Chapter 3

Discussion of Technologies

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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 ex periments 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.

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- *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 capabllity, 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 Unlverslty 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

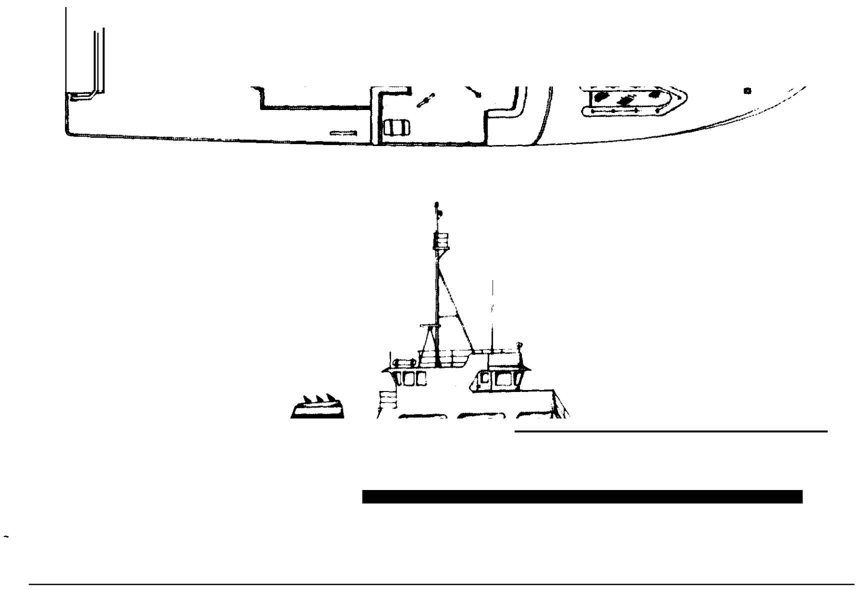
Table 10.—The Navy Oceanographic Fleet (July 1980)

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

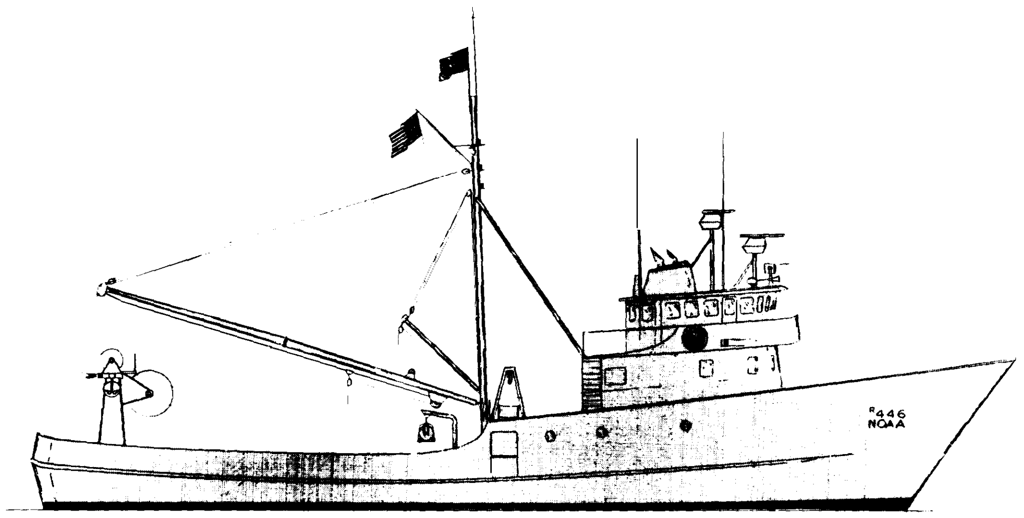
Figure



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

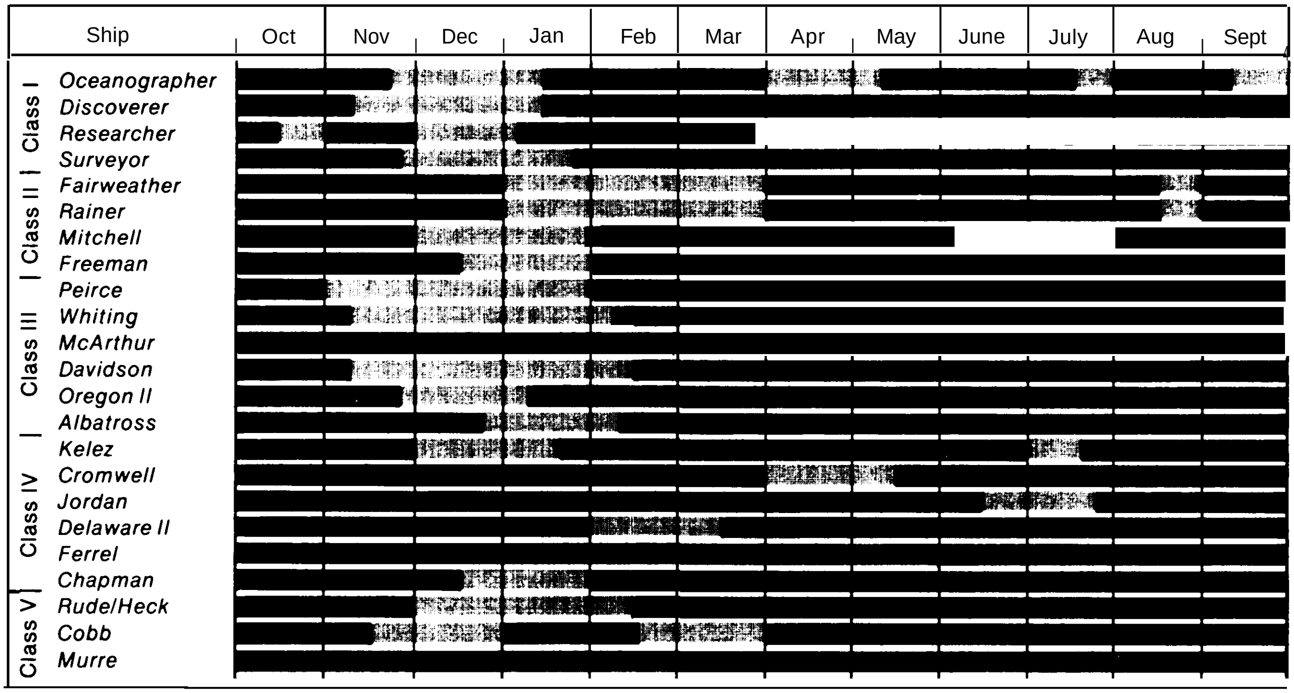
Economic studies by NOAA indicate that even though refurbishing and upgrading of key equipment is costly, it is an overall saving compared to replacing the ships at age 25. This approach appears to have been adopted as cost-effective by Navy with classes of warships. Furthermore, NOAA's analysis points 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



Legend: port time& repairs _ Research programs

Fisheries surveys _ Charting

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
[a]Launch 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-

