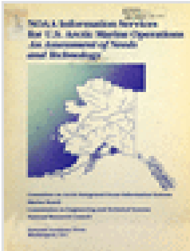

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NOAA INFORMATION SERVICES FOR U.S. ARCTIC MARINE OPERATIONS: AN ASSESSMENT OF NEEDS AND TECHNOLOGY

Committee on Arctic Integrated Ocean
Information Systems
Marine Board
Commission on Engineering and Technical Systems
National Research Council

NATIONAL ACADEMY PRESS
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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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COMMITTEE ON ARCTIC INTEGRATED OCEAN INFORMATION SYSTEMS

James A. Rickard, Chairman
Sohio Petroleum Company
Houston, Texas

Vera Alexander
University of Alaska
Fairbanks, Alaska

Roger G. Barry
University of Colorado
Boulder, Colorado

Donald E. Bevan
University of Washington
Seattle, Washington

Warren W. Denner
Scientific Applications
International Corporation
Monterey, California

William M. Evans
ARCO Resources Technology
Dallas, Texas

René O. Ramseier
Ice Centre, Environment Canada
Ottawa, Ontario, Canada

Richard P. Voelker
ARCTEC
Columbia, Maryland

Staff

Donald W. Perkins
Associate Director for Planning

PREFACE

Alaska's arctic seas and coasts are a focus of interest to the engineer and scientist who must know and use the latest technology to develop and protect resources in the nation's largest and most environmentally challenging frontier. Since 1980, the need for information and data for engineering and research in the Arctic has been well identified in reports prepared by the National Research Council (1979, 1981a, 1981b, 1982, 1984, 1985).

The need for arctic oceanographic and meteorological data and information continues to increase, despite fluctuations in offshore oil and gas leasing activity. Indeed, long-term pressures to discover, develop, and transport nonliving and living resources continue. The following examples reflect the present pace of resource use and probable development:

- Based on known reserves, of every two barrels of oil extracted from United States oil fields, one is likely to be from Alaska. Such a likelihood accentuates the urgency to further develop Alaska's oil fields because of the rapid depletion of the Prudhoe Bay Field, which now supplies 17 percent of U.S. domestic oil production (i.e., 1.5 million barrels per day [U.S. Department of the Interior, 1985)]. Oil must be found beneath Alaska's Outer Continental Shelf if the nation's domestic supply is to be maintained.
- The Bering Sea fisheries' allowable catch in 1984 was set at 2 million metric tons, and accounted for 40 percent of all fish caught within the 200-mile Exclusive Economic Zone (EEZ) of the United States.

Local coastal inhabitants also have increasing needs for environmental data services to support planning and operations in a harsh and rapidly changeable climate. There is an increasing reliance on air and sea transport of people and supplies, which often cannot overcome unexpected hazards, storms, and system failures in remote areas.

ORIGINS OF THE STUDY

In support of its ocean service responsibilities, the National Oceanic and Atmospheric Administration (NOAA) has made organizational changes and sought ways to enhance the quality and usefulness of its environmental data products. The arctic marine environment presents a uniquely difficult challenge to improving and changing the acquisition, processing, and dissemination of data. Moreover, user needs may be highly diffuse. Accordingly, at the request of NOAA, the Marine Board agreed in 1985 to undertake an assessment of the agency's environmental data that would provide the technical basis for government decisions regarding these activities in ocean areas off Alaska, particularly in arctic and ice-frequented waters.

STUDY SCOPE AND APPROACH

This report encompasses the Bering, Chukchi, and Beaufort seas--as well as the subarctic Prince William Sound and Cook Inlet where there is some seasonal sea ice. A committee was appointed to identify and assess various user needs for oceanographic and meteorological data and information services, available technology, and practices employed to respond to user needs. The technology assessed was to include remote-sensing systems, and data processing, interpretation, transmission, and dissemination. Deficiencies in information systems and processes were to be identified, along with research required to improve them and alternatives for integrating changes in existing systems.

The committee chose not to include information services involving geotechnical and seismic data acquisition. Given the assessment task, these technical areas are beyond key NOAA mission objectives--except for tsunami warning--and involve issues (e.g., national security) that extend beyond the main interests of providing arctic marine environmental data services on a real-time or rapid-access basis.

The role of private industries and services (sometimes known as "value-added" industries) and their relation to NOAA environmental services in the Arctic were not included in the committee's assessment. However, the report does note several technical problems that need to be resolved before basic information systems or data handling processes can be considered to be available to support value-added services. Judgments regarding benefits and problems associated with privatization of arctic environmental services are largely economic and public policy issues which are partially influenced by data and information system availability, reliability, and capital and operating costs.

COMMITTEE COMPOSITION

The committee consisted of experts in the areas of engineering and technical planning for arctic maritime operations, oil and gas exploration and production, fishery operations in the Bering Sea and the Gulf of Alaska, and support for scientific research of U.S. arctic coastal waters. The committee's expertise also included remote sensing and data analysis as well as meteorology.

ASSESSMENT APPROACH

The committee's study was based on presentations and information provided by technical and program administrators from NOAA, other government agencies, users of NOAA services, and technical personnel who provide the data acquisition systems and dissemination processes. Committee members provided documentation for review and assessment and met four times between April and December 1985.

ORGANIZATION OF REPORT

Following the Executive Summary, the report first addresses general data needs for major user groups: the government itself, offshore oil and gas developers, fisheries managers and fishermen, shipping and maritime operators, and scientists who investigate the vast marine areas off Alaska. Chapter 2 addresses available technology and deficiencies that need to be eliminated or reduced by further development or research. The conclusions and recommendations of the committee are contained in Chapter 3.

CONTENTS

EXECUTIVE SUMMARY

This study addresses the special needs for oceanographic and meteorological data and information services for Alaska's arctic and subarctic ocean areas: the Beaufort, Chukchi, and Bering seas, and areas where seasonal ice occurs in Cook Inlet and Prince William Sound. These oceanic regions are rich in fisheries resources--about 40 percent of the total U.S. allowable catch--and have long-term potential for oil and gas development--possibly over half of the U.S. Outer Continental Shelf resources.

The National Oceanic and Atmospheric Administration (NOAA) is faced with expensive and sometimes difficult technical choices in providing environmental data and information services to remote and sparsely settled arctic marine and coastal areas. To assist in its planning for the enhancement of present services and future improvements, NOAA requested that the National Research Council conduct a study, under the auspices of the Marine Board, to identify the major user needs and to assess the technical means of responding to these needs. The Committee on Arctic Integrated Ocean Information Systems was appointed to conduct this assessment.

The needs of arctic marine users addressed by the study were broadly perceived to be for those services that enhance productivity and safety. NOAA arctic activities include weather forecasts and storm warnings; environmental satellite operations, data archiving, and data dissemination and exchange; and management of fishery resources. Users of data and services include federal (primarily NOAA, U.S. Navy, U.S. Coast Guard, and Minerals Management Service), state, and local governments; industry (oil and gas, fishing, mining, and maritime); and research organizations.

Many of the issues confronting NOAA with regard to environmental services supporting operations and research in U.S. arctic and subarctic marine areas are also concerns common to much of the nation: making optimum use of the government's present and pending investment in meteorological satellite systems, integrating data processing to use the special capabilities of the major agencies that provide data (e.g., Navy, Air Force, and NOAA), providing adequate validation of satellite data, integrating both earth-based and satellite data, and determining what long-term data should be acquired and archived.

What makes these concerns special, in the arctic and subarctic context, are the environmental conditions which are characterized by:

- winter darkness, fog, and summer clouds, which often occlude visual observation and high-resolution satellite-borne sensors;
- ice movement, which can threaten coastal communities and facilities, endanger fishing operations, and halt or hinder seasonal shipping;
- arctic lows and rapidly developing storms, which are seldom detectable in their early development from satellite observations; few commercial vessels transit these areas even in the open water season, and no other surface-based sensors exist to provide data for real-time forecasting;
- rich fisheries and an abundance of marine mammals, which occupy the subarctic Bering Sea and northern Gulf of Alaska; as prey and predators, both fish and mammals are intricately related in fisheries management policy as well as in protection of threatened or important sea life;
- expensive and often difficult accessibility to arctic areas for research and for making ground measurements to validate satellite data.

NOAA SERVICES: ASSESSMENT AND RECOMMENDATIONS

In general, NOAA's products and services satisfy current government and industry needs. However, there are deficiencies in forecasting and data dissemination systems, and problems are expected in the future as new satellites come on line. The most critical need is that of planning for the processing and utilization of the huge volumes of data that will be acquired by satellites scheduled to be launched in the next decade.

As discussed below, the common problems of lack of basic data and poor access to data affect three general areas: forecasting, data management, and fisheries management.

1. Oceanographic and Meteorological Forecasting Improvements are needed in forecasting and warning capability concerning small-scale severe weather, rapidly developing low-pressure systems, and tsunamis. Since there is little commercial ship traffic in the eastern Bering Sea, the opportunities to obtain meteorological observations from ships are minimal and irregular. Except for one buoy in the Bering Sea (Navarin Basin), there are no continuous sea-surface weather observation buoys. The committee recommends increasing frequency and density of ocean and weather observations by encouraging more reporting by fishing vessels (foreign and domestic), using automated shipboard reporting units (e.g., "black boxes"); and using ocean data buoys.

This report questions the validity of existing numerical models used for environmental forecasting north of the Aleutian Islands, because the models in use were designed for mid-latitudes, not high latitudes. The committee recommends that models be developed to account for arctic parameters.

The committee notes inadequate real-time capability in monitoring and forecasting ice edge and ice cover movement. Ice movement is tracked by satellite, with some aerial reconnaissance of critical areas. The two principal platforms used are NASA's NIMBUS-7 scanning multichannel microwave radiometer (SMMR) and NOAA's advanced very high resolution radiometer (AVHRR). The SMMR has low resolution (25 km) but can see through cloud cover; AVHRR has very high resolution (1.1 km) but cannot penetrate clouds. Inadequate digital processing capability has resulted in underutilization of SMMR data for strategic ice monitoring.

Synthetic aperture radar (SAR) data from the European Space Agency Remote Sensing Satellite (ERS-1), scheduled to be launched in 1990, will provide both high resolution (25-40 m) and cloud penetration capability. The SAR sensors on ERS-1 and other new satellites have an extremely high data acquisition rate, which precludes on-board image processing. U.S. access to ERS-1's SAR data is dependent on establishing a receiving station at Fairbanks, which NASA plans to construct and the committee endorses. However, the committee notes that data are to be processed for research use, and it is not clear whether SAR data will be available on a real-time basis for operations and forecasting. The committee recommends that NOAA execute the necessary interagency planning to add this real-time capability.

2. **Data Management** Image processing must be combined with satellite and in situ numerical data to provide for optimum use of current and future satellites. Extracting numerical information from images (both SAR and AVHRR produce images) is difficult and is limited by lack of multifrequency systems. At present, no single microwave sensor is operational; the first will be the special sensor microwave imager (SSM/I) in late 1986. The committee recommends that funds and programs be directed to obtaining surface-based and airborne measurements to validate satellite sensor data and the algorithms used in processing them. Further, the committee recommends that NOAA operational and research elements develop appropriate hardware and software systems to combine satellite and surface-based data to optimize current and future sensor capabilities.

In assessing data-processing systems, the committee notes that poor accessibility of archival and new data presents immediate difficulties to users and is expected to be further complicated in the future by the archival needs of more sophisticated satellite systems. Currently, users often must contact different offices or operations to obtain data that may be archived separately by source (sensor platform), discipline, or type (e.g., climate, ice). The archiving of historical data is not integrated. The committee recommends upgrading data processing and dissemination systems for future and archival data, and developing systems to integrate satellite and surface-based data.

Despite initial planning, the committee expresses concern that the Department of Defense/NOAA Shared Processing Program will not meet its full-capability target date of 1988. The committee views NOAA's participation in this program as essential to optimum utilization of satellite capabilities and to improved ice, sea-surface, and meteorological forecasting and analysis, and recommends a firm long-term commitment to the program. The committee further recommends that routine exchange of data among the three Centers of Expertise (NOAA, Navy, Air Force) designated in the program be fully automated.

3. **Fisheries Management** NOAA accumulates and analyzes economic information from the fishing industry to ascertain the benefit of fisheries allocation, as required by the Fishery Conservation and Management Act of 1976. The committee concludes, however, that information needed to assess fish stocks and determine allocations to various fishing gear groups is limited. The committee further concludes that collection and validation of catch data and continuation of the domestic observer program cannot be adequately accomplished under present funding. Budgets will be further depleted by loss of fees due to reduced foreign fishing activity.

Short- to medium-range transport and water column structure prediction models are needed for fishery management and development. Lack of focused arctic environmental studies and limited time-series data have proved to be a major hindrance to development of models. Sea-surface thermal analyses, which have been conducted in other regions, are lacking for the eastern Bering Sea and northern Gulf of Alaska. Oceanographic research to establish key baseline data is inadequate. The committee recommends that adequate fisheries data collection systems be developed for domestic fisheries in U.S. arctic and subarctic waters.

1

USER NEEDS AND PRESENT CAPABILITIES

INTRODUCTION

The following sections of this report identify and describe "user needs." It is important to recognize that these are not needs in the dictionary sense of being necessities or an imperative demand. Most user groups identified in this report have been operating in the Arctic for many years without the benefit of many of the oceanographic, meteorological, and data analysis services now available. These people coped with the environment as they encountered it and managed to live with the unpredicted hazards, sometimes paying a price in property damage, injury, and even loss of life.

Improvements in technology have made possible the dissemination of more extensive and more accurate marine-related services, however. Users in the Arctic have benefited from these services and have learned to expect more of them. With continued improvements as new satellite remote-sensing systems are put in place, there will be an enormous growth in the information available to the people who live and work in the Arctic. To make the best use of these new data, systems necessary to process them, convert them to useful products, and disseminate them must be planned.

In rare cases, some law may require that specific oceanographic data be available for environmental enforcement. More often, however, enforcement agencies have considerable latitude in writing regulations and considerable leeway in interpreting available environmental data. For example, if the Minerals Management Service of the Department of the Interior wants platforms to withstand a 100-year storm and has only a few years of data, it may employ statistical methods to extrapolate to 100 years. The methods used are considered quite reliable within limits but are necessarily conservative. Therefore, agencies are able to perform their missions even if their preceived needs are not met in many cases.

