monitoring Study (NOAA)
RFC – Research Facilities Center (NOAA)
RFP – Request for Proposal
ROV – remotely operated vehicle
SAR – synthetic aperture radar
SASS — microwave scatterometer
SCATT – radar scatterometer system
SDSD — Satellite Data Services Division (NOAA/EDIS)
SEAS – Shipboard Environmental Data Acquisition System (NOAA)
SEM — space environment monitor
SFSS – Satellite Field Services Stations
SIO – Scripps Institution of Oceanography
SMMR – scanning multichannel microwave radiometer
SMS – Synchronous Meteorological Satellite (NASA)
SOFAR – Sound Fixing and Ranging
SPURV — self-propelled underwater research vehicle
SST — sea-surface temperature
STD — salinity-temperature-depth
STS – Space Transportation System
TOPEX – Topography Experiment (NASA)
TOVS – Tires operational vertical sounder
TRDSS – Tracking and Data Relay Satellite System (Western Union)
UNOLS – University-National Oceanographic Laboratory System (NSF)
USGS – U.S. Geological Survey (DOI)
VACM — vector-averaging current meter
VHF — very high frequency
VIRR — visual and infrared radiometer
VISSR — visible and infrared spin-scan radiometer
WEFAX – Weather Facsimile System
WMO – World Meteorological Organization
WPL – Wave Propagation Laboratory
XBT — expendable bathythermograph

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U.S. GOVERNMENT PRINTING OFFICE : 1981 O - 80-710