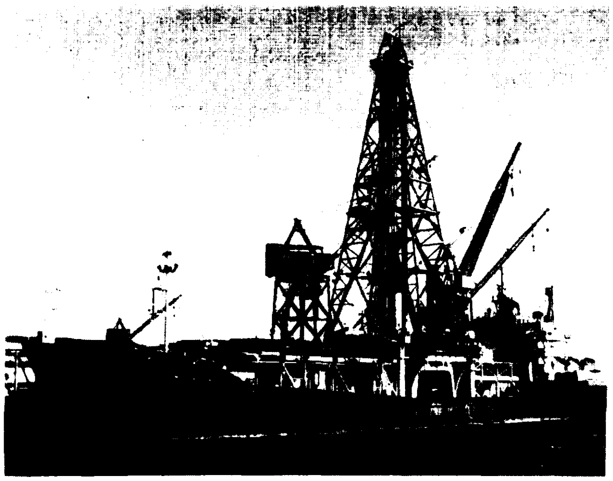


Photo credit Scripps /nst/tut/on o/ Oceanography

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,

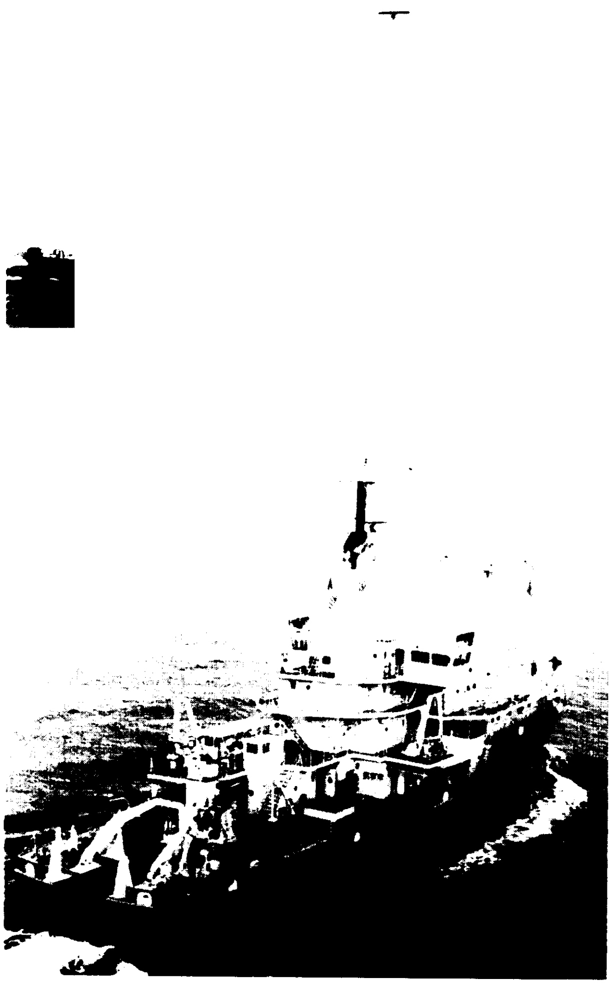


Photo credit .Skwpps Institution of Oceanography

Two of the larger, deep-ocean ships of the Academic Fleet are the *At/antis //* (top) from Woods Hole Oceanographic Institution and the *Me/vi//e* 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.

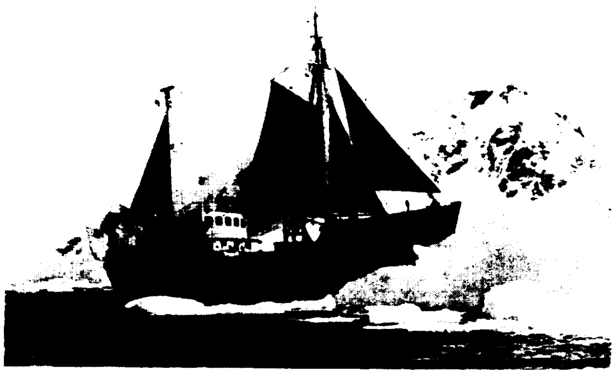


Photo credit Wm R Curtsinger

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

'Ha rbridge House, Inc. , "Eltanin Cost Analysis, " prepared for National Science Foundation. November 1979.

Phofo credft National Sc/ence 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

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.

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.

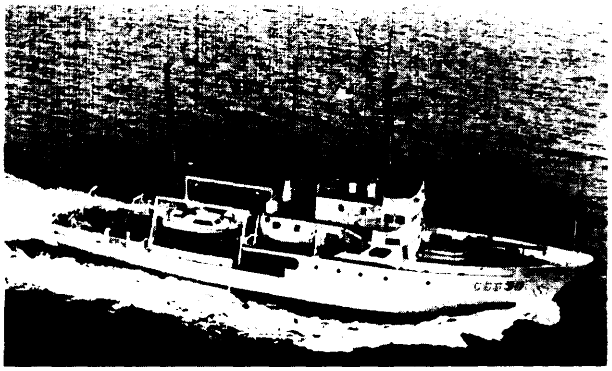
NOAA and Other Agency Fleet Plans

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 .%111 (1)', FY 81, FY 84, FY 88*, prepared for NOAA, Office of Fleet Operations, contract No. NA-79-SAC600632, Aug. 23, 1979.



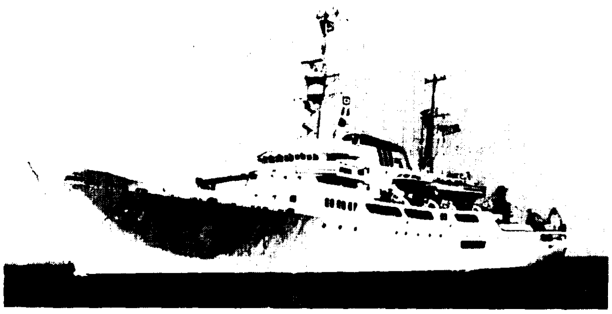


Photo credits Naf/orra/ Ocean/c arrd Atrnospher/c Adrnlrr/sfrat/on

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.

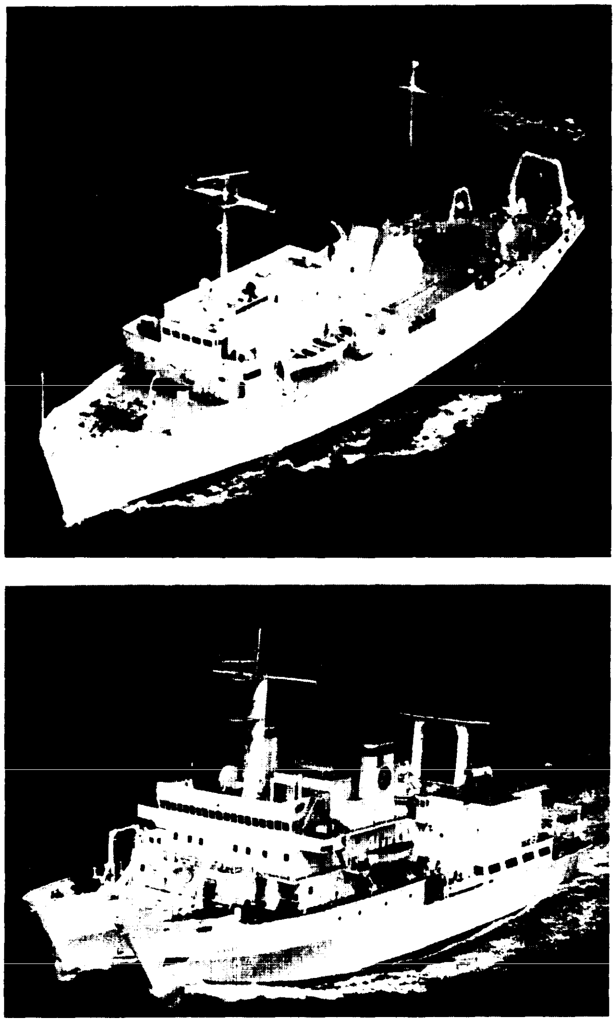


Photo credits. US, Navy

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.

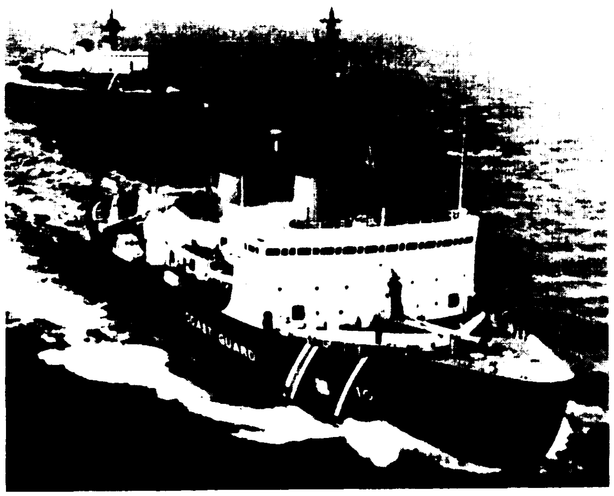


Photo credit U S Coast Guard

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 Oceanographic 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
UNIOLS								
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	—	—	—