A user's appetite for environmental data is essentially open-ended. For example, those responsible for identifying and protecting endangered species will want to know first how many exist, then where they travel, what they eat, what predators exist, what affects breeding, etc. Each of these factors could be regarded as being data needs when actually they are data "wants" or "desires."

Because the history of technology has shown that technological advances have produced more and better environmental data, it may be misleading to speak of "needs" as imperatives. Rather, in this report the word "needs" means data that users are accustomed to receiving and relying upon, plus additional or better-quality data as a near-term improvement.

The committee recognizes that it is not feasible in this report to detail the individual datum or series of data needed by all users. Such a listing could take several volumes. The Fleet Numerical Oceanographic Center (FNOC) of the U.S. Navy, for example, is a single central forecast installation, which produces several hundred environmental products: a listing of its products generated by analyzing available satellite data is 14 pages long. Furthermore, significant increases in quantity and quality of data will result from new generations of satellites and automated systems. An attempt has been made, however, to identify user needs for oceanographic and meteorological data, available data services, deficiencies and problems with these services, and ways to improve them.

Finally, it should be noted that in addition to the government and industry users described in this report, the coastal inhabitants of the U.S. Arctic are also important users of environmental data. Inhabitants of this region north of the Aleutians are primarily Yupik and Inuit Eskimos. Because of their leadership role in local government and their increasing participation in research and development and industry, their environmental data requirements are similar to those of other major users. In addition, subsistence hunting and fishing are still important to indigenous peoples, and their coastal hunting and fishing grounds are exposed to impact by sea ice and storm surges. However, they need no longer face unpredicted hazards: meteorological and oceanographic forecasting and services now provide them new tools to cope with this hostile environment.

GOVERNMENT USERS

Federal, State, and Local Governments

Governments comprise the largest category of users of arctic environmental information (Figure 1-1). Their requirements stem from responsibilities that are usually--but not always--specified by legislation, and which may result in considerable overlap in applications for such data.

Some responsibilities are shared between two or more levels of government (e.g., environmental protection), while others reside with only one (e.g., defense and environmental forecasts). The type, frequency, quantity, quality, and format of required data depend upon the intended use.

State and local needs are not necessarily less sophisticated than federal needs, but generally information that satisfies federal requirements will satisfy all levels of government. For this reason, the following discussion will be confined to federal users of arctic

Government Agency or Function	Data Types							
	Meteorological Data	Meteorological Analysis	Meteorological Prediction	Meteorological Warnings	Oceanographic Data	Oceanographic Analysis	Oceanographic Prediction	Oceanographic Warnings
Federal Organizations								
NOAA	●	●	●	●	●	●	●	●
Minerals Management Service	●	●			●	●		
Navy	●	●	●	●	●	●	●	●
Coast Guard	●	●	●	●	●	●	●	●
U.S. Geological Survey	●				●			
Environmental Protection Agency	●	●			●	●		
Federal Emergency Mgmt Agency	●		●	●	●		●	
Federal Aviation Administration	●	●	●	●				
State, e.g.:								
Environmental Conservation Authorities	●	●	●	●	●	●	●	●
Fish & Game Commissions	●		●	●	●	●	●	●
Natural Resource Departmenta	●				●			
Transportation Departments	●			●	●			●
Health & Social Services	●			●	●			●
Emergency Services	●		●	●			●	●
Economic Development Authorities	●				●			
State Police	●		●	●	●			●
Education Departments	●		●	●	●			
Local, e.g.:								
Environmental Control	●	●	●	●	●	●	●	●
Fishery Councils	●		●	●	●	●	●	●
Coastal Zone Management Zones	●			●	●	●	●	●
Port & Harbor Authorities	●		●	●	●		●	●
Police	●		●	●	●		●	●
Economic Development & Planning	●		●	●	●	●		●
Communications—Press, TV, etc.	●	●	●	●	●			●

FIGURE 1-1 Federal, state, and local government needs for arctic environmental information.

meteorological and environmental data from the National Oceanic and Atmospheric Administration (NOAA).

National Oceanic and Atmospheric Administration

Among all federal users, NOAA is undoubtedly the largest single user of its own environmental data. Although the committee was not asked to advise NOAA on its own internal needs for arctic data, in the interest of covering all major federal users, NOAA was asked to provide a discussion of its own needs for the arctic environmental information that it generates.

A listing of NOAA's major components indicates the range and sophistication of its operations:

- National Ocean Service (NOS)--nautical charts, ocean and coastal resource management, oceanographic surveys and assessments;
- National Weather Service (NWS)--weather forecasting;
- National Marine Fisheries Service (NMFS)--data and information about conservation, management, and development of living resources;
- National Environmental Satellite, Data, and Information Service (NESDIS)--satellite-based data acquisition and analysis;
- Office of Oceanic and Atmospheric Research (OOAR).

The general activities and environmental data needs of these major components are described in more detail in Appendix A. (Further information about data and product requirements of various government agencies is found in a survey report prepared by the Jet Propulsion Laboratory, 1984.) The statutory basis for NOAA's authorized and mandated requirements are given in Appendix B.

Minerals Management Service (MMS)

The MMS (Department of the Interior) manages offshore resources of the federal government. Its responsibilities include the following functions that use NOAA-generated environmental data:

- Resource evaluation and environment assessment--environmental studies (as required by OCS Lands Act), preparation of environmental impact statements, biological monitoring and assessments, endangered species and marine sanctuary proposal reviews, oil spill trajectory analysis, environmental regulation development and review;
- Offshore lease sales and activities--oversight of offshore structures standards;
- Regulation, inspection, and enforcement--oversight of oil spill contingency plans.

To perform its mandated responsibilities, MMS needs data to calculate the effects of wind, waves, currents, and ice on offshore rigs and platforms.

MMS's data needs differ between the lease permit application period and the post-permit period. Offshore oil and gas leases are issued for 5 years, and sometimes 10 years, and involve extensive consulting with local and state government agencies, environmental action groups, industry, and the general public. Detailed environmental impact data are required before permits are issued. Even then, many environmental concerns and conflicts may be encountered, resulting in needs for more and better data after permits are issued, especially if a lease decision is appealed.

U.S. Navy

Navy activities are significantly affected by arctic weather and strongly influence the Navy's need for environmental data from NOAA. These activities include:

- research and development,
- fleet operations and planning,
- flight operations and planning (land and carrier based),
- amphibious landings,
- antisubmarine and antiaircraft operations,
- search and rescue,
- communications,
- intelligence.

Navy activities include surface, subsurface, and atmospheric investigations conducted in open water areas, along the marginal ice zone, and on the ice itself. Typical areas of research interest include acoustics, geophysics, oceanography, sea ice, and meteorology.

Fleet operations in arctic regions range from those involving only a few ships to exercises comprising up to three battle groups (aircraft carrier, escort submarines, and logistical support ships). Fleet operations requirements have much finer tolerance levels than those for commercial vessels. Carrier aircraft operations are particularly sensitive to environmental effects: visibility (fog/haze), cloud cover (ceiling height), and roll and pitch (wave height/swell) are critical parameters for the successful takeoff and landing of aircraft; wind and chill factors determine the topside staytime of flightdeck crews and change of personnel while the ship is under way. Icing is a particular problem when it appears on aircraft and on the superstructure of warships, affecting their stability. Submarines in distress must be able to locate polynyas and leads in a minimum amount of time. Finally, the performance of weapons and sensors in or near the ice is affected by environmental factors.

NOAA-acquired data validate and refine the Navy's own information about weather, wave heights, sea-surface temperature, and ice edge location produced by the Fleet Numerical Oceanography Center (FNOC) in Monterey, California. Navy environmental data products include acoustic analyses and forecasts, radar propagation analyses based on atmospheric refractive effects, and aviation support that is provided by the Naval Oceanographic Command Detachment, Adak, Alaska.

Support for naval analysis and operations is also provided by the Navy/NOAA Joint Ice Center (JIC) in Suitland, Maryland. Over 80 percent of the data used to derive ice edge location is obtained from satellites. Current analytical methods are labor intensive and do not fully utilize all available data due to the lack of a digital image processor for satellite data. The Navy and NOAA have identified the necessary digital imaging processor to exploit fully the data currently available and to ensure that the additional satellite data to be available in the next 5 years can be effectively utilized. Continued NOAA support is necessary to implement this important effort.

The Arctic Data Buoy Program provides data from buoys that accommodate a wide range of sensors, including pressure, temperature, and oceanographic measurements. The Navy has obligated funds to support this program and relies on continuing NOAA cooperative participation and funding support.

Other Navy initiatives to improve environmental support in the Arctic include measuring the ice by air (characterization and thickness), deploying sensors on the ice, compiling environmental guides and data bases in cooperation with NOAA and the Air Force, and improving high-latitude weather forecasts.

U.S. Coast Guard

Weather and sea conditions affect the full range of U.S. Coast Guard functions in the Arctic: development of vessel navigation and safety standards and regulations, dissemination of environmental information for protection of persons at sea, search and rescue operations, Exclusive Economic Zone (EEZ) fisheries and coastal law enforcement, and icebreaker operations. In support of these activities, the Coast Guard requires the following data and analysis:

- Ice information is required to identify federal anchorages and marine safety zones for vessels. Hourly meteorological, tidal, and ice information is needed for vessel traffic systems, such as the one in Prince William Sound.
- Wind and current speed and direction are used to monitor oil spills and develop prediction models. Offshore blowouts or oil spills with international implications (Soviet Union and Canada) may require special capabilities, such as spill tracking via satellite to determine ice drift and extent.
- Daily ocean current forecast, wind speed, wave conditions, and water and air temperatures are essential to operate search and rescue vessels and aircraft and to determine survival time for floundering vessels and seamen in the water.
- Remote-sensing information, water and air temperature, ice cover, and ocean color analysis in at least 3-day intervals are used for fisheries law enforcement.
- Ice information and forecasts are needed by the polar icebreaker fleet, which must respond to emergencies in the Bering and Chukchi seas and part of the Beaufort Sea in the summer and the Bering Sea southward in the winter. Until the POLAR Class icebreakers are stationed closer to the Bering Sea, however, they cannot respond to many emergencies there due to the mobilization time from Seattle (home port). Therefore, data needs exist only for the short durations that they are in the area.

Specific data needed for icebreaker operations are given in Table 1-1. These data are not all currently available, but they are projected to be available by the mid-1990s, assuming the ERS-1, Navy Remote Ocean Sensing System (NROSS), and Canada's RADARSAT missions are on schedule and real-time readout is available from Alaska.

TABLE 1-1 U.S. Coast Guard Sea Ice Reconnaissance Requirements Projected to Mid-1990s

				Observational Requirement Resolution				Product Delivery	
	Type of	Accuracy		Space		Frequency (days)		(time delay)	
Parameter	Observation	Desired	Minimum	Desired	Minimum	Desired	Minimim	Desired	Minimum
Thickness	Area average	0.2 m	1 m	50 m	1 km	daily	3	<3 hrs	<1 day
Boundary	Line position	1 km	10 km	1 km	10 km	daily	3	<3 hrs	<1 day
Concentration	% of area	5%	10%	1 km	10 km	daily	3	<3 hrs	<1 day
Motion	Point displacement	100 m per day	2 km per day	5 km	20 km	4/day	1	<3 hrs	<8 hrs
Ridging									
Density	Number/area	10%	25%	100 m	1 km	daily	3	<3 hrs	<1 day
Orientation	Orientation	10°	30°	NA	NA	daily	3	<3 hrs	<1 day
Height	Height sail/keel	1 m	2 m	NA	NA	daily	3	<3 hrs	<1 day
Ice type	% of area by type	5%	10%	1 km	10 km	daily	3	<3 hrs	<1 day
Leads									
Location	Line position	20 m	100 m	100 m	1 km	2/day	1	<3 hrs	<12 hrs
Orientation	Orientation	10°	30°	NA	NA	2/day	1	<3 hrs	<12 hrs
Floe position	Point location	20 m	100 m	20 m	100 m	4/day	1	<3 hrs	<12 hrs
Surface melting	% of area	5%	10%	50 m	1 km	daily	3	<3 hrs	<1 day
Snow cover	% of area	5%	10%	100 m	1 km	daily	3	<3 hrs	<1 day
	Thickness	0.2 m	0.5 m	50 m	1 km	daily	3	<3 hrs	<1 day

SOURCE: U.S. Coast Guard.

INDUSTRY USERS

Offshore Oil and Gas

Exploration, site assessment (economic evaluation), and production of Alaska's offshore oil and gas fields require marine-related data and services in support of operational planning, facilities and vessel design, weather and ice forecasting, and oil spill analysis.

Operational plans and decisions are based on "normal" weather and ocean conditions, i.e., other than extreme states. Conditions normal to this region are already extreme compared to the "lower 48" states, however, and require that the industry perform planning analyses to (1) predict downtime for various systems, vessels, and platforms, and (2) avoid over- and underdesign. Data most useful to these tasks are oceanographic and meteorological information in the form of bivariate analyses (e.g., wind and speed versus direction; wave height versus period), persistence statistics, presence and duration of ice, and historical data and time-series.

To determine design criteria for vessels and facilities, the oil and gas industry most often needs extreme values of wave and swell heights, periods, and direction; wind speeds and direction; storm surge; and current profiles. Statistics for these parameters under extreme conditions generally must be formulated from hindcasts of data from past storms (about 50) over the longest time available. The parameters (derived from archived weather maps and station listings) needed to prepare a hindcast model are:

- barometric pressure fields,
- air and sea-surface temperature,
- wind velocities,
- wave heights and periods (including swells),
- sea-ice distribution and concentration.

To calibrate the model, the industry requires time-series of the primary parameters during several severe storms, and must be confident that the time-series are of sufficient quality, length, and storm intensity, and cover suitable locations. The longest hindcast return interval calculated should not exceed 4 times the length of the data base (2 to 3 times is preferable). Since a common design criterion is the 100-year return interval, the data base must be at least 25 years long. Adequate data sets are rare. In many cases, the industry has conducted measurements specifically designed to verify and calibrate its own models.