aBy 1982

SOURCE Office of Technology Assessment

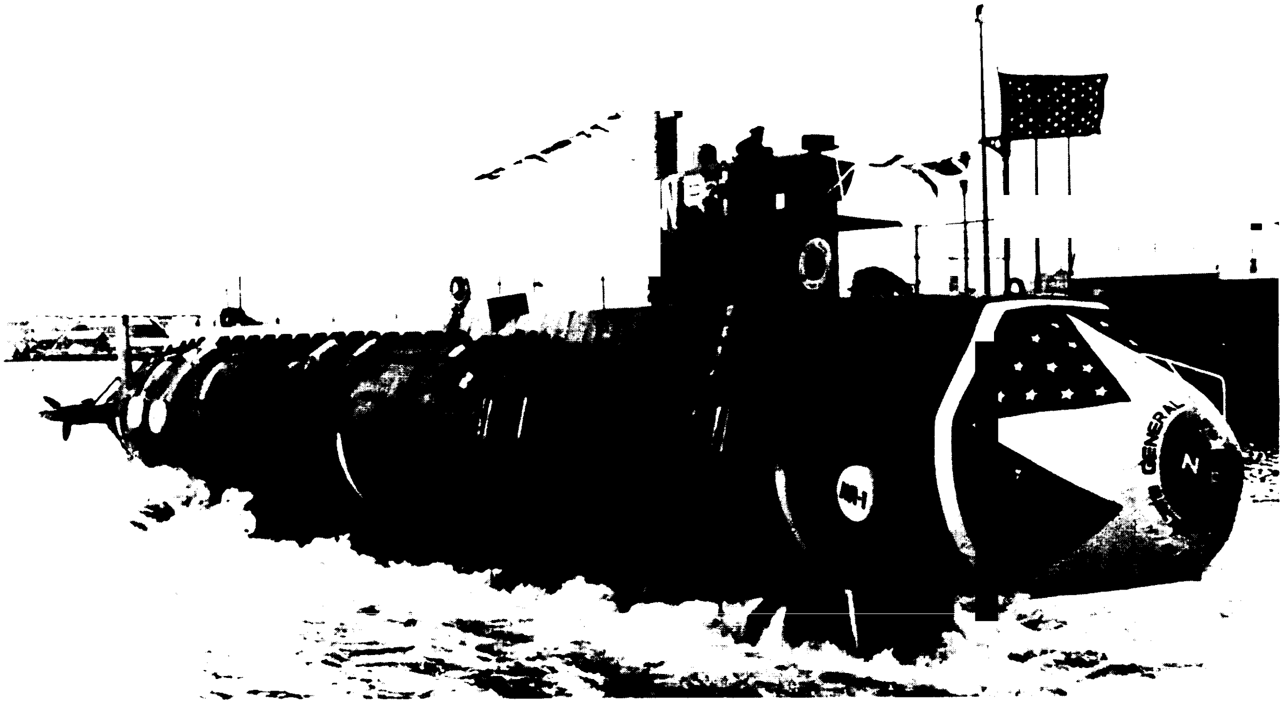


Photo credff U .S *Navy*

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

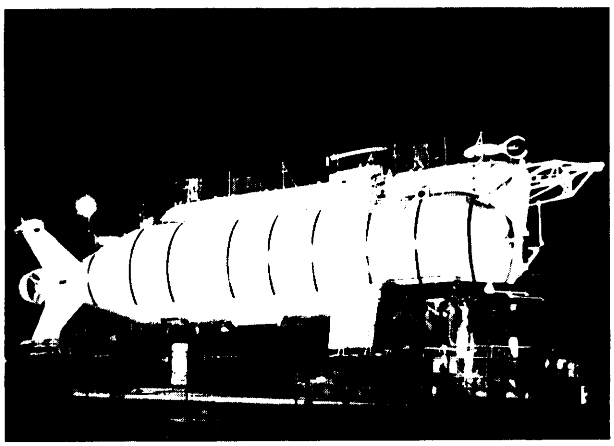


Photo credit U S Navy

Trieste II

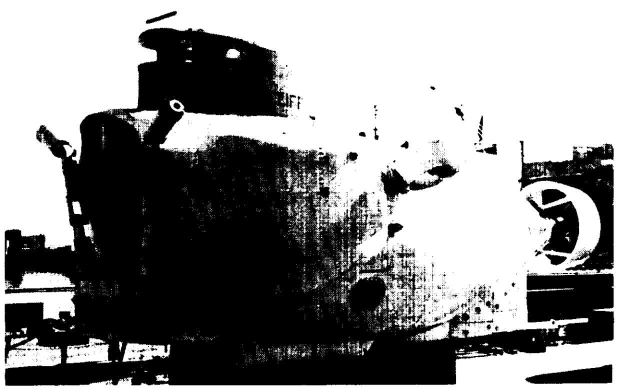


Photo credit U S Navy

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.

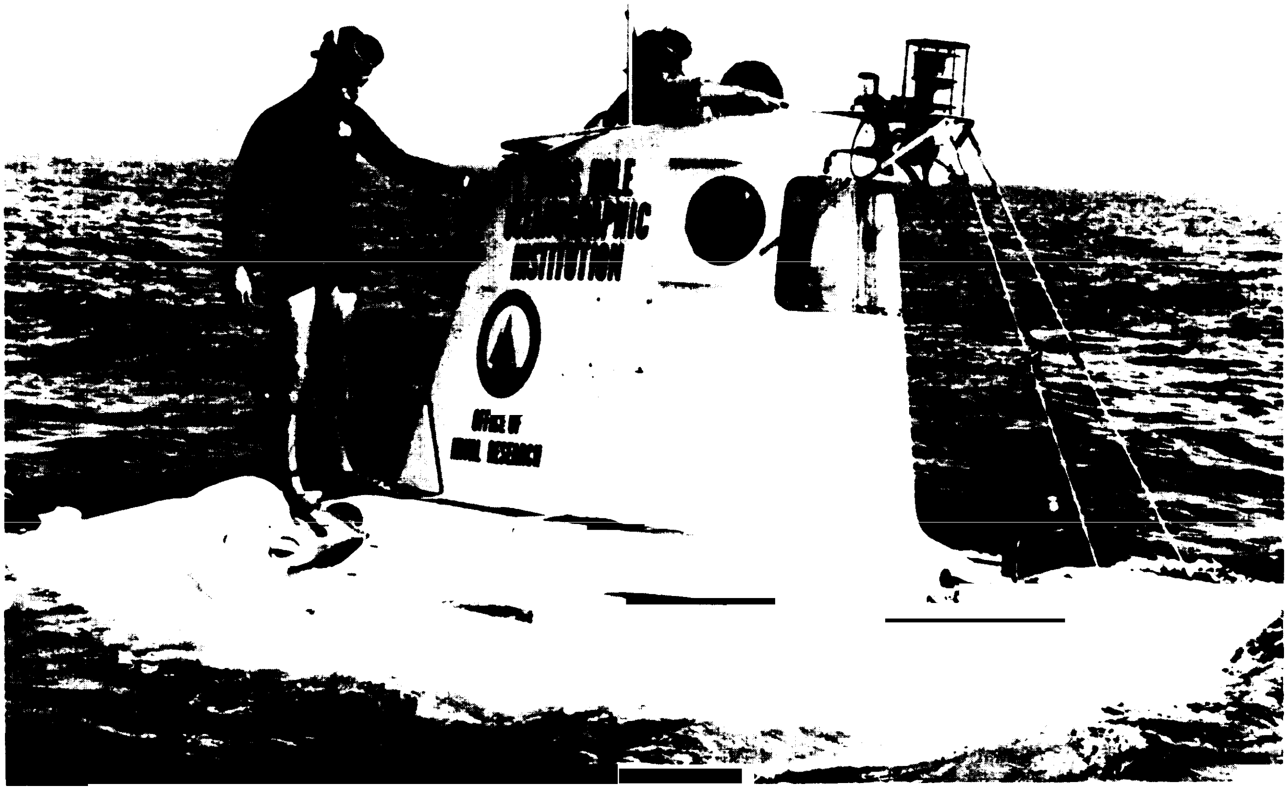


Photo credlf Woods Ho/e Oceanographic Institution

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

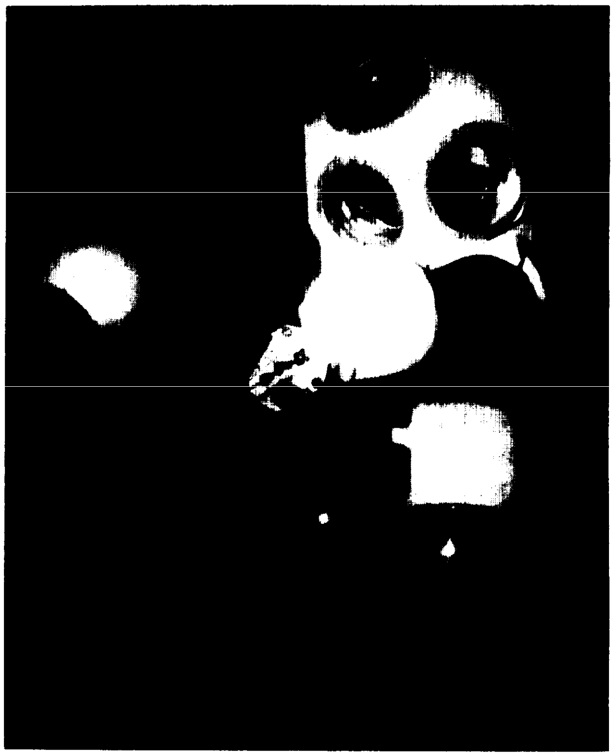


Photo credit National Oceanic and Atmospheric Adm/n/sfrat/on

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 Illa	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, Cal if.
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, Cal if.
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&llb	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, Cal if.
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, Cal if.
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]Telhered
[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 Monitoring Survey Diver assistance Search/identification Installation/retrieval Cleaning	Inspection Search/identification Installation/retrieval	Inspection Survey Installation/retrieval
Towed vehicles		
Survey	Search/identification/location Survey Fine-grained mapping Water sampling Radiation measurements	Geological/geophysical investigations Broad area reconnaissance Water analysis Biological/geological sampling Bioassay Manganese nodule survey
Untethered *vehicles*		
Iceberg measurements	Conductivity/temperature/pressure-profiling Wake turbulence measurements Under-ice acoustic profiling	Bathymetry Photography Arctic ice Underside roughness
Bottom-crawling vehicles		
Pipe trenching Cable burial Bulldozing Dredging Survey/inspection	None	Implanting ocean-floor instruments

SOURCE Office of Technology Assessment

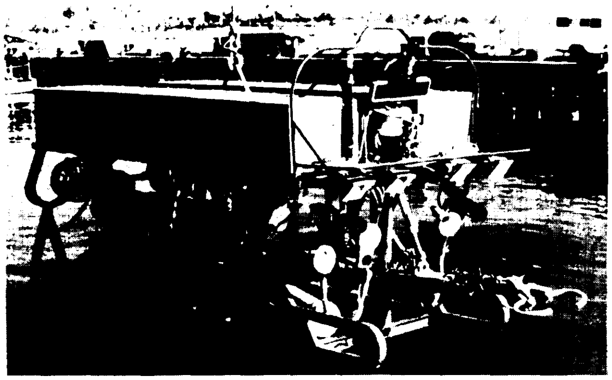


Photo credit U S Navy

Navy's tethered, free-swimming *CURV-III*

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 free-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 III	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 Office of Technology Assessment

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.

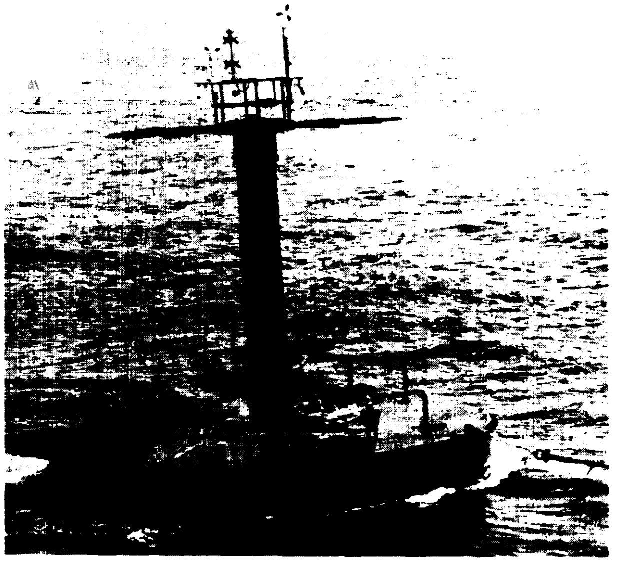


Photo credit General Dynamics

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, multi-buoy 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-

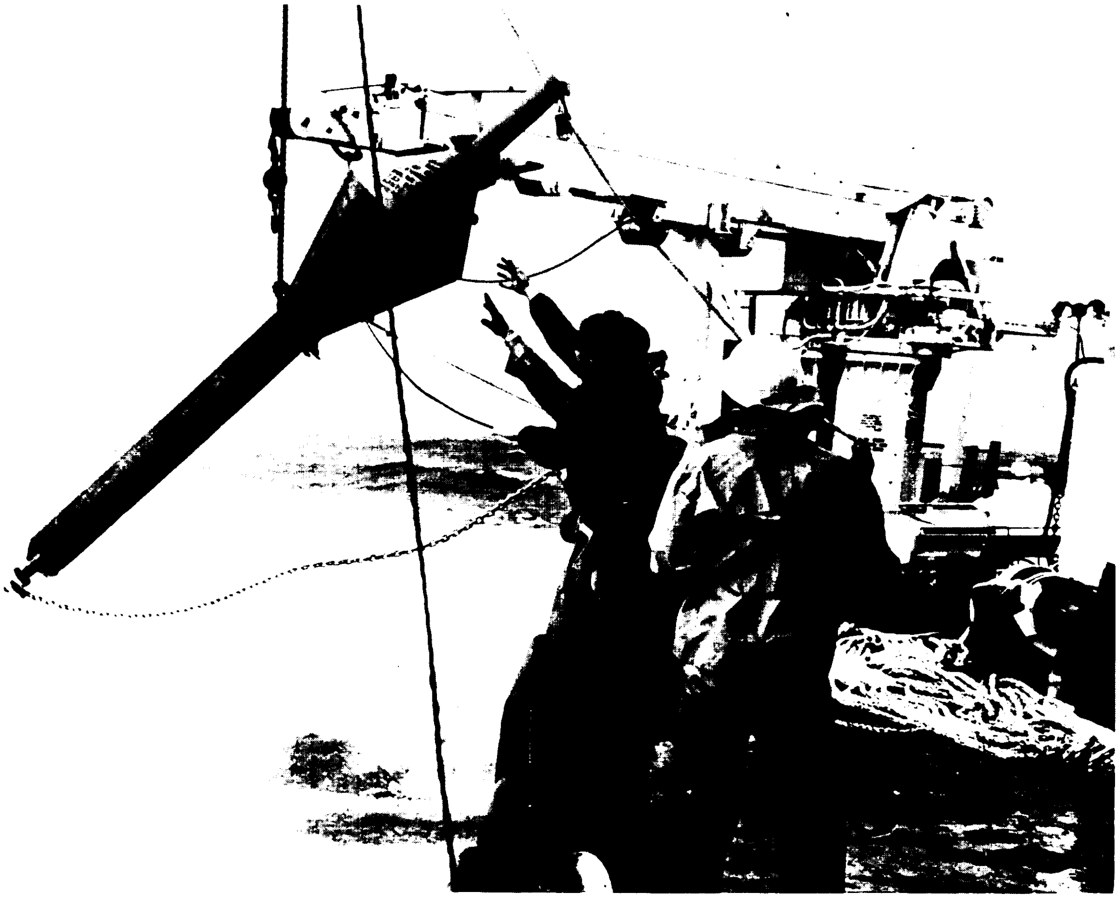


Photo credit Peter Wiebe, Woods Ho/e Oceanographic Institution

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

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[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.