The potential exists for enhancing the storm data base by adding data from a buoy that NOAA deployed in the Bering Sea in 1985 (with the assistance of the industry, which paid for refurbishing it), along with new satellite data, providing it is suitably archived.

Weather and ice forecasting are of particular importance to the industry, which uses private weather forecasting services whose data comes from NWS, supplemented with data from additional stations. Especially critical to oil and gas rigs and drilling operations are ice monitoring and forecasting data:

- type, distribution, and movement,
- sea-ice edge position,
- sizes and locations of floes and open water leads,
- height of ridges and depth of keels.

The industry is presently developing ice edge prediction models that will use these data along with the atmospheric and oceanographic parameters required for hindcast models. Most of the necessary ice data are gathered by satellite systems, which are discussed in greater detail in Chapter 2. In addition, ice atlases have been prepared based largely on previously published compilations of aerial ice reconnaissance observations and more recently on satellite observations. These data bases are limited, and it is recognized that they are not adequate to characterize Alaskan offshore ice conditions on a long-term basis. Consideration should be given to establishing automatic remote stations at key locations within the Bering and Chukchi seas' seasonal ice zones, such as Little Diomede, St. Lawrence, and St. Matthew islands (personal communication, Sea Ice Consultants, Inc., 1985).

Computer models are also used to analyze potential oil spill trajectories and impact sites. These models require the same information for verification, calibration, initialization, and updating as the other previously discussed models.

Coastal Mining

Coastal mining operations mostly involve gravel extraction and, to a lesser extent, extraction of heavy metals. Mining operations are limited and usually conducted in shallow water close to shore, which becomes fast ice during part of the year. These operations require marine-related data and services similar to the oil and gas industry needs, except for the data and information supporting spill analyses.

Marine Transportation and Ports

Except for the exploration and development of Alaska's oil fields, marine traffic and port activities have remained essentially unchanged during the last 20 years. Goods and materials for coastal communities have been successfully supplied by an open water tug-barge flotilla, with periodic support from ice-worthy vessels.

However, the addition of oil tanker traffic, north of the Aleutian Islands, would drastically change the traditional seasonal vessel movements to a year-round transportation system. Such a system would probably require construction of an offshore marine terminal and ice-capable ships. Potential routes for these ships (Figure 1-2) were identified by a National Petroleum Council study on arctic oil and gas (NPC, 1981).

Because seasonal open water tug-barge operations are significantly different from icebreaking ship operations, the need for NOAA-related services will expand in the 1990s. The decade of the 1990s would be

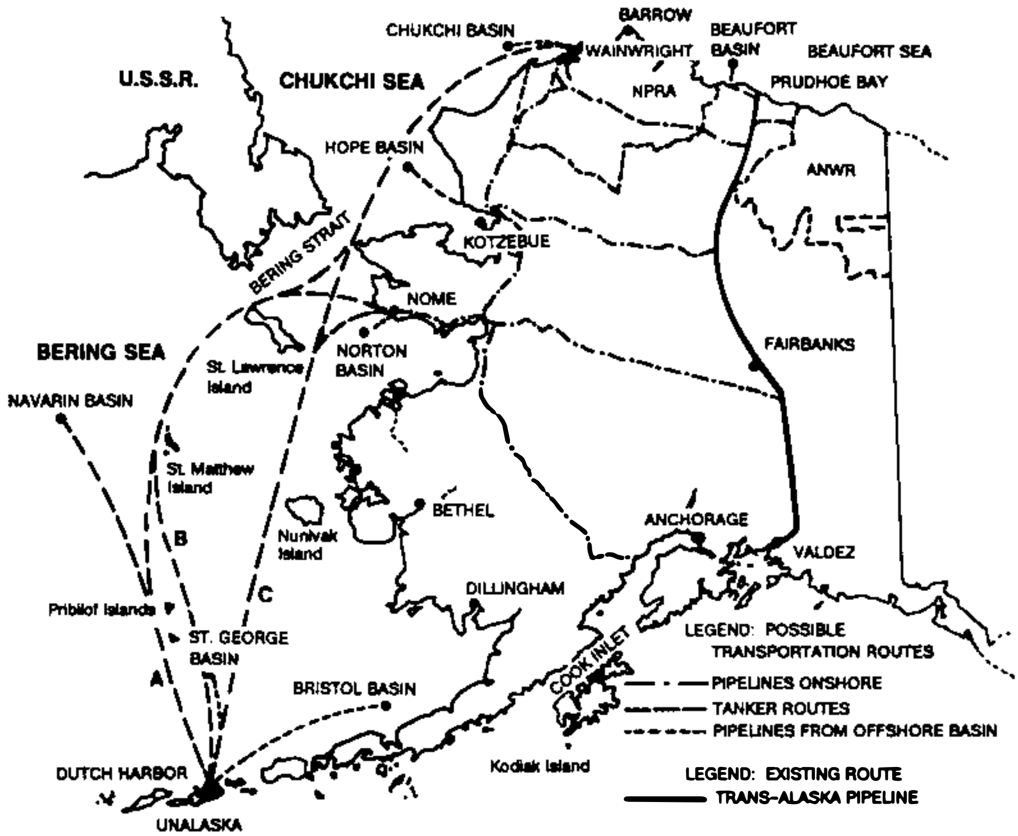

FIGURE 1-2 Possible arctic transportation routes. Source: NPC, 1981.

when icebreaking tankers could be expected to be operating. More specifically, offshore petroleum development scenarios project 7 to 10 years between discovery and production.

Current user requirements (1986 to 1990) are for (1) real-time data and products and (2) access to archival data and products of weather, sea, and ice conditions. In general, these NOAA-generated data and products have proven adequate for current marine transportation needs. For locations on the Bering Sea where oil drilling activities have been focused, extensive side-looking airborne radar flights have been used by industry to supplement NOAA data products.

Future user requirements (1990 to 2000) will probably require enhanced NOAA data and products. This need will be dictated by the fleet of ice-worthy ships that will have to navigate precisely through open water leads and areas of low ice resistance. Such capability will necessitate direct transmission of processed satellite ice imagery (SAR) from a ground station to an orbiting satellite for relay to the vessels. This new capability is termed "tactical navigation," whereas the current capability is best described as "strategic navigation." A summary of future requirements for marine transportation systems was given in Table 1-1, in the discussion of Coast Guard requirements.

The only operationally capable, ice-transiting ships presently operating in the Alaskan Arctic are U.S. Coast Guard icebreakers. Of the three classes of icebreakers in service, it is the more powerful POLAR Class that has supported almost exclusive operations in Alaska during the last 7 years. These icebreakers have a proven year-round capability in the Bering Sea and have made two mid-winter transits in the Chukchi Sea during the Maritime Administration's continuing, multi-year, trafficability program. The transits to the north Chukchi Sea were very successful, but demonstrated a number of concerns. Specifically, the operational capabilities were limited by fuel capacity and by a lack of tactical navigation equipment. Current satellite ice imagery (NOAA/AVHRR), although useful for strategic planning, is inadequate for tactical operations (Figure 1-3).

Although operational capability and needs of ice-transiting ships have only recently been determined through the Maritime Administration Trafficability Program, the general findings of the National Petroleum Council's 1981 report remain valid:

> There is very reasonable expectation that ice-capable vessels can be built, powered, and operated to maintain reliable year-round rateable* offtake from ports south of the Bering Strait. Year-round tanker operation to ports north of the Bering Strait can probably be established, but reliability is uncertain.

Port facilities north of the Aleutian Islands are almost non-existent. The present deepest draft facility in the area is located at Prudhoe Bay; it accommodates vessels of approximately 10 feet draft. A new causeway under construction at Nome will increase the port's vessel-draft capacity from 6 to 30 feet. Port facilities are inadequate to accommodate icebreaker tankers, should they be operated, and, as a result, special deepwater (60 feet and greater) marine terminals would have to be built further offshore.

Fisheries

The Bering Sea is one of the most productive fishery regions in the world. In 1984 the total allowable catch** from the U.S. Fishery

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*Rateable: sufficient operational and cost experience exist to allow the establishment of freight rates.

**The total allowable catch off the United States coast equals that taken and landed in the United States by U.S. fishermen, that caught by U.S. fishermen and landed on foreign processors, and that caught by foreign vessels.

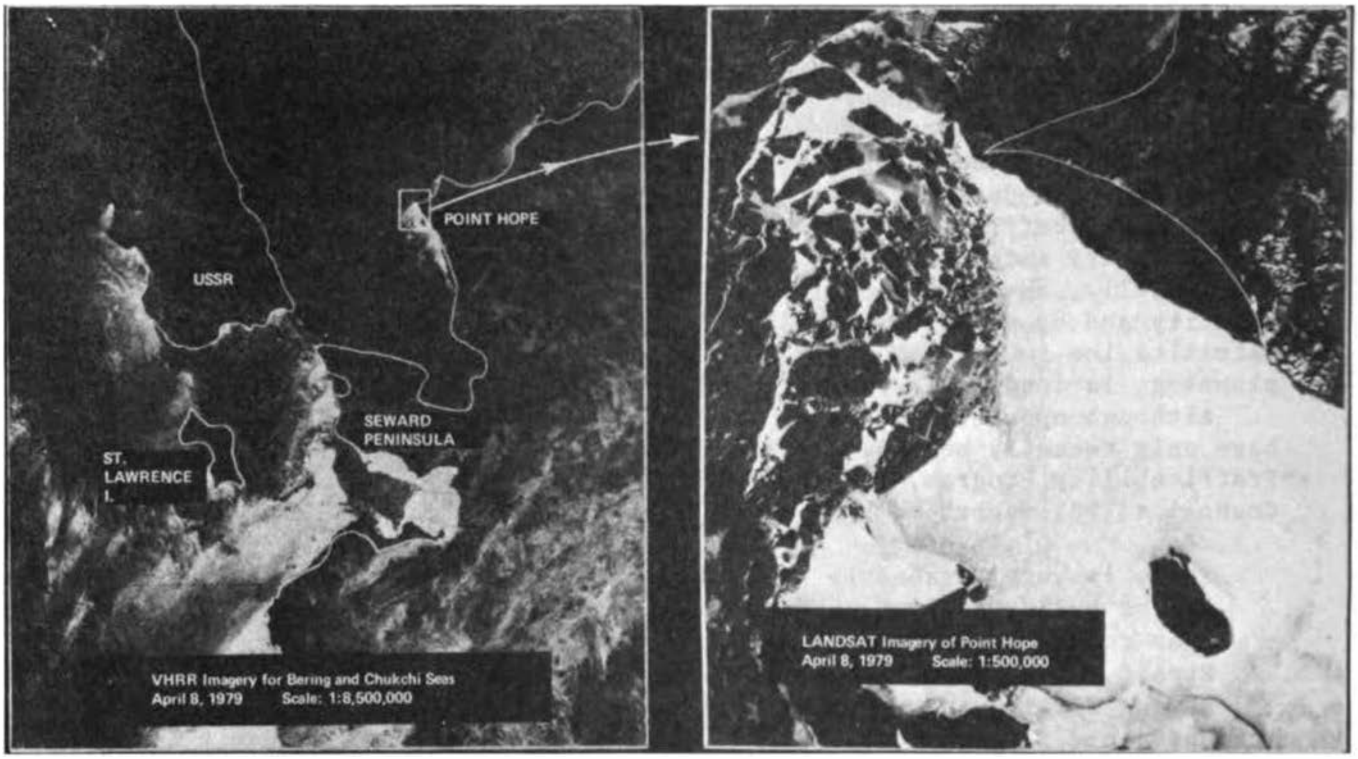

FIGURE 1-3 Comparison of current satellite ice imagery received aboard ships (left) to that desired (right). Although the Landsat data base is smaller than either the SMMR and AVHRR, Landsat has been more useful because of its better resolution. Several industry projects, sponsored by the Alaska Oil and Gas Association, have used Landsat imagery extensively and other studies have used its imagery as supporting information (i.e., locating ice floes, leads, etc.).

Conservation Zone* (the FCZ parallels the EEZ) in the Bering Sea and the Aleutian Islands was set at about 2 million metric tons: U.S. and foreign catches for that year for the entire United States EEZ were about 5 million metric tons. In addition to commercial fisheries, a significant portion of the world's marine mammal populations live in

*The Fishery Conservation Zone was established by the Magnuson Fishery Conservation and Management Act of 1976 (MFCMA). It extends from the seaward boundaries of the territorial sea (3 nautical miles from shore in most cases) to 200 miles from shore.

the Bering Sea. Their predator-prey interactions with fish and parasite-host relationships are largely unknown. The extent to which these populations can or should be maintained at their present levels is a question whose answer is dependent upon additional scientific information and the development of a consensus of our society's goals.

The Bering Sea is of major importance for NOAA in carrying out its role to gather data and disseminate informational products to the fishing industry and fisheries management agencies. Data and services needed include weather forecasting and environmental parameters for assessing fish stocks and managing the fisheries.

NWS forecast services are essential to fishermen, who need a higher density of weather observations in fishing areas, forecasting for smaller areas, and improved dissemination. Significant improvement in short-term synoptic weather forecasts requires more data. These data come largely from ship reports, but since there is little commercial and military ship traffic in the eastern Bering Sea, the data base is minimal (Figure 1-4). Fishermen also need ice prediction capabilities for the medium term, days to weeks. For example, preparation and transit to participate in the herring fishery in Togiak Bay in 1985 involved a long period of uncertainty for several hundred participants because of unusual ice conditions. In this particular fishery, there also exists the potential for a major disaster should intense storms occur during the transit of small vessels from False Pass to Togiak.

Fishing practices and manning levels preclude submission of detailed weather reports in the normal ship reporting format. However, data access and availability could be enhanced by consideration of alternatives to current reporting methods, such as the following:

- Simplify reporting systems to provide wider participation by smaller fishing vessels.
- Increase use of remotely sensed data, such as might be relayed from transmitters mounted on vessels, and/or more data buoys. Data collection via satellite telemetry from buoys or instrumented fishing vessels would not be limited by cloud coverage and could provide a source of "ground truth" to compare to satellite-borne sensor data.
- Require certain fishing vessels--such as foreign factory ships and fishing vessels with larger crews--to submit weather data as a condition of their fishing permit: time, position, air and water temperature, wind direction and velocity, solar radiation, salinity, and surface current. Ship positions could be coded, if the operators do not wish to broadcast to the world where the fish are.

Fishing data could also be collected by foreign vessels, including preprocessed acoustic records; gear activity such as trawl times, depths, and warp tension; and vessel operations variables such as vector velocity, roll, pitch, and loading. Since a large number of foreign vessels have U.S. observers aboard, some kind of manual data entry could be provided. All of this could be accessed through satellite data readout to provide real-time information.

Predictions of occurrence, distribution, abundance, aggregation, and migration of fish are the major factors considered in managing a

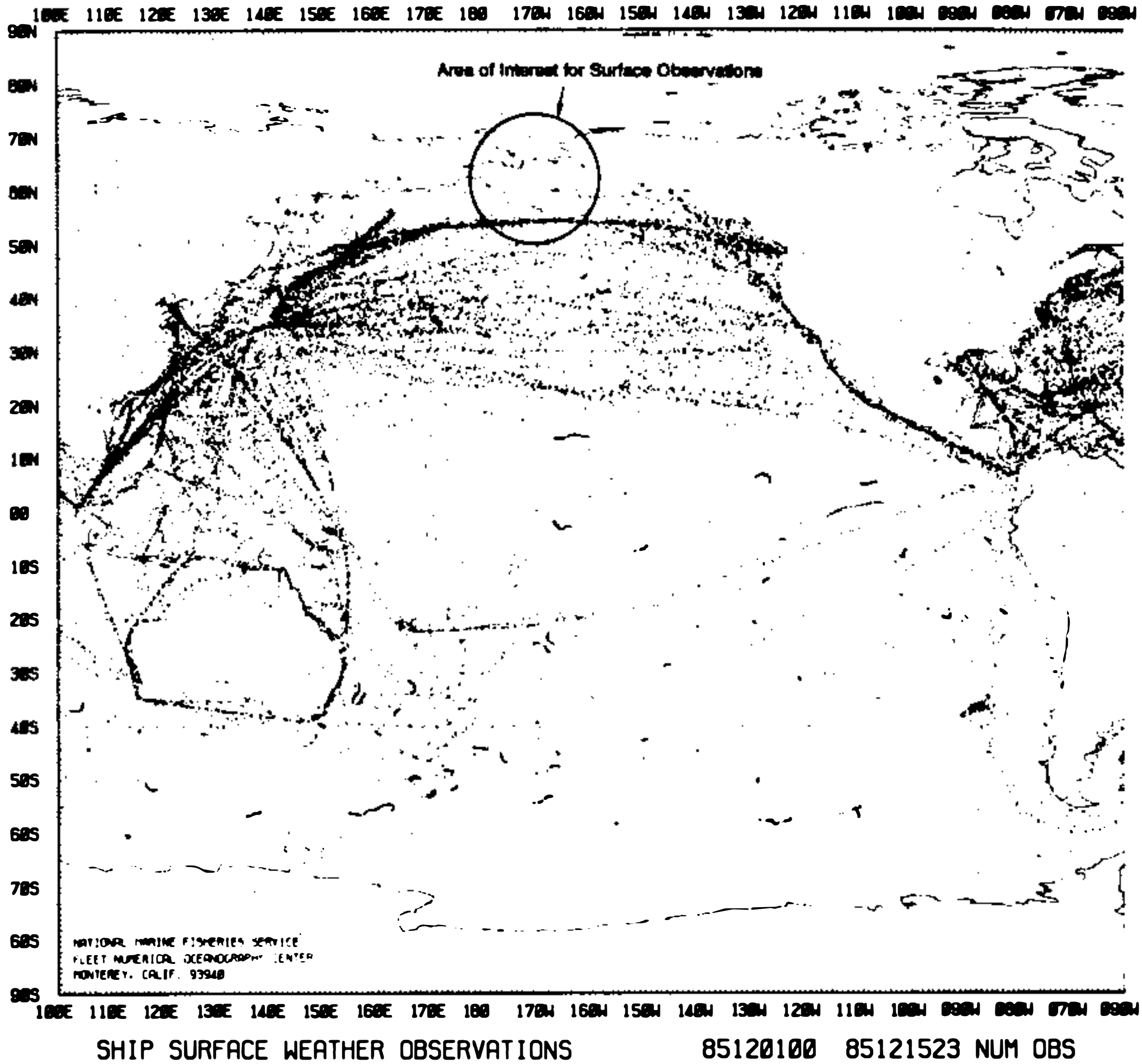

FIGURE 1-4 The density of synoptic sea-surface temperature reports, based on ship surface observations, December 1-15, 1985. SOURCE: National Marine Fisheries Service and U.S. Navy Fleet Numerical Oceanography Center.

fishery. These assessments include quantitative measurement of prediction parameters, together with an understanding of fish behavior in order to estimate the availability of fish to fishing gear. Long-range estimation of natural (environmental) fluctuations of fish stocks are also required to provide quantitative guidance about year-to-year and season-to-season variations.

The data demands and analytical products required to support fisheries management demand rapid delivery of fine-scale data products related to fish concentrating mechanisms, such as water mass boundaries and local upwelling patterns. Priority needs include data models that successfully predict short- to medium-range transport and water column structure. An effort to analyze wind pressure fields in the Arctic and to provide synoptic prediction of transport turbulence would also be of significant value in studying the causes of--and ultimately, predicting--variations in stocks. Yet, a significant constraint to fishery development in Alaska is the lack of focus of major environmental studies.

Present stock assessment in U.S. arctic waters for species other than shrimp, halibut, herring, and salmon is based on catch information from direct fishing surveys and data from the foreign observer program. The program is presently funded either directly by foreign interests or by fishing fees. As foreign fishing is phased out and replaced by domestic fishing, the validation and collection of catch data for several species will be difficult to accomplish with present financial resources.

The management of arctic fishery resources is complicated by the common property nature of the resource. The fish are public property, but they are not bought and sold by bid, such as in oil and gas or forest product production or harvesting. Fish do not become private property until they are captured and brought aboard a fishing vessel. Therefore, fisheries management is based on allocation of available stocks among fishermen. While the FCMA requires that management allocations provide the best benefit to the nation, data on costs and benefits generally do not exist. For the near future, allocations will probably rest on revenue estimates, adjusted by economic multipliers to estimate benefits. This process will require that NOAA collect and analyze economic information from the fishing industry.

ARCTIC RESEARCH AND COOPERATIVE EFFORTS

Arctic Marine Research

The relationship between the research community and NOAA is a two-way channel: both academic and industrial scientists can and do provide many of the data products from basic and applied research archived by NOAA. Furthermore, substantial university and private-sector arctic marine environmental research has been funded by NOAA in the past.

NOAA-supplied meteorological and oceanographic data are important to effective planning and safe and productive operations in arctic marine research efforts. Real-time satellite ice information is particularly crucial to arctic fieldwork. Researchers can obtain such information through the Geophysical Institute at the University of Alaska. Ice analysis of the Bering, Chukchi, and Beaufort seas is available in hard copy from NOAA's Anchorage office.

Archived data needed by researchers include historical weather observations and statistics for specific areas at specific times of year, synoptic analyses of surface and upper-atmosphere data, and maps showing monthly variations in sea-surface levels. Long time-series of oceanographic information are particularly critical to understanding current trends and assessing long-term effects of year-to-year climatic variations on physical and biological regimes and to developing and verifying models. Data needed by the NOAA supported Sea Grant Program also require primarily archived data: the University of Alaska Sea Grant Marine Advisory Program uses such data in its regional training operations.

Among the data products available from NOAA by subscription or request, some of the most useful are weekly ice maps, monthly and annual climatological data, local climatological data publications, and sea-surface temperature analyses and anomalies. NOAA disseminates its products (on microfiche or hard copy) through federal and state channels, such as NWS, the National Climatic Data Center (NCDC), and the Alaska Climate Center.

The University of Alaska's Arctic Environmental Information and Data Center (AEIDC) in Anchorage provides information and referral services and operates the Alaska Climate Center. It maintains a coastal bibliographic data base and an Alaskan current research data base. AEIDC maintains a close working relationship with NOAA, although they provide different data and information services. AEIDC's Alaska Climate Center provides many free services, such as NCDC reports and weather maps, whereas local NOAA services emphasize marine rather than climate information. AEIDC is also writing a national plan for an arctic information and data network, under a grant from the National Science Foundation,* in response to the Arctic Research Commission's recommendations.

The Arctic Data Buoy Program has provided extensive data on sea-ice motion and atmospheric pressure (Untersteiner and Thorndike, 1982), which are archived at the National Snow and Ice Data Center (NSIDC) in Boulder, Colorado. A planned arctic buoy program (1986) will continue to provide these data, with a great potential for producing large volumes of useful information.

A very desirable data set currently available is photographic quality imagery, which is much better than the hard copy obtained through telephone lines. NOAA imagery is prepared in Fairbanks and archived in the University of Alaska's Geophysical Institute. Research scientists using these photographs believe this capability is important because its ready accessibility and high quality makes the imagery very useful for research interpretation.

Strategic assessment data atlases covering the Bering, Chukchi, and Beaufort seas will be available in 1986, and for the Gulf of Alaska by 1988, prepared by the NOS Ocean Assessment Division.

NOAA has a role in both the conduct and support of marine research. During the early planning phases of the Outer Continental Shelf Environmental Assessment Program (OCSEAP), NOAA was delegated the major

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*National Science Foundation Grant DPP85-16409. The commission is authorized by the Arctic Research and Policy Act of 1984 to oversee the activities of the interagency committee and to make recommendations on planning.

role for Alaska through an interagency agreement with the Bureau of Land Management (BLM). The BLM was responsible for financial support, but NOAA designed and executed the research. The program produced valuable information on continental shelf systems off the Gulf of Alaska, the Bering Sea, and the Beaufort Sea, with some work on the Chukchi Sea added later.

The NOAA-OCSEAP Arctic Project Office at the University of Alaska maintained an integrated program with good logistic support for most of the time that NOAA was responsible for the program. The OCSEAP program markedly advanced the understanding of Alaska's marine ecosystems; however, as the level of support has decreased over time, progress in the acquisition of baseline data has slowed appreciably.

National, International, and Industrial Cooperation

The nation's forecasting capability depends on communications circuits and large central computer data processing and modeling centers operated by NOAA, the Navy, and the Air Force. These computer centers--located respectively at Suitland, Maryland; Monterey, California; and Omaha, Nebraska--are linked, and routinely share data and products. In turn, NOAA (National Weather Service) is linked with the World Meteorological Organization's Global Telecommunications System (GTS), allowing for the transfer of meteorological and marine data throughout the world. These links are essential to the operation of regional forecast centers. Dissemination of NOAA data and products between the centers, regional offices, and users is accomplished by personal communication, telephone, teletype, mail, GTS, telecopier, Automated Field Operations and Services (AFOS), and facsimile (FAX, DIFAX).

The advent of remote environmental sensing using satellites has induced interagency and intergovernmental cooperation in sharing and managing the enormous volume of data and information available. State-of-the-art computers are the only practical way of accomplishing this, and agencies are linking their computer and satellite data gathering sources. Examples of the joint use of capabilities are the Shared Processing Program, the NOAA/Navy Oceanographic Data Distribution System (NODDS), and the Navy/NOAA Joint Ice Center (JIC).

The Shared Processing Program Development Plan (OAO Corporation, 1985) outlines how the three principal government users of satellite data--NOAA, the Navy, and the Air Force--intend to process and use the data from environmental satellites. (This plan is discussed further in Chapter 2.)

NOAA provides a variety of unclassified data products to government and commercial users on an operational basis. NODDS, located at the Fleet Nautical Oceanography Center (FNOC) in Monterey, California, was designed using FNOC computer components for data acquisition, transfer, conversion, and distribution to users in near real-time. NODDS data products are stored on a PDP 11/60 minicomputer for access by the user on an "on-demand" basis. The user may access the system over a public packet switching network (TYMNET) or through direct telephone line connections to the PDP 11/60 computer.

NODDS evolved from the Satellite Data Distribution System (SDDS), which was originally established so commercial users could receive SEASAT data in real-time through FNOC's computer and communications facilities. After 3 months, the SEASAT satellite failed in October 1978, and SDDS was terminated in 1982. Rather than let this system's capability sit idle, the Navy chose to substitute some of their unclassified oceanographic and meteorological products for the SEASAT data, such as the brightness temperatures from the scanning multichannel microwave radiometer on NIMBUS-7.

Oceanographic products available from the NODDS include two-dimensional wave spectra (energy as a function of frequency and direction), as well as derived spectral products, such as significant wave heights, primary and secondary wave directions, primary and secondary wave products, and horizontal and vertical sea-surface temperature analyses. Meteorological products include on-line analyses and forecasts up to 120 hours for standard fields such as surface wind speed and direction, surface pressure, and upper air pressure height and temperatures.

The JIC, which operates in association with the U.S. Naval Polar Oceanography Center, provides geophysics officers and aerographer's mates to monitor ice conditions in both the Arctic and the Antarctic. NOAA provides a small complement of civilian technical personnel (ice forecaster/analyst, ice analyst/meteorological technician, satellite photo-interpretation specialist, and computer programmer) to assist in analyzing and interpreting satellite sensor data emanating from the NOAA TIROS-N polar orbiting platforms and the DOD's Defense Meteorology System Program (DMSP). NOAA/NESDIS provides a continuous flow of polar orbiter data from the AVHRR sensors to JIC for analysis. NOAA and the Navy jointly prepare analysis, forecasts, and other advisory information for use by the military and the civil sector. In the Arctic, JIC materials are used as guidance by the NWS Anchorage Forecast Office. In the Antarctic, forecasts and advisories are occasionally sent directly to users through the Naval Telecommunications System.

The Arctic Research and Policy Act of 1984 mandates interagency planning through an Arctic Research Policy Committee, and an integrated budget for research concerning the U.S. arctic lands and oceans is also required. The National Science Foundation serves as the administrative agency for the Arctic Research Policy Committee.

The two primary ice observation satellite systems in use today are NASA's NIMBUS-7 scanning multichannel microwave radiometer (SMMR) and the NOAA (series) advanced very high resolution radiometer (AVHRR). SMMR has the advantage of being able to see through cloud cover, but has the disadvantage of very low resolution (25 km). AVHRR imagery has much higher resolution (1.1 km), but the sensors cannot penetrate clouds.