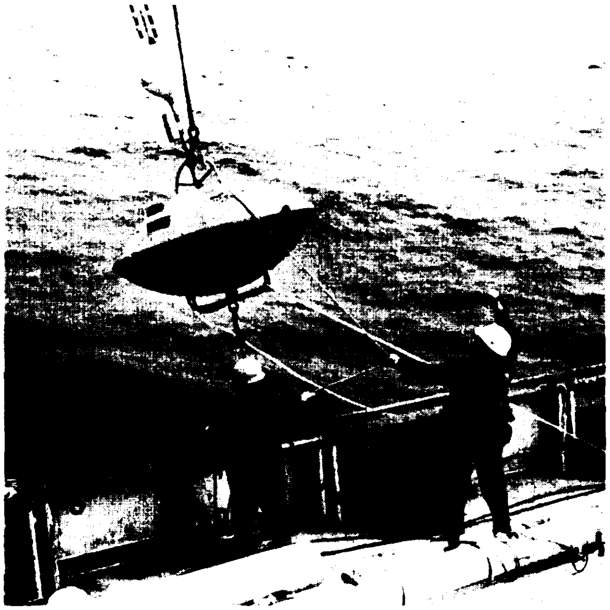
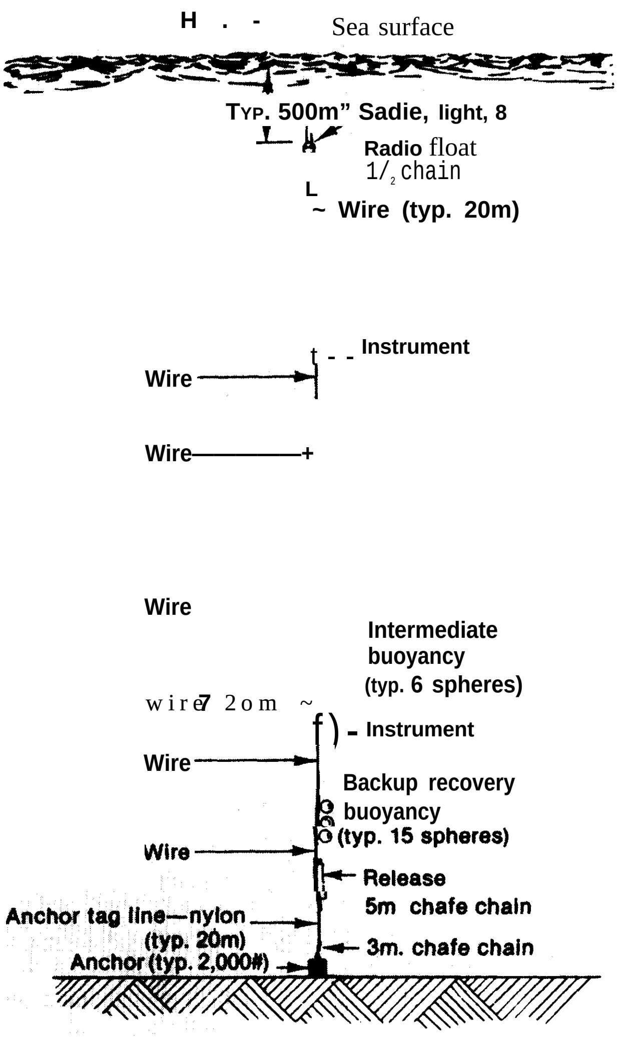


Photo credif Woods Ho/e Oceanography /nstItuflon

Mooring buoy being launched

Figure 6.— Intermediate Mooring



SOURCE: Woods Hole Oceanographic Instltutlon

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 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).

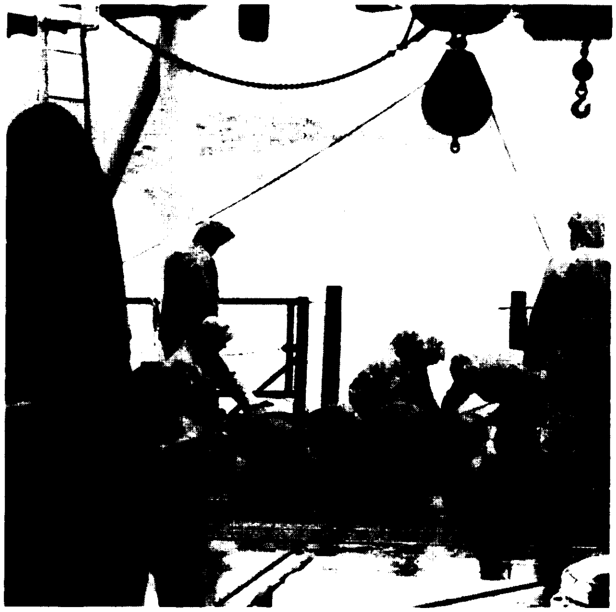
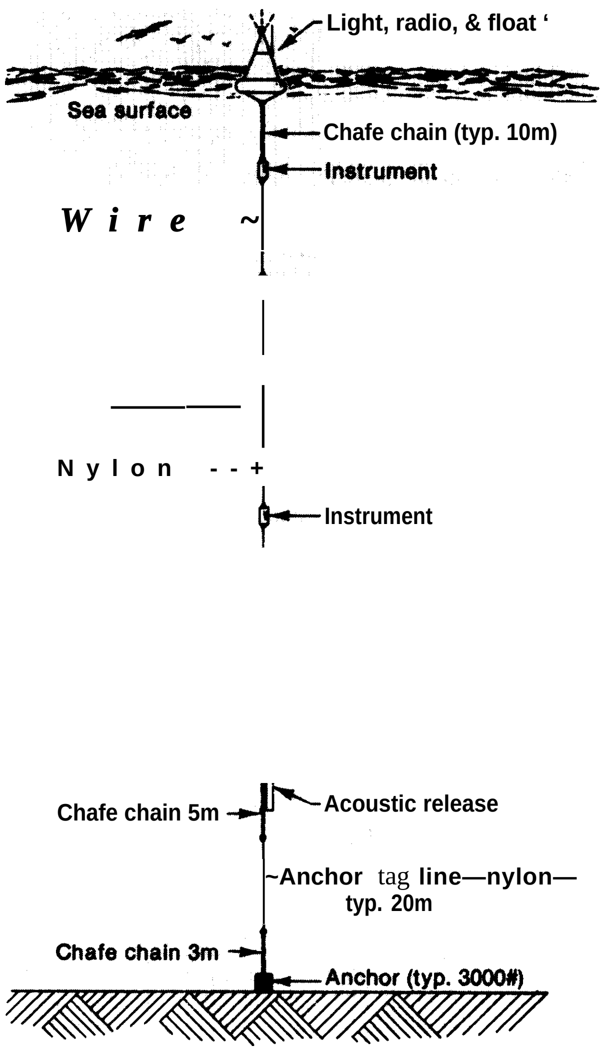


Photo credit Woods Hole Oceanographic Institution

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.

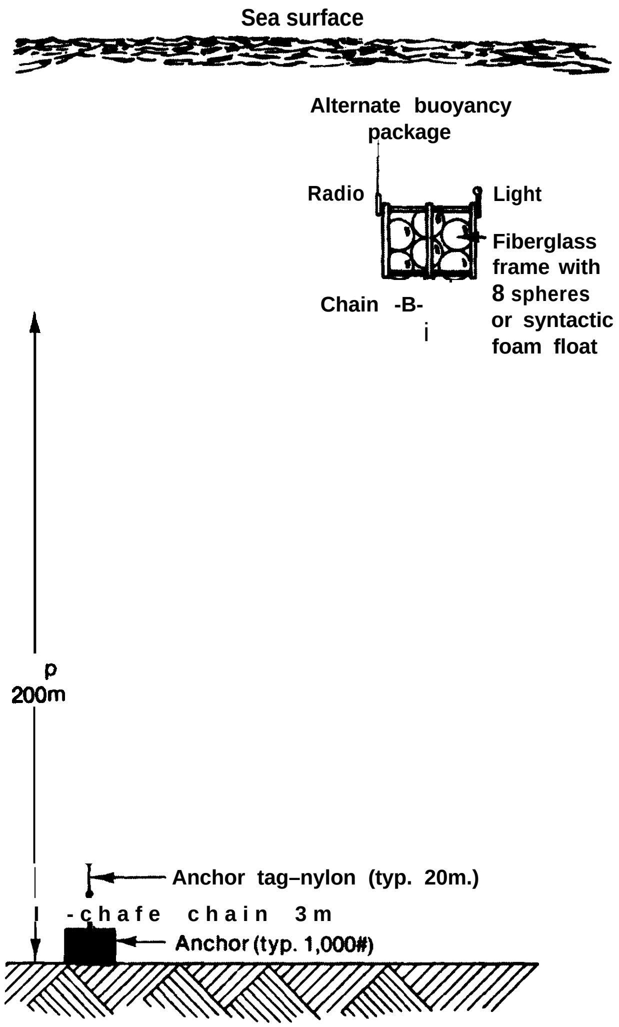
Acoustic release became a key item as soon as it was confirmed that the subsurface moorings were significantly more reliable. The timed releases and weak links used earlier were adequate as long as mooring durations were short; but with longer and longer mooring durations being dictated by program needs 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,