Government and private analysts use the two types of imagery together to produce the best possible ice charts. Satellite observations are supplemented by aerial reconnaissance flights for critical areas, such as the summer sea routes to Prudhoe Bay, and oil drilling operations in the Bering and Beaufort seas. Reconnaissance flights are expensive, but indispensable to ice forecasting under present conditions. Maintenance of ice monitoring data already archived by NOAA (SDSD) and ready access by users requesting them will provide a useful service to marine interests operating on arctic seas.

Additional ice data could be acquired; for example, the U.S. Navy's GEOSAT, launched in March 1985, includes a satellite altimeter that can accurately detect the position of the sea-ice margin. It covers 72° S to 72° N latitude, which includes Alaskan waters of interest to the oil industry. However, there are two difficulties in making these data useful to the public: (1) some of the GEOSAT data are classified, and (2) due to processing requirements, the information cannot be readily available to the public, in a useable format, within 6 hours or less of the time of data acquisition. A 6-hour processing period is compatible with other data used in forecasting; any longer would degrade forecast quality. NOAA is working with the Navy to overcome these constraints in the following ways:

- The classified data related to strategic requirements will be stripped from the data stream.
- The unclassified data will be made available to NOAA through FNOC.
- The processing issue is being addressed by NOAA.
- GEOSAT wind speed and significant wave height data will be made available through NODDS.
- The Navy is continuing the development of the ice algorithm.

A second ice information source, due to be launched in 1990, is synthetic aperture radar (SAR) data from the European Space Agency's Remote Sensing Satellite (ERS-1). SAR sensors combine high resolution (25-40 m) with the capability to penetrate cloud cover. The main disadvantage to SAR is its extremely high data acquisition rate, which precludes onboard data storage. Data must be received on the ground in real-time, and processing is extremely complex and time-consuming. NASA is developing a high-speed processor designed to process SAR data to full resolution in near real-time. Also, NASA is planning to install a receiver at Fairbanks, Alaska, to acquire ERS-1 data coverage of the Bering, Chukchi, and Beaufort seas. NASA's mission is primarily research oriented, with no provisions to make the data publicly available within a time frame useful to forecasters. There is a clear need for a NOAA-operated processor at the Fairbanks facility to provide government and private forecasters with near real-time (6 hours or less) ice information. This information should be archived for future climatological studies.

Landsat satellite images of ice cover are another ice data source, as discussed later in this chapter. Real-time imagery is available through the University of Alaska, which operates the nation's only Quick-Look Landsat facility. The Landsat images are particularly useful for high-resolution studies and forecasts of local conditions, ice motion (e.g., shorefast ice, ice in the Bering Strait and other shipping channels). However, the Landsat services are available for a very limited period, about three passes per week at this time. NOAA's Gilmore Creek tracking station provides the ground link to the university and stores extensive Landsat imagery dating back to 1972.

DEFICIENCIES AND PROBLEMS

The shortcomings of current arctic environmental data systems tend to fall into two general categories: accessibility of available data and completeness of the data base. The extent of deficiencies in the actual data base is not clear, because information on arctic and subarctic seas is not extensive compared with other regions. Nevertheless, the biggest problem is accessibility.

One overriding observation became apparent early in the course of the study: a user must often contact several NOAA offices or field operations to obtain information. Some archival data is available in Alaska, but much of it is archived--according to source (particular sensor platforms) or by discipline--in the Washington, D.C., area (National Meteorological Center, Joint Ice Center), Boulder, Colorado (World Data Center-A for Glaciology), and Asheville, North Carolina (National Climate Data Center).

Landsat information is less frequently used in oceanography than NOAA's AVHRR because Landsat data are not available through NOAA for arctic operations except under very limited conditions. Users currently must forgo meaningful access to Landsat and the French SPOT* program because of cost and lack of receiving and processing facilities for real-time data dissemination.

Current transportation research aboard the POLAR Class icebreakers indicates a need for tactical-type data to support navigation through ice. In 1983, real-time satellite ice imagery was received aboard icebreakers for the first time. Yet, icebreaker operators still receive the weekly and 30-day ice forecast charts by mail during their 4- to 6-month trips to the Arctic. These charts would be more valuable (i.e., timely) if they were sent by facsimile or other system. However, facsimile quality (transmitted from Kodiak) degrades quickly the farther north it is sent, and becomes poor to nonexistent in the vicinity of Cape Lisburne and Wainwright. Furthermore, transmissions would be improved by:

- use of Mercator projections, instead of Gnonomic, to show weather farther west and northwest of Point Barrow; and
- transmission of forecasts at 1000Z,** in addition to the 2200Z, so that information is available by first light.

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*SPOT, Satellite Pour l'Observation de la Terre, is a French remote-sensing commercial satellite, launched February 21, 1986. Northern latitude receiving stations are located at Kiruna, Sweden; and Prince Albert, Saskatchewan, and Gatineau, Quebec, Canada. SPOT provides 10-m ground resolution in panchromatic and 20-m in the multispectral mode; two instruments mounted vertically cover a 117-km track width. Directable mirrors allow for acquisition of scenes up to 27° from the vertical (providing three-dimensional perspective). SPOT acquisition opportunities at 66° N latitude are 20 visits in 26 days.

**Z: Often called "Zulu" time, or net GMT (Greenwich Mean Time).

The importance of remotely sensed ice imagery to future ice navigation has been cited by Brigham and Voelker (1985). Their report notes that direct ice imagery, received from a satellite, during the U.S. Coast Guard icebreaker transit from the Bering Sea to Wainwright, Alaska, in 1983, proved the "strategic" application of real-time, low-resolution imagery. In the future, enhanced, high-resolution systems such as satellite and aircraft synthetic aperture radar will aid tactical support to icebreaking vessels throughout arctic seas.

Data accessibility presents problems for academic research planning, because the high costs of data retrieval are often beyond the means of academic researchers. Difficulty in obtaining financial support for long-term data acquisition consequently limits, and will continue to limit, the data base. Some research scientists have given up trying to use archived data from NOAA: academic oceanographers tend to obtain data sets directly from colleagues at their own or other institutions.

NOAA requirements for arctic data are expected to grow with the addition of new satellites and sensors. In the next 5 years, data volume and processing requirements from more sophisticated satellite platforms will increase. The Shared Processing Program is a key element in optimizing multi-agency flow of these data. A NOAA commitment to provide financial support is needed to assure timely implementation of the program and continued agency coordination. The program calls for a NOAA Center of Expertise for distribution of specific data products to be operational in September 1988.

Among future planned satellites, it would be highly desirable to obtain DMSP data through NOAA. This system has a passby frequency of 2 to 4 times each day, and will provide useful sea-ice imagery. There is also a need for high-resolution radar sea-ice imagery--for this, a readout station in Fairbanks for the ERS-1 satellite will be most useful and will provide the necessary link to combine data sets for all Arctic ocean areas.

The data base for meteorological information and forecasting has major limitations:

- The number of weather reporting stations--particularly in the Bering Sea, the northwest Alaskan coast, and the arctic coast--is insufficient. The number of weather observations along Alaska's western coast diminished significantly in the past year. Military bases that used to take daily observation now only take weather observations when they expect aircraft. Further, replacement of some 20 manned stations by automatic stations has resulted in a loss of much historical data, due to the high cost of data retrieval. A first-order* meteorological station at Prudhoe Bay was first recommended in 1969 by the Federal Aviation Administration and the Federal Field Committee, and most recently at a public workshop on NOAA services held in Anchorage in 1984. It has not yet been realized.

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*A first-order meteorological station makes observations on a 24-hour basis and reports to a synoptic schedule (4 times per day).

- Data from Summaries of Synoptic Meteorological Observations (SSMO) are probably biased toward less severe weather because they are developed primarily from ship reporting, and (1) ships try to avoid bad weather conditions, and (2) there is limited ship traffic in the Bering Sea. The SSMO, provided by the U.S. Naval Weather Service Command, is a data source for planning operations related to resource development in the Bering Sea.
- Satellite data and reporting frequency often do not fit into the synoptic schedule for integration into forecasts.
- Integration of these data into forecast models will require several years to complete and consolidate.
- Global numerical forecast models do not accurately predict arctic surface wind velocity and other parameters needed to forecast sea-ice drift.
- Tide levels have not been sufficiently defined on Alaska's western coast; no water level recording units are in place there.
- An improved tsunami warning network needs to be developed. Models do not presently include amplitude, and the warning system needs to be able to provide for timely alert.
- Better understanding is needed of the causative relationship of land, ocean, and ice temperatures on rapid changes in atmospheric pressure.
- There is no systematic research on the physics and forces driving sea ice through the Bering Strait, Chukchi Sea, and along the Beaufort Sea. While observations have been made and theories established concerning forces on ice and their effects, the results have not been useful for operational forecasting.
- There is no understanding of the contribution of solar radiation and warm water advection on the spring retreat of the Chukchi ice pack, and there are no data and analyses to support development of forecast models.
- There are insufficient site-specific data. The Navy-developed spectral ocean-wave model (SOWM) for the Bering Sea has grid points that are widely spaced, and the chance of a grid point falling close to a specific location is low. Also, the SOWM model does not account for the effect of the Aleutian Islands.
- Although the research value and practicality of operating meteorological buoys in the polar ice pack has been proved, NOAA is unable to take advantage of the technology for operational meteorology because of the difficulty and cost of integrating data from buoy sensors into the NWS synoptic reporting system.

NOAA's requirements for certain long-term data are usually best collected through research conducted by academic institutions. Current government procurement procedures, however, deter making long-term arrangements between universities and NOAA, and NOAA often cannot take advantage of academic research capabilities. NOAA also does not currently have the financial resources to carry out a major research role in the Arctic, so its overall impact on Alaskan academic research is minor.

Questions also can be raised regarding the responsibility of NOAA for addressing societal needs as well as user needs. For example, should NOAA provide long-term information to predict climate change in addition to other information that is needed by science? The arctic regions are expected to respond to global warming trends, and therefore monitoring will be needed to produce advanced warning data as well as data needed to evaluate effects.

Interagency cooperation and collaboration fostered by the Arctic Research and Policy Act of 1984 (P.L. 98-173) might provide a forum for addressing such responsibilities. The act provides an excellent mechanism for coordinating arctic research activities and handling the resultant data.

2

TECHNOLOGY FOR ACQUIRING, PROCESSING, AND DISSEMINATING DATA

DATA REQUIREMENTS, SYSTEM CAPABILITIES, AND DEVELOPMENT

The information needs of the user communities described in Chapter 1 in general terms must now be translated into quantifiable parameters, such as ice edge position, ice concentration, ice type, wind speed, wave height, and frequency of observation. Very often, users' requirements for a particular parameter--such as floe size--may vary significantly and need to be related to a particular application or function, such as navigation in ice-frequented waters (Hayes, 1985). As the technology progresses, more and more parametric requirements may be accommodated by refinements in data products.

User requirements have been generalized in Chapter 1. Tables 2-1, 2-2, and 2-3 summarize the most stringent requirements for all major user groups (derived primarily from Carsey et al., 1982; Lapp and Lapp, 1982; and modified by additional information provided by the committee and government agencies).

To enhance planning for the deployment and use of sensor platforms and sensors, critical user requirements can be summarized as tactical or strategic:

- Tactical requirements are close tactical support (up to 6 hours) and tactical support (6 to 24 hours).
- Strategic requirements are strategic support (1 to 5 days) and planning support (5 days or more).

In the following summary tables, critical user requirements for ice have been grouped by strategic (Table 2-1) and tactical (Table 2-2), and both for ocean information (Table 2-3).

Remote-Sensing Systems

Satellite Platforms

During the next decade satellite missions for operational and research applications will gather significant data set in Alaska (NOAA, 1985; PIPOR, 1985). The types of mission, key sensors, orbits, and

TABLE 2-1 Critical Strategic Ice Information Requirements

Parametric Requirements			Specifications			
Parameter	Description[a]	Type of Information Required	Accuracy	Spatial Resolution	Repetition of Coverage (hours)	Turnaround of Information (hours)
Boundary/edge	OI, FY	Location	100 m	100 m	6	2
	TI	Velocity	1 km/day	1 km	24	6
Type	OI, FY, TI, OW	% by area	5%	25 m	6	2
Concentration	OI, FY, TI	% by area	5%	10 m	24	6
Thickness	OI, FY, TI	Meters (m)	0.2 m	0.2 m	24	6
Landfast ice	OI, FY	Location	<500 m	500 m	24	6
Floes	OI, FY	Size	10 m	20 m	12	3
		Velocity	1 km/day	25 m	12	6
Ridges	OI, FY	Height	<1 m	1 m	6	2
		Density	5%	20 m	6	2
		Orientation	10°	--	6	2
		Separation	<20 m	20 m	12	2
		Type	FY/OI	--	6	2
Leads	OI, TI	Orientation	10°	25 m	6	2
		% area	2%	20 m	6	2
		Width	25 m	25 m	12	3
		Separation	<500 m	500 m	12	3
Pressure	OI, FY	Convergence	Positive sign	2 km	6	2
Icebergs, bergy bits, growlers	FWI	Size	5 m	10 m	6	2
		Height	3 m	3 m	6	2
		Location	20 m	100 m	12	3
Ice island fragments	FWI	Size	<20 m	20 m	12	3
		Height	<1 m	1 m	12	3
		Location	20 m	100 m	24	6
Snow cover	On all ice types	Thickness	0.2 m	--	12	3
Deterioration	OI, FY	% meltponds	5%	--	12	3
Surface characteristics	OI, FY	--	10 m	$10\ m^2$	6	2

[a]Old ice, OI; First year, FY; Thin ice, TI; Open water, OW; Freshwater ice, FWI.