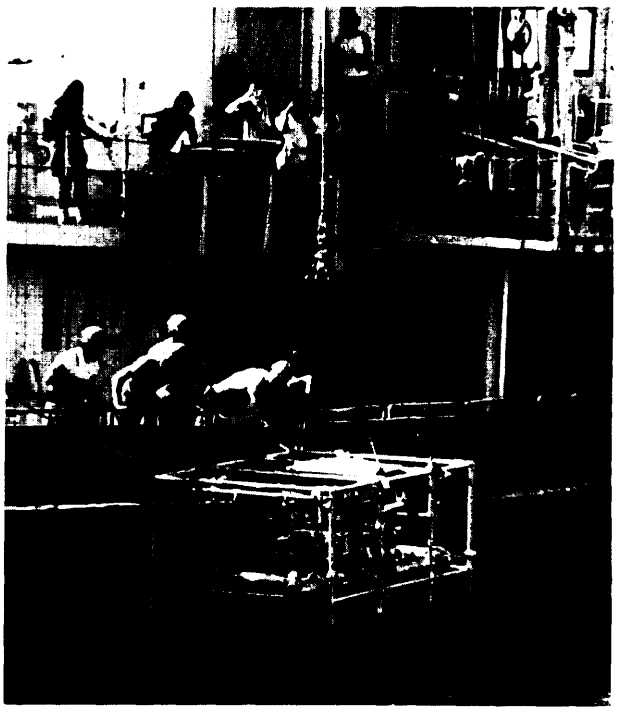


Photo credit Woods Ho/e Oceanographic /nst/fut/on

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.

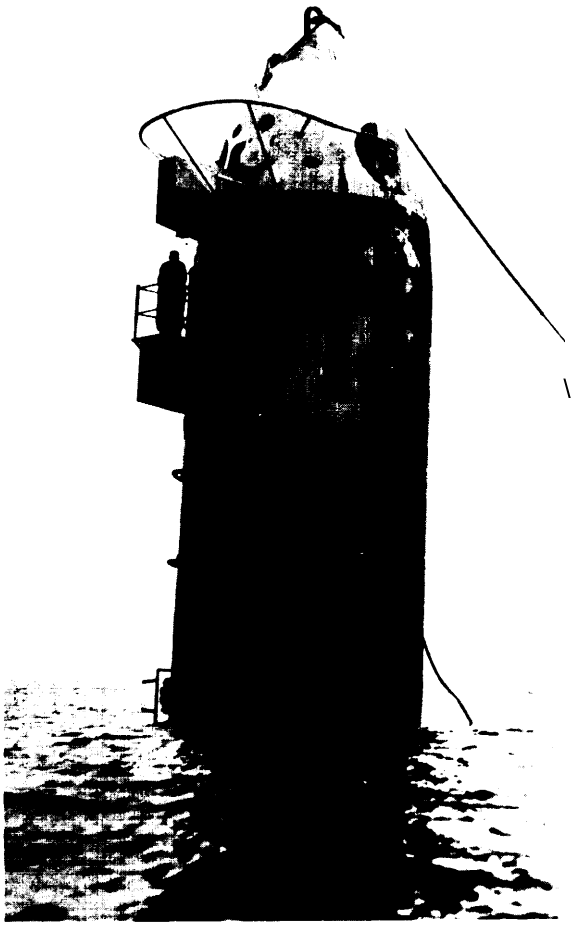


Photo credjt U S Navy

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

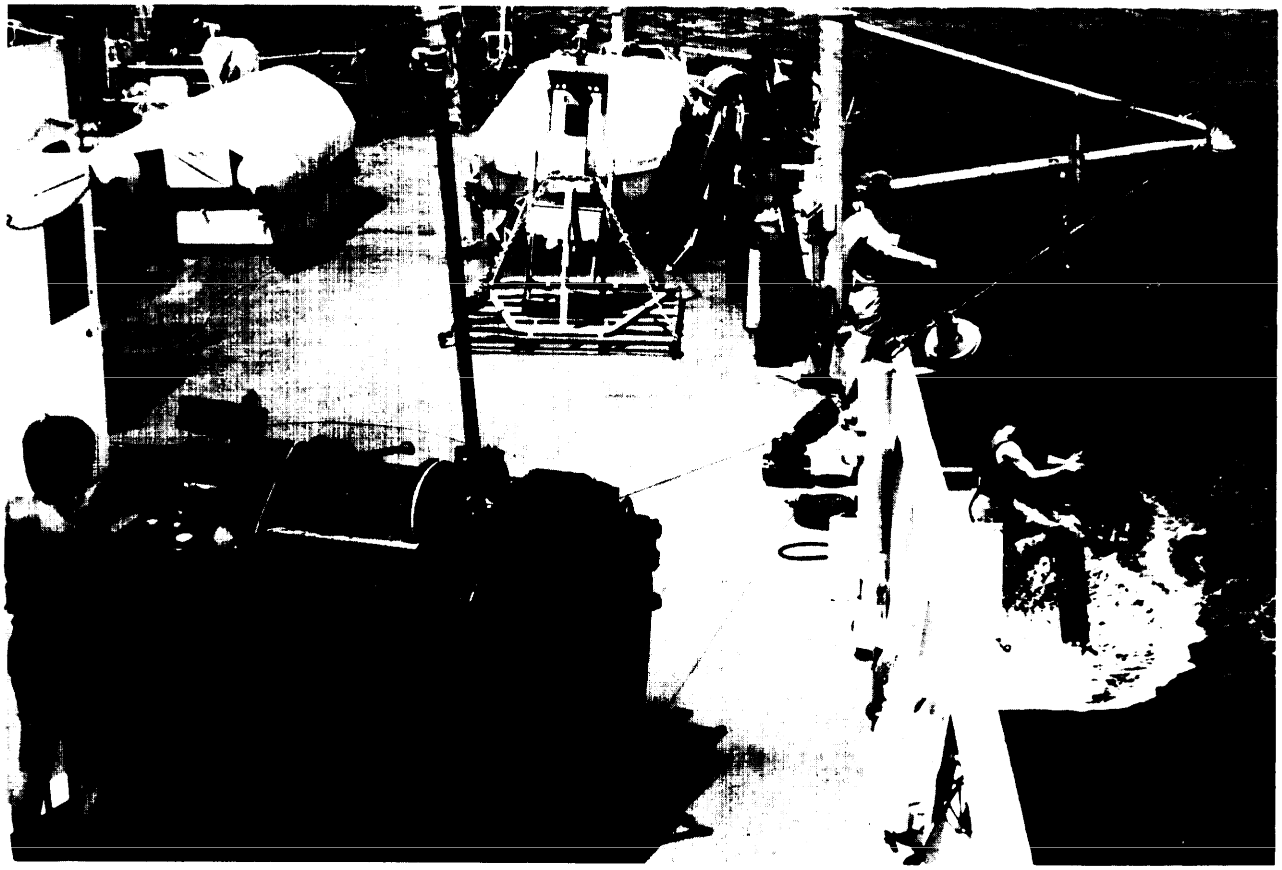


Photo **credit National** *Oceanic and Atrnospher/c Administration*

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.

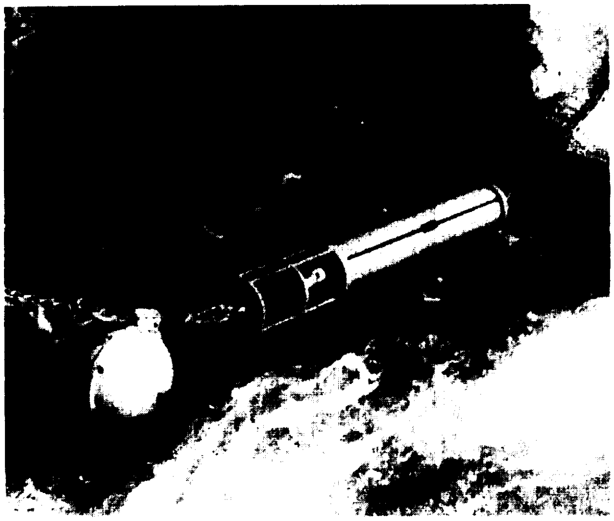
Instruments and Related Hardware

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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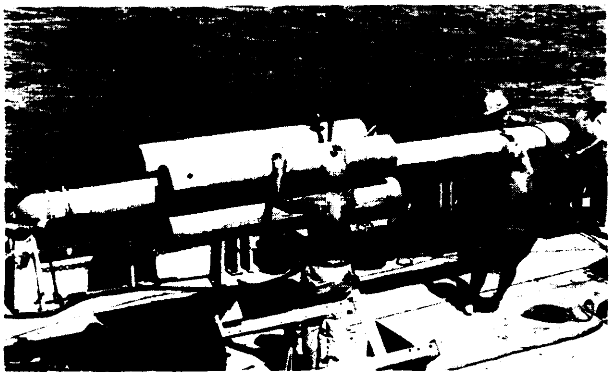
Neutrally Buoyant Floats. –Neutrally buoyant floats are special versions of current meters which are launched into the ocean to drift with the currents and are then tracked by a surface ship. Measurement of currents by the use of floats requires sophisticated methods of tracking the floats. The great 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 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.

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

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-I 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			I-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.	I-5km	I-5km	I-5km	weekly
	Leads	50cm	25m	25m	25m	2-4/d
	Icebergs	IOcm	I-50m	I-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]

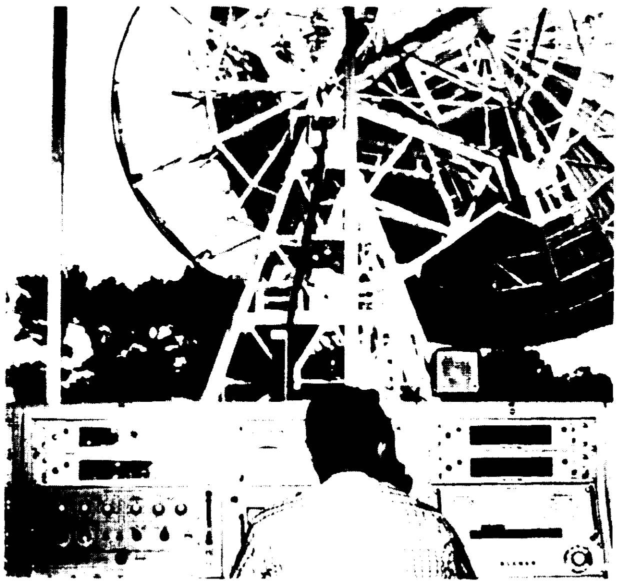

Photo credit Nat/onal Ocearrlc and Atmospheric Administration

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, *A n 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
VISSR	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
MSS.	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,

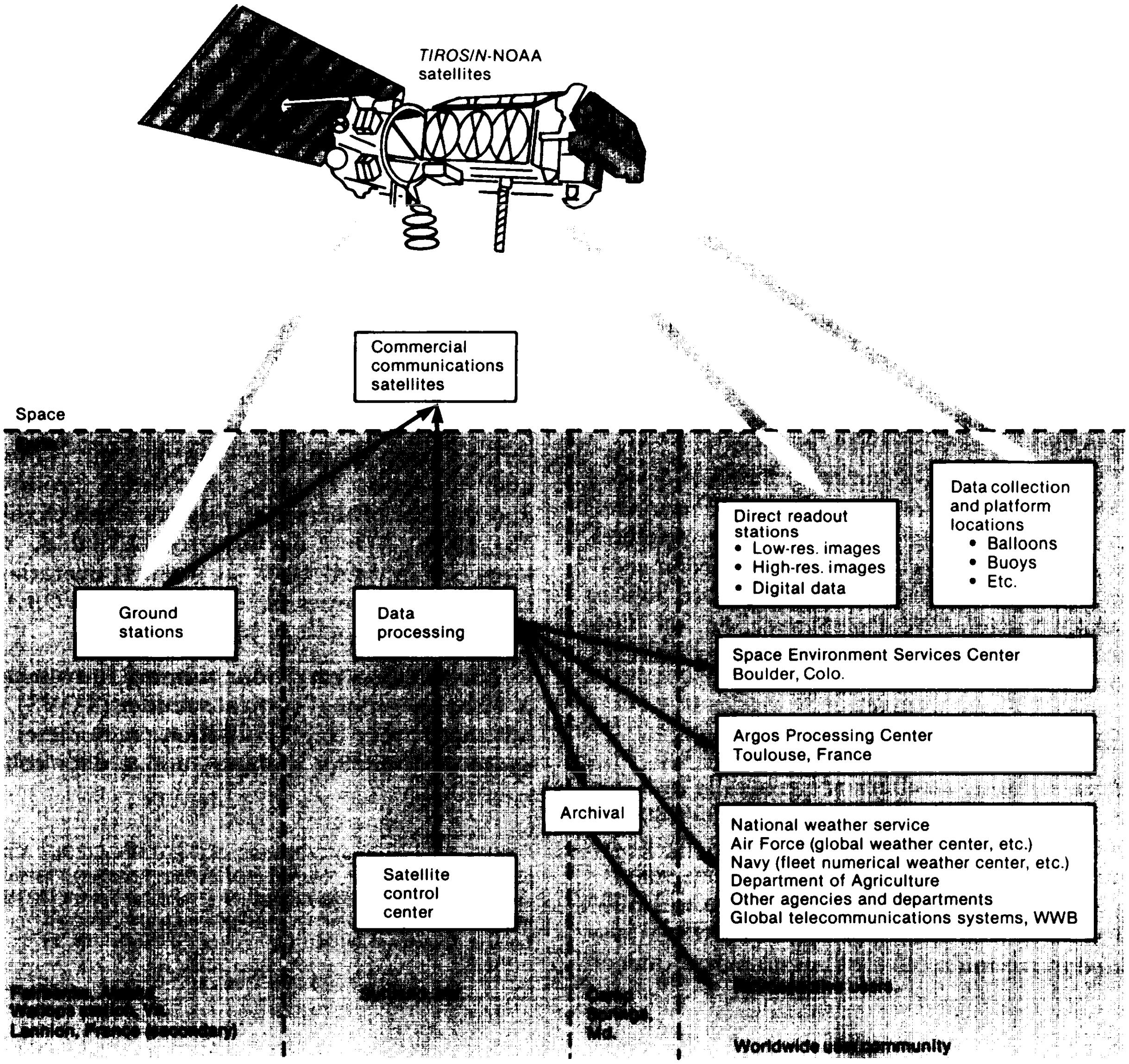
[33]Ibid.

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

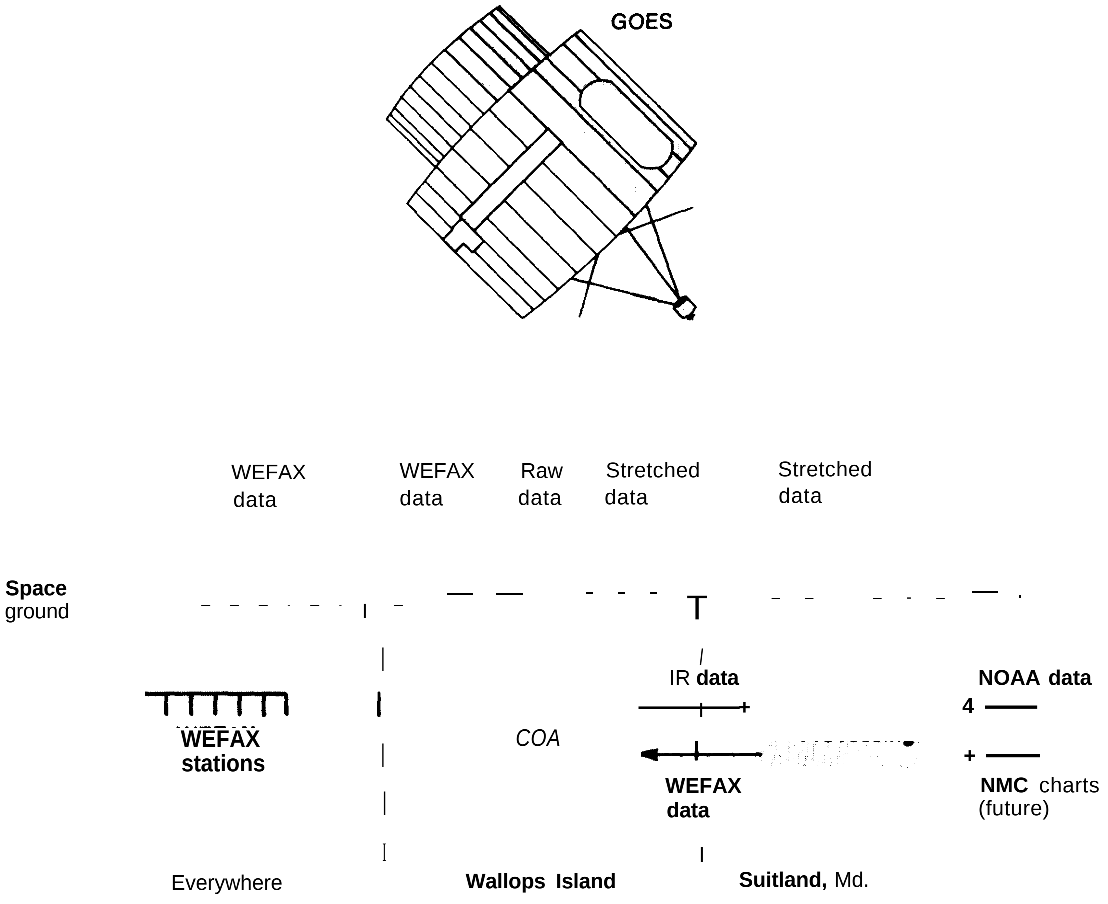
Because of the extremely large volume of digital data delivered by these satellites, it was necessary to install a new ground system which was completed in June 1978. The system is functionally divided into two subsystems called the Data Acquisition and Control Subsystem (DACS) and the Data Processing 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.