TABLE 2-2 Summary of Critical Tactical Ice Information Requirements

Parametric Requirements			Specifications			
Parameter	Description[a]	Type of Information Required	Accuracy	Spatial Resolution	Repetition of Coverage	Turnaround of Information
Type	OI, FY	% of area	2%	25 m	Continuous	Instantaneous
Concentration	OI, FY, TI	% of area	5%	10 m	Continuous	Instantaneous
Thickness	OI, FY	Meters (m)	1 m	--	12 hr	2 hr
Boundary/edge	OI, FY, TI	Movement	1 km/day	1 km	Continuous	Instantaneous
		Location	100 m	100 m	1 hr	Instantaneous
Landfast ice	OI, FY	Location	50 m	500 m	12 hr	2 hr
Floes	OI, FY	Size	10 m^2	20 m	Continuous	Instantaneous
		Direction	5°	5°	Continuous	Instantaneous
		Magnitude	1 km/day	1 km	Continuous	Instantaneous
Ridges	OI, FY	Height	0.25	1 m	Continuous	Instantaneous
		Density	5%	20 m	12 hr	<12 hr
		Width	1 m	10 m	12 hr	<12 hr
		Keel depth	1 m	1 m	24 hr	<24 hr
		Type	FY/OI	10 m	Continuous	Instantaneous
		Separation	<30 m	30 m	Continuous	Instantaneous
Leads	OW, TI	% of area	2%	20 m	3 hr	2 hr
		Width	25 m	5 m	Continuous	Instantaneous
		Pattern	25 m	25 m	3 hr	<3 hr
		Separation	<500 m	500 m	Continuous	Instantaneous
Pressure	OI, FY	Convergence	Positive sign	10 km^2	3 hr	2 hr
Icebergs	FWI	Location	20 m	100 m	Continuous	Instantaneous
		Movement dir.	5°	5°	1 hr	<1 hr
		Size	5 m	5 m	Continuous	Instantaneous
		Height	<3 m	3 m	Continuous	Instantaneous
Ice island	FWI	Size	<20 m	20 m	Continuous	Instantaneous
		Height	<1 m	1 m	Continuous	Instantaneous
		Location	20 m	100 m	12 hr	2 hr
Snow cover	On all ice types	Yes/no, thickness	0.2 m	10 m	Continuous	Instantaneous

[a]Old ice, OI; First year, FY; Thin ice, TI; Open water, OW; Freshwater ice, FWI.

maximum latitudes for approved or proposed polar orbiting satellite missions are listed in Table 2-4.

Aircraft Platforms

Aircraft for obtaining ice information in Alaskan waters are operated by the U.S. Navy, the U.S. Coast Guard, the Canadian Atmospheric Environment Service (AES), and by industry. Navy aircraft usually have two ice observers on board, supported by a search radar. The AES Electra, with a complement of four to five ice observers, supported by side-looking airborne radar (SLAR) and a laser profilo-

TABLE 2-3 Summary of Critical Ocean Information Requirements

Parametric Requirements		Parametric Specifications							
	Type of Information	Accuracy		Spatial Resolution		Repetition of Coverage		Turnaround of Information	
Parameter	Required	Strategic	Tactical	Strategic	Tactical	Strategic	Tactical	Strategic	Tactical
Sea state	Height	1 m	0.5 m	50 km^2	<1 m	6 hr	1 hr	<6 hr	Instantaneous
	Period	5 sec	0.5 sec	50 km^2	50 km^2	6 hr	1 hr	<6 hr	Instantaneous
	Direction	--	5°	--	--	--	6 hr	--	1 hr
Swell	Height	--	<1 m	--	<1 m	--	<3 m	--	<<3 hr
	Period	--	NS[a]	--	NS[a]	--	<3 hr	--	<<3 hr
Wind	Velocity	1 m/s	0.5 m/s	100 km^2	--	6 hr	1 hr	<6 hr	Instantaneous
	Direction	20°	5°	--	--	6 hr	1 hr	<6 hr	Instantaneous
Surface currents	Velocity	--	0-0.25 m/s ±5%	--	--	--	3 hr	--	1 hr
Sea-surface temperature	°C	0.25	0.25	100 km^2	--	6 hr	<3 hr	<6 hr	<<3 hr

[a]NS: not specified.

TABLE 2-4 Approved/Planned Polar-Orbiting Satellite Missions

Country	Mission/ Type	Main Sensors	Orbit (Altitude)/ Maximum Latitude	Launch Dates	Comments
United States	NOAA-Series/ operational	AVHRR, AMSU, HIRS	854 km/sun-synchronous	1985-1993	
	DMSP operational	SSMI/I SSM/T	837 km/86° N sun-synchronous	1986-1993	
	NROSS-1 operational	Radar altimeter scatter-ometer, SSM/I, LFMR	830 km/sun-synchronous	1989-1990	
	GEOSAT operational	Radar altimeter	800 km/72° N	1985	
Europe	ERS-1 research	SAR, wind scatter-ometer, radar altimeter	780 km/82° N sun-synchronous	1990	
	ERS-2 operational	SAR Wind scatter-ometer radar altimeter		1992	Proposed
Canada	RADARSAT research	SAR, scatter-ometer, AVHRR	1001 km/76° N sun-synchronous (SAR)	1990	Phase B
Japan	MOS-1	MESSR, VTIR, MSR	909 km/82° N sun-synchronous	1986	
	JERS-1	SAR, VNIR	570 km/sun-synchronous	1990	
France	SPOT-1		832 km/82° N sun-synchronous	1986	Launched

NOTES:
- AVHRR: advanced very high resolution radiometer
- AMSU: advanced microwave sounding unit
- HIRS: high-resolution infrared radiation sounder
- SSMI/I: special sensor microwave/imager
- SSM/T: special sensor microwave/temperature
- LFMR: low frequency microwave radiometer
- SAR: synthetic aperture radar
- MESSR: multispectral electonic self-scanning radiometer
- VTIR: visible and thermal radiometer
- MSR: microwave scanning radiometer
- VNIR: visible and near infrared radiometer

meter, provides ice information along the northern shore of Alaska from June to mid-October. The existing ice charts produced from data gathered during these aircraft surveillance flights are transmitted to the AES Ice Centre in Ottawa and Joint Ice Center (JIC) in Suitland, Maryland.

Sensors

Of the sensors listed in Table 2-5, the microwave systems have the capability to provide the most data; they operate in nearly all weather conditions, day and night. The two sensors used for ice operations are the passive microwave radiometer (PMR) and the synthetic aperture radar (SAR). The scatterometer data acquisition capability, when used in ice-frequented waters, has not yet been fully explored. Lasers, which are operated from aircraft, provide roughness profiles of the ice. Useful information can also be obtained from visible and infrared sensors.

For open water conditions, the scatterometer, altimeter, and passive microwave radiometer provide the bulk of the operational data potentially available from satellites. Table 2-5 lists the main characteristics of these sensors, and Table 2-6 provides an indication of their limits.

Data Requirements and Satellite Platform/Sensor Capabilities

Table 2-7 compares the critical user requirements with the platform/sensor capabilities, which are characterized

- (E) being established;
- (P) potentially useful;
- (R) feasible, requiring research (R); and
- (*) limited.

To obtain Table 2-7, Tables 2-1 to 2-6 were used to make a judgment based on the availability of technology over the next 10 years. Since no new technology or increase in the number of platforms is anticipated over this period beyond those listed, the assessment should be reasonable.

It is clear from examining Table 2-6, that the SAR satellite sensor shows great potential. Its limitations primarily relate to tactical requirements, the lack of frequency of satellite coverage, and turn-around time. To satisfy these very stringent requirements would require several orbiting SAR satellites and extensive data processing facilities. The passive microwave radiometer data are primarily limited by resolution. Future generations of radiometers might reduce the resolution to 100 m, from 15 km available today. However, this capability is not expected to be operational in the time frame under consideration.

From a tactical viewpoint, data and information derived from satellite sensors appear very limited, while the aircraft sensors show significant promise. Specifically, the complementary characteristics of the SAR and PMR sensors provide synergistic performance advantages.

For ocean applications, the useful satellite sensors are primarily the PMR, scatterometer (SCAT), and altimeter (ALT). The altimeter is particularly useful for providing some surface verification of wave height derived from wind fields. In regard to sensing winds, the PMR

TABLE 2-5 Sensor Characteristics

Name	Acronym	Frequency	Spatial Resolution	Swath Width	Scanning Mode	Incident Angle
Wind scatterometer	SCAT	13.995 GHz	25 km	1200 km, with 300-km hole at center	Continuous	--
Radar altimeter	ALT	13.5 GHz	30 km	--	Continuous	Nadir
Passive microwave radiometer	SSM/I	19.35 GHz H&V Pol.	70 x 45 km	1394 km	Continuous	53.1
		22.235 GHz V Pol.	60 x 40 km	1394 km		53.1
		37.0 GHz H&V Pol.	38 x 30 km	1394 km		53.1
		85.56 GHz H&V Pol.	16 x 14 km	1394 km		53.1
Advanced very high resolution radiometer	AVHRR/2	0.58 - 0.68 m	1.1 km	--	--	--
		0.785 - 1.10 m	1.1 km	--	--	--
		3.55 - 3.93 m	1.1 km	--	--	--
		10.3 - 11.3 m	1.1 km	--	--	--
		11.5 - 12.5 m	1.1 km	--	--	--
Synthetic aperture radar	SAR	5.3 GHz	25 m	500 km, accessible with four steps	10 min/orbit	20-45?

TABLE 2-6 Limits for Environmental Parameters Obtainable from Satellite Sensors

Sensor (Satellite)	Parameter Measured	Capability Value	Range	Resolution	Remarks
Scatterometer (NROSS)	Wind speed	±1.3 m/s	4-26 m/s	--	
	Wind vector resolution	--	--	50 km	
	Wind direction	±16°	0-360°	--	90% of solutions with two ambiguities about 180° apart
Altimeter (NROSS)	Altitude	8 cm	--	--	When H 1/3 $\cong$ 5 cm or 10%, whichever is larger
	Significant wave height (H 1/3)	0.5 m	--	--	
	Wind speed	±2 m/s	1-18 m/s	--	
	Ice edge location	--	--	--	
Microwave imager SSM/I (DMSP, NROSS)	Wind speed	±2 m/s	2-60 m/s	25 km	
	Ice edge	±12.5 km	--	--	±7.5 km in polar regions
	Ice type	Quanta	--	25 km	Thin, first year, old ice
	Ice type fraction	12%	0-100%	25 km	
	Ice concentration	8%	0-100%	25 km	
	Water vapor	±0.01 g/cm^2	0-0.13 g/cm^2	25 km	
	Liquid water	±0.2 g/cm^2	0-0.61 g/cm^2	25 km	
	Precipitation rate	±5 mm/hr	0-29 mm/hr	12.5 km	
Low-frequency microwave	Sea-surface temperature	±1.0° C	-2-30° C	25 km	
Radiometer, LFMR (NROSS)	Total ice concentration	5%	0-100%	13 km	
	Wind speed	--	--	25 km	
SAR (ERS-1, RADARSAT)	Ice edge	±12.5 m	--	--	
	Ice type	Quanta	--	25 m	Intensive signature studies and algorithm development required
	Ice concentration	--	--	25 m	

TABLE 2-7 Platform/Sensor Capabilities as Compared to Strategic (S) and Tactical (T) Critical User Requirements

	Satellite[a]										Aircraft[a]		
	SAR		PMR		SCAT		ALT		+AVHRR/?		LASER	PMR	SAR
Parameters	S	T	S	T	S	T	S	T	S	T	T	T	T
Ice													
Boundary/edge	E	E*	E*	E*	P*	P*	E	E*	E	E*	E	E	E
Type	P	P*	E*	E*	R*	R*	--	--	E*	E*	--	E	P
Concentration	P	P*	E*	E*	R*	R*	--	--	P	P*	--	E	P
Thickness	--	--	--	--	--	--	--	--	--	--	P	--	--
Landfast ice	E	E	E*	E*	R*	R*	--	--	E*	E*	--	E	E
Floes	E	E*	--	--	--	--	--	--	--	--	P*	--	--
Ridges	E*	E*	--	--	--	--	--	--	--	--	E*	E*	E*
Leads	E	E*	--	--	--	--	--	--	E*	--	E*	E	E*
Pressure	R*	R*	P*	P*	R*	R*	--	--	--	--	--	P	P
Icebergs	R	R*	R*	--	--	--	--	--	--	--	--	E*	E*
Ice island	R	R*	R*	--	--	--	--	--	--	--	--	E*	E
Snow cover	R	R*	P*	P*	--	--	--	--	--	--	--	P	P
Deterioration	P	P*	P*	P*	--	--	--	--	E	E*	--	E	P
Surface characteristics	R	--	--	--	--	--	--	--	--	--	--	E*	P
Ocean													
Sea state	P	P	P*	--	P	P	E	E*	--	--	--	E*	E*
Swell	--	E	--	--	--	--	--	E	--	--	--	--	E
Wind	--	--	E*	--	E*	--	E*	--	--	--	--	E*	--
Surface currents	--	--	--	--	--	--	--?	?	--	--	--	--	--
Sea-surface temp.	--	--	E*	--	--	--	--	--	E*	E*	--	E	--

[a]Codes: E--established, P--potentially useful, R--feasible, requires research, *--limited, and +--affected by the presence of clouds.

and SCAT are complementary; the SCAT provides wind speed (3-30 m/s) and direction, while the PMR provides wind speed over a greater range (3-60 m/s), but no wind direction. While the SAR has proven itself to be useful for operational ice applications in the form of an image (for derived parameters such as floe size), operational use of SAR data in open ocean applications is still in the research domain. However, ERS-1 plans include a derived product which provides wave image spectra in polar coordinates.

The advanced very high resolution radiometer is an impressive data source, providing the sea surface is not obstructed by clouds. Unfortunately, cloud cover is common during the summer when most operational and research activities occur. Therefore, the AVHRR is not a reliable sole sensor without the support of the microwave sensors.

An additional problem concerning SAR and AVHRR sensors is that they produce images. It is difficult to extract automated, quantitative data from images, and the process is limited by the lack of multifrequency systems for the SAR.

Although Tables 2-1 through 2-3 list critical parameters based on many user categories, less stringent platform/sensor requirements might satisfy many specific user group requirements, partially or in full, if data products were timely. If tactical requirements were omitted, or if it were assumed that certain tactical data were provided by the private sector for site-specific needs, the severity of requirements for the satellite data would be reduced. Moreover, it should be emphasized that no single microwave sensor is yet operational. The first to become operational will be the microwave imager (SSM/I). Once the product has been validated and the various algorithms tested, the use of these new data sets in conjunction with the available data from NOAA and Defense Meteorological Satellite Program (DMSP) satellites will provide a significantly enhanced product that might satisfy many strategic user requirements.

Validation of Platform/Sensor Data

Validation of data acquired by satellite sensor is critical to understanding and utilizing space data. Two actions are required: first, an engineering evaluation of sensor performance and specifications; and second, evaluation of sensor radiometric signals in comparison to surface properties and conditions. Validation of space-borne data is difficult because it involves integration of aircraft, satellite, and surface data, which are usually in point form. Measurements at all three levels must involve similar and/or compatible sensors and must be obtained concurrently. Since similar sensors are not always available, multispectral data should also be used for validation for the aircraft and satellite levels.

Due to the seasonal variability of sea ice, validation experiments must be carried out at different times and at different geographical locations, e.g., the Bering and the Beaufort seas. Parallel to the geophysical validation, the space sensor calibration needs to be monitored using natural calibration in areas where properties do not change significantly with time.

Meteorological and Oceanographic Systems

Meteorological Observing Network

The network of first-order synoptic* reporting and contract observing stations is shown on the map opposite page 1. There are

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*Synoptic implies an instantaneous depiction of the large-scale atmospheric pressure, wind fields, and weather conditions. The pressure field and frontal features are analyzed so as to ignore local detail due to mesoscale phenomena and topographic modifications.

essentially no reports over the sea areas during winter. Moreover, during most of the year, the view of the surface from satellite-based visible and infrared (IR) sensors is limited by cloud cover. Surface observations of weather elements and essential sources of calibration data for satellite remote sensing are provided by manned arctic stations. Despite the high costs of these stations, such records need to be maintained to fulfill NOAA's responsibility for participating in meteorological reporting worldwide.

Much of NOAA's routine data, especially for weather forecasting, originates from data buoys, the Coastal Marine Automated Network [C-MAN], and voluntary weather observers aboard cooperating vessels. To aid in information gathering, NOAA has established the Shipboard Environmental Data Acquisition Systems (SEAS) to receive, store, and transmit meteorological and oceanographic data accurately and quickly by using the GOES satellite. Information is telemetered to the National Environmental Satellite, Data, and Information Service (NESDIS) at Suitland, Maryland, and made available to the National Weather Service (NWS). The data also are held in a 2-day temporary buffer that can be interrogated by interested investigators.

The routine real-time collection of meteorological data from buoys and ships has assisted forecasting for the North Pacific and the Gulf of Alaska. However, both NOAA and industry have been concerned that meteorological sensing and observation points have been too few in number and location to provide timely information for the Bering Sea and adjacent coast. In a major effort to improve the situation, a cooperative government-industry program between NOAA and the several member companies of the Alaska Oil and Gas Association (AOGA) has begun. In the fall of 1985, a 12-meter diameter discus buoy was installed in the Bering Sea at 56° N 178° W (see Figure 2-1). The buoy's payload includes dual air temperature, wind speed and direction sensors; dual barometers; a sea-surface temperature sensor; and a nondirectional wave measurement system (Table 2-8). Directional wave measurement capability is under development, and may be added later in this 5-year project. Six companies, working through AOGA, have funded the initial refurbishment of the buoy and sensor preparation; NOAA is providing fiscal support for deployment, routine maintenance, and data processing. The Exxon Company is the agent for the AOGA participants in the Bering Sea Comprehensive Oceanographic Measurement Program. Data will be relayed through NOAA's GOES Data Collection System (DCS).

The SSM/I onboard the DMSP will provide wind speed information for the ice-free portions of the seas to be augmented by scatterometer wind speed and direction information once NROSS has been launched.

With the availability of a nearly all-weather, day and night remote-sensing capability from sensors such as the SSM/I and SAR, it is possible for the first time to provide data to initialize and update operational sea-ice dynamics models. An operational sea-ice model for the Bering Sea will be tested in the near future. However, there is little activity directed toward developing operational ice dynamics models for other areas such as the Beaufort Sea and upgrading the Bering Sea model as new satellite data become available.

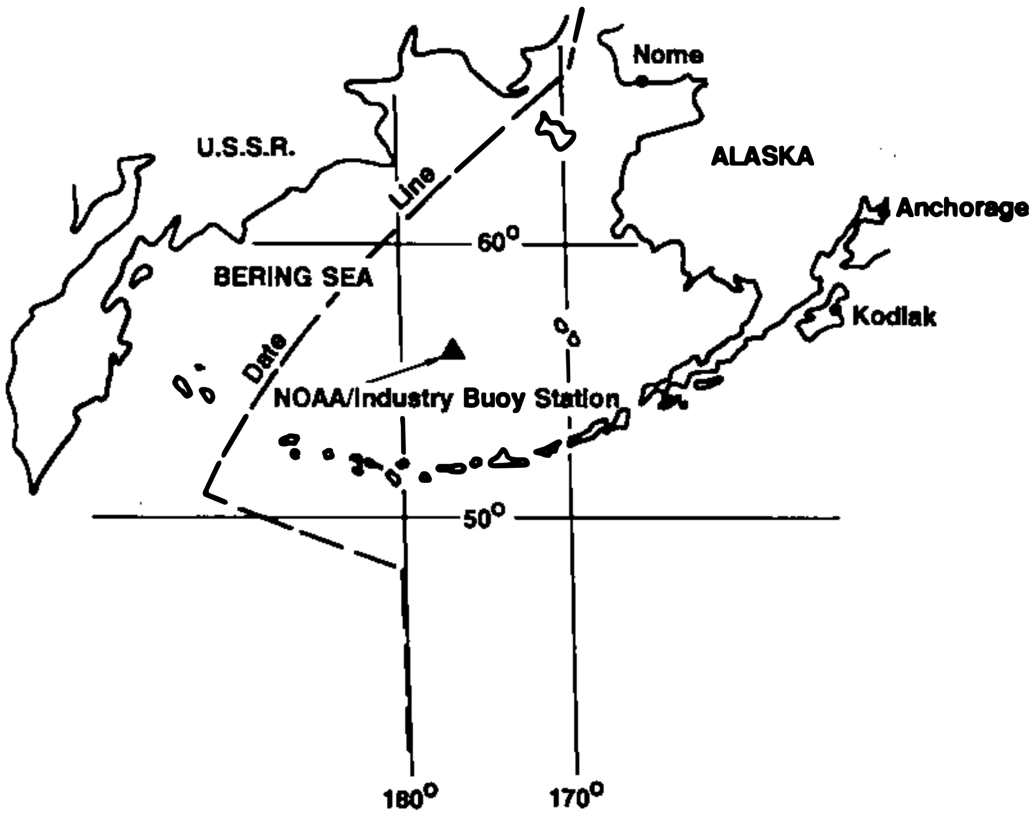

FIGURE 2-1 Bering Sea location of NOAA/industry oceanographic and meteorology buoy.

TABLE 2-8 Moored Buoy Payload Data

Parameter	Reporting Range	Reporting Resolution	Sample Interval	Sample Period	Total System Accuracy
Wind speed	0-80 m/s	1 m/s	1 sec	8.5 min	±1/ms (10%)
Wind direction	0-360°	10°	1 sec	8.5 min	±10°
Wind gust[a]	0-80 m/s	1 m/s	1 sec	8.5 min	±1 l/sec (10%)
Air temperature	-40°-50° C	0.5° C	90 sec	90 sec	±1° C
Barometric pressure	900-1100 mb	0.1 mb	4 sec	8.5 sec	±1 mb
Significant wave height	0-20 m	0.5 m	0.67 sec	20 min	±0.5 m
Wave period	2-30 sec	1 sec	0.67 sec	20 min	±1 sec
Wave spectra	0.01-0.5 Hz	0.01 Hz	0.67 sec	20 min	
Surface water temperature	-15°-50° C	0.5° C	1 sec	1 sec	±1° C

[a]Highest 8-second wind average retained.

The Global Positioning System

The Global Positioning System (GPS) is a precision three-dimensional satellite positioning system presently being installed by the Department of Defense (DOD). It will consist of 18 satellites when fully operational in 1989 and will provide accurate all-weather positioning to GPS users anywhere on the earth. Full dynamic accuracy (<10 m) will only be available to DOD users (P-Code), but position information to a 16-meter accuracy will be available to commercial users (C/A Code). Final details of non-DOD access are being worked out by government agencies. For survey applications, long baseline interferometric techniques capable of providing <10-cm accuracy in a differential mode have been demonstrated. This technique is not capable of operating in a dynamic mode but also does not require access to either the C/A or P-Code.

GPS will provide excellent support to meet research and operational requirements in the Arctic. Research is one important area where the GPS will allow significant advances. Use of GPS with the new satellites will allow the investigation of air-sea-ice interaction, which was not previously possible except by using expensive manned platforms. Commercial and government vessel operations in ice-frequented waters should be safer with GPS support.

Polar Drifting Buoys

The relatively recent development of automated observational systems has proven to be an important data source in supporting arctic operations. The Soviets developed an unmanned meteorological buoy which used high frequency communications to link shore stations in the early 1950s. These expanded systems were effectively deployed along the Northern Sea Route. More recently (in the 1980s), the Danes have deployed unmanned weather stations relying on satellite communications.

In 1979, the Arctic Data Buoy Program was initiated with National Science Foundation (NSF) support. NOAA, the Canadian Atmospheric Environment Service (AES), and the U.S. Office of Naval Research (ONR) picked up support of this program in 1984, and again in 1985 when NSF dropped out of the project. The Navy and the Minerals Management Service became the primary sponsors, along with Canadian and Norwegian support. The buoy sensors record sea-level pressure, air temperature, and position, and telemeter these data through the ARGOS System.* Other sensors can be attached to make meteorological and oceanographic measurements. Those buoys provide essential data used for research and operational requirements. Combined with satellite sensors and the Global Positioning System, arctic buoys will become even more valuable.

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*The ARGOS system is a cooperative project among the Centre National D'Etudes Spaciales (CNES, France), NASA, and NOAA. It collects and relays environmental data from buoys, balloons, and other platforms located anywhere on the earth's surface.

Furthermore, satellite atmospheric sounders do not provide satisfactory data in much of the Arctic during the winter because of inversions.

While arctic researchers have demonstrated the practicality of operating expendable meteorological buoys on the polar ice pack, this technology has never been transferred to operational meteorology within NOAA. Consequently, the number of buoys displayed and their placement schedule has been determined by the ever-changing needs of individual research projects and principal investigators. This has been a source of continuing frustration to those within the NWS responsible for providing the Alaskan forecasts.

Two major benefits could come from a well-designed polar drifting buoy program:

1. Routine forecast and warnings. A few strategically deployed buoys would significantly improve the meager suite of shore observations of barometric pressure and temperature presently available around the rim of the Arctic Ocean. Forecasters depend heavily on any and all valid observations to make short-term forecasts for the North Slope.
2. Initialization of National Meteorological Center atmospheric forecast models. The present 18-layer, 40-wave spectral model now being evaluated at the National Meteorological Center lacks sensitivity to polar conditions, largely because of the difficulty in obtaining polar meteorological observations with suitable spacing and temporal distribution to provide definitive analyses of initial conditions. Consequently, the forecast model outputs are tuned to be most effective in the mid-latitude regions where the majority of public needs and political interest reside. A small, continuing research program could provide a reasonably dense base of observations with which to better analyze initial conditions and would benefit all Northern Hemisphere nations. Polar orbiting satellite transponders can be operated routinely to relay data to national centers around the world.

Meteorological Systems: Vertical Structure of the Atmosphere

Information on the vertical structure of atmospheric temperature, pressure, wind velocity, moisture content, cloud, and aerosols is needed for analysis and prediction of weather and climate. Numerical weather prediction models specifically require three-dimensional data on temperature, pressure, and moisture content twice daily over the globe. While there are about 440 radiosonde stations poleward of 30° N (NOAA, 1985), only 38 of these are in the Arctic north of approximately 70° N (24 are operated by the Soviet Union, 2 by the United States, 6 by Canada, and 6 by other nations--see Figure 2-2). Fifty percent of the earth's surface north of 30° N is water surface, and there are few observing points in this area. These large gaps have been filled by indirect satellite sounding of the atmosphere since 1972, although these techniques cannot replace balloon-borne measurement.