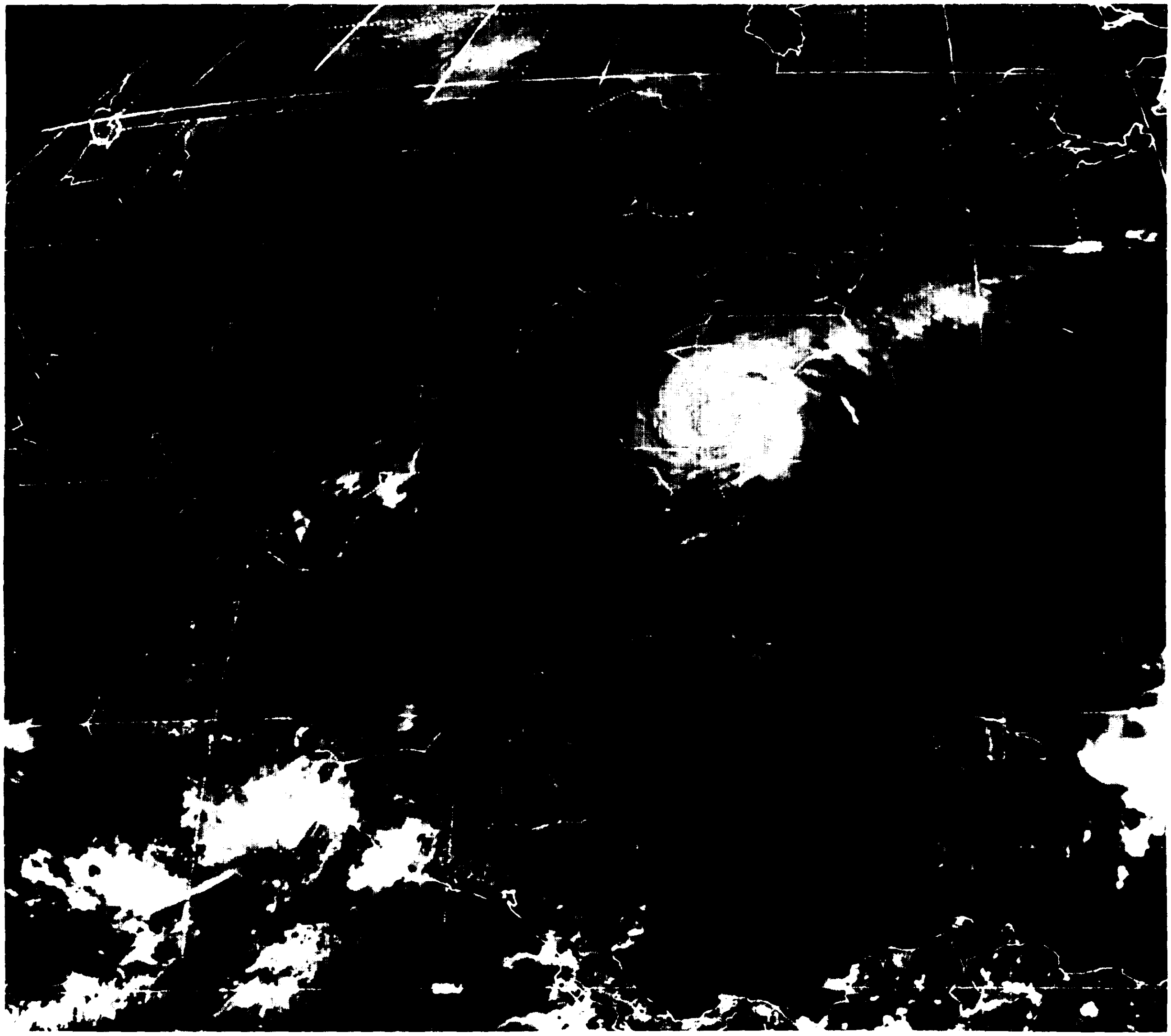
SMS/GOES satellites also carry a space environment monitor for observing solar radiation and the Earth's magnetic field and a data-collection system for collecting and relaying environmental data from remote observing platforms on the Earth's surface. Such sensing devices include river and rain gages, 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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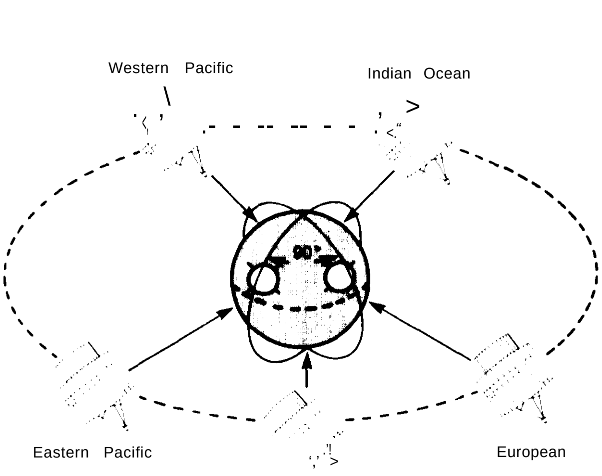
Recent Satellite Developments

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 Administration

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.

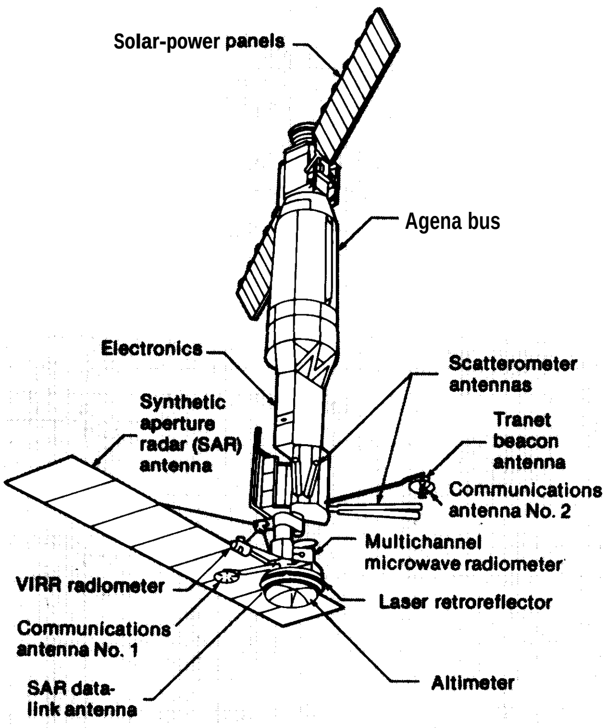
Two major surface experiments were conducted during the mission. The first of these was the multinational Joint Air-Sea Interaction Experiment (JASIN), which was conducted in the eastern Atlantic near Scotland. Planned and conducted by a group of European and American scientists, JASIN was an intensive 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 Dumping 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]

- *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 pro-

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

9(3-710 0 - 81 - 8

grams 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 com**puterized 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.

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[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.