The polar-orbiting operational environmental satellites (POES) do not yet provide high spatial resolution sounding data with the accuracy and vertical resolution of balloon soundings in clear and cloudy

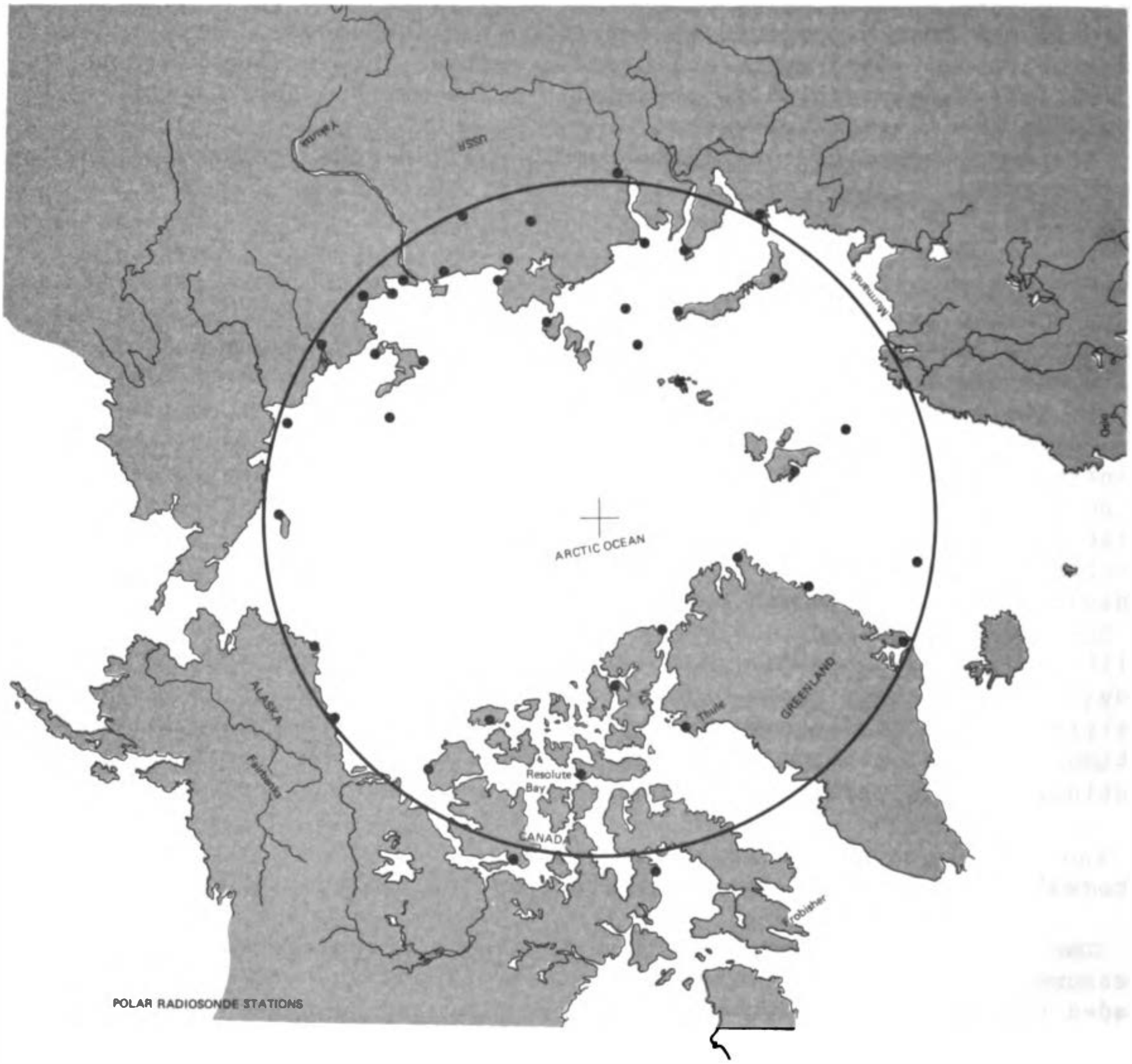


FIGURE 2-2 Polar radiosonde stations.

atmospheres. The advanced microwave sensor unit (AMSU) on NOAA-K, L, and M satellites will provide soundings in cloudy areas with improved accuracy for temperature and water vapor, and better vertical and horizontal resolutions. However, in high latitudes during winter, the arctic inversion presents a significant problem for satellite data retrieval. This problem may have to be resolved by the combined use of surface profilers. A prototype system of boundary-layer wind profilers is planned in the coterminous United States for the late 1980s or early 1990s, but is unlikely to be installed in the Arctic during this century.

DATA PROCESSING, PRODUCTS, AND ARCHIVES

Oceanographic, meteorological, and related environmental data in the Arctic include

- operational satellite remote-sensing information on weather systems, ocean surface properties, and sea-ice cover;
- routine coastal and shipboard measurements of atmospheric properties and sea-surface conditions;
- geodetic and marine surveys of the coastline and continental shelf.

Data are collected primarily by the three organizations within NOAA: NESDIS, NWS, and the National Ocean Service (NOS). Since December 1983, NOS has had lead responsibility for integrating meteorological and oceanographic services to the marine community. In addition, more specialized data are collected both by the private sector and by research programs of NOAA's Environmental Research Laboratory (NOAA-ERL), the U.S. Department of Defense, and satellite projects of NASA, and research conducted by university groups.

Data Processing and Distribution Centers

Organization for Real-Time and Rapid-Access Data Services

NESDIS was created specifically to manage environmental data and information for use by commerce, industry, the scientific community, the general public, and federal, state, and local governments. NESDIS administers all operational, civilian, satellite-based, environmental remote-sensing systems and the associated processing, archiving, and distribution of data through its national and related World Data Center-A subcenters.

Within NESDIS, the Office of Satellite Data Processing and Distribution operates ground facilities to process satellite data and to manage real-time (first 6 hours) data distribution. Data from NOAA's polar orbiting satellites (currently NOAA 7 and NOAA 9) are received at Gilmore Creek, Alaska, and relayed to the Central Satellite Data Processing Office at Suitland, Maryland. The Satellite Data Services Division (SDSD) of the National Climate Data Center (NCDC) then manages the permanent archiving and user services activity for these data.

Meteorological data from land stations and ships are collected for the standard synoptic reporting times by NOAA's National Meteorological Center (NMC), Camp Springs, Maryland. This is one of the nodal points for the Global Telecommunications Systems (GTS) of the World Meteorological Organization. It has a Class 6 computer system.

Routine and special marine reports for Alaskan waters are collected by marine radio, whenever possible, for the local NWS offices.

Real-time data for operational analysis and forecasting needs are handled by the NMC. Meteorological data are assembled and climatological values are derived for archiving at the NCDC, Asheville, North Carolina.

Oceanographic data include information on waves, currents, water levels, subsurface temperatures and other physical and chemical properties, and bathymetry. Some of these are collected in real-time by ships and buoys (e.g., marine reports of wave height), others involve only research programs.

Operational data on currents and subsurface parameters are handled by NOS and by NMC for coded messages. Records of water levels, tides, and ocean circulation are processed and held by the Office of Oceanographic and Marine Services of NOS. Buoy records are transmitted via satellite to Bay St. Louis, Mississippi, for processing by the NOS National Data Buoy Center and relayed in near real-time to NMC. All ocean data sets are archived by the National Oceanographic Data Center (NODC) of NESDIS in Washington, D.C.

Sea-ice data collected by U.S. Coast Guard ships and ice reconnaissance aircraft, Canadian AES ice reconnaissance, and operational and NASA research satellites are transmitted to the JIC.

Data Archiving Centers

All of the NESDIS centers contain arctic environmental data. In most cases there are no exclusively arctic data sets, since the observations are collected for international or national programs.

National Climate Data Center (NCDC) Hourly and daily reports on surface and upper-air weather variables, atmospheric properties, and derived data are archived together with derived climatic statistics. They are available on magnetic tape, diskette hard copy, or microfiche.

The Satellite Data Services Division of NCDC archives raw and summarized digital remote-sensing data, photographic products, and certain analysis products from the NOAA polar orbiters, which provide twice-daily coverage for the arctic region.

National Geophysical Data Center (NGDC) This center, located in Boulder, Colorado, manages data on marine geology and geophysics, including tsunamis, bathymetry, and marine minerals. Closely linked with NGDC is the National Snow and Ice Data Center (and WDC-A for Glaciology), operated under contract from NOAA/NESDIS through the Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder. This center archives hard copy and digital data on sea ice, snow cover, glaciers, and ground ice. It also archives imagery from the DMSP for SDSD.

National Oceanographic Data Center (NODC) Data on physical and chemical ocean properties (temperature, salinity, dissolved oxygen, and nutrients) together with data from the U.S. Outer Continental Shelf, including Alaska, are held at NODC. Additionally, there are data sets on plankton, fish, and shellfish resources and marine pollutants.

National Environmental Data Referral Service (NEDRES) The Assessment and Information Services Center of NESDIS operates NEDRES to identify, locate, and catalog environmental data sets. Its data base is a public information service that can be accessed through commercial data communication networks. An inventory of arctic data holdings in NESDIS centers will be available in 1986.

Climate Analysis Center Products derived from NMC analyses are retained by the Climate Analysis Center (CAC) of NMC. These are gridded data, and are primarily of interest to researchers.

Products and Services

Near Real-Time Data Services

The Alaskan region is served by the NOAA Anchorage office and several NWS weather offices, four with forecasters in Juneau, Anchorage, Valdez, and Fairbanks. The staff in Anchorage represents NOS, NWS, NESDIS, the National Marine Fisheries Service (NMFS), and the University of Alaska Sea Grant Program, and provides various forecasting, warning, and information services.

Products prepared by NOAA for the arctic sector are analyses and forecasts or outlooks. Additionally, warnings are issued in plain language. These products and services are summarized in Tables 2-9, 2-10, and 2-11. Several experimental products are included in these lists.

Retrospective Data

The NESDIS data centers each produce catalogs and inventories of data holdings as well as fliers for all new data sets. Special atlases of marine climatology and ice conditions have been developed by NCDC and also by the University of Alaska's Arctic Environmental Information and Data Center (AEIDC).

Assessment of Data Products and Deficiencies

Assessment of the adequacy of data products in relation to the diverse needs of user communities is largely a matter of subjective judgment since there have been few quantitative surveys. The relevant characteristics of each of the products are frequency (daily or weekly), timeliness of availability to the user, specificity of intensity and location of phenomena, prediction accuracy, and mode of dissemination.

The synoptic-scale Pacific Ocean analyses are essential input to NWS forecast offices in Alaska as a basis for the regional marine forecasts and warning services. These and the JIC ice analyses are also used to produce the regional ice analyses and forecasts. The most serious limitation for Alaskan forecasting is the meager data base over

TABLE 2-9 Analyses for the Arctic Sector[a]

Type	Coverage	Issued	Specificity	Sources	Map Scale	Producers	Comments
Southern ice limit analysis	Bering Sea	Weekly (22 GMT)	Extent, concentration, age	NASA, NOAA, DMSP satellites, aircraft, ship, ground observation	1:5.0 million	JIC[d]	Heterogeneity and non-simultaneity of input data
North Slope ice analysis	1. Chukchi, North Bering, and Beaufort seas	MWF[c] (04 GMT)	Extent, concentration, age	Satellite[b] imagery, wind vectors, recon.	1:4.0 million	JIC	"
Alaskan sea ice analyses (boundaries vary dependent on season)	1. Chukchi, Bering, and Beaufort seas	MWF (04 GMT)	Extent, concentration, age	Satellite imagery, wind vectors, recon.	1:2.4 million	JIC and NWS[e] Anchorage	" Cloud cover limits satellite mapping
	2. Cook Inlet	MWF (04 GMT) Nov-Apr		Satellite imagery, wind vectors, recon.	1:5.0 million	NWS, Anchorage	
North Pacific synoptic analysis	180°-120° W 80°-40° W	4/day (00,06,12, 18 GMT)	1. MSL[f] 2. Rel. humidity at 700 mb 3. Temperature at 850 mb		1:10 million	NMC	Limited detail (e.g., polar lows)
Sea-surface thermal analysis	180°-158° W 66°-54° N	3/week (Apr-Sept) 1/week (Oct-Mar)	Temperature, ice edge, mixed layer, depth	Satellite imagery Soon: microwave data	1:10 million	NWS, Anchorage	Variable input data coverage

[a]This list omits hemispheric analyses by the National Meteorological Center (NMC) used for forecast guidance at Alaskan Weather Service Forecast Offices.
[b]Satellite sensors are NASA (NIMBUS), NOAA (AVHRR), SMMR passive radiometer, GEOSAT (Navy) radar altimeter.
[c]Monday, Wednesday, Friday; time expressed in Greenwich Mean Time, 04 = 0400 hrs.
[d]Navy/NOAA Joint Ice Center.
[e]National Weather Service.
[f]Mean Sea Level.

TABLE 2-10 NOAA Graphic Forecast Products

Type	Coverage	Frequency/ Time Issued	Time Covered	Specificity	Map Scale	Producer	Comments
Seasonal western Arctic	Alaskan north coast	1/yr	5 months	Ice severity	Tabular	JIC	
Western arctic ice	90° E-90° W	2/month	30 days	Extent, concentration, age	1:11.6 million	JIC	
Ice accretion (structural icing)	Approx. 180°-125° W 70°-30° N	1/day	24 hrs 36 hrs 48 hrs	Rate/3 hr (contours)		NWS/NMC Marine Products Branch	Experimental
North Pacific surface winds		2/day	24) 36) hrs 48)	Vectors at grid points	1:20 mil-lion	NMC	
Ice motion	180°-165° W	1/day	6 days	Drift vectors in pack	1:2 mil-lion	JIC/NMC, Marine Products Branch	Experimental (2 models)
North Pacific prognosis	180°-120° W 80° N-40° N	2/day	24 hr + 24 hr outlook 36) 48) hr 60)	1. MSL 2. Rel. humidity at 700 mb 3. Vertical velocity and precipitation at 700 mb		NWS, Forecast Office, San Francisco; NWS, Anchorage--Bering Sea and Arctic	
Ice forecast maps (E. Bering Sea, Cook Inlet)	180°-158° W 80° N-54° N	MWF (04 GMT)	5 days	Ice edge, concentration, age	1:10 mil-lion	NWS, Anchorage	
Significant wave (deep water)	Whole Gulf of Alaska/ Bering Sea	1/day (22 GMT)	Next day 12 hrs GMT		1:10 mil-lion	NWS Anchorage	Navy/NOAA global spectral wave model
North Pacific marine weather outlook		1/day (10 GMT)	5 days	General synoptic situation			Experimental (based on T_a, SST, and wind velocity over ocean)

NOTES: GMT--Greenwich mean time
MSL--mean sea level
NWS--National Weather Service
NMC--National Meteorological Center
JIC--Joint Ice Center
T_a--sea-column temperature
SST--sea-surface temperature

the ocean areas, especially the lack of ship weather reports during night hours. These are critical input data to the 1200Z (0400 local Standard Time) forecast chart. Small-scale features--such as arctic lows, which can develop and intensify within 12 hours--are generally missed by such analyses and, in their early state of development, even by the 12- to 24-hour operational satellite passes.

The sea-surface thermal analysis depicting ice edge, sea-surface temperatures (SST), and mixed layer depth also suffers from variable space-time coverage of input data and heterogeneous sources and types of SST data (ships and satellites).

The data input and model limitations for the two synoptic analyses affect the accuracy and reliability of the twice-daily North Pacific weather forecast map and marine weather forecast map for Alaskan

TABLE 2-11 Forecast Products: Plain Language

Type	Coverage	Frequency Time Issued	Time Covered	Specificity	Producer	Comments
Marine weather coastal forecasts	20 coastal sections	2/day	24 hr +24 hr	Weather, winds, sea state	NWS (4 WSFOS[a] in Alaska)	Warnings (if any)
High seas forecast	N of 50° N E of 180°	4/day	24 hr	Winds, sea state	NWS, Anchorage	Warnings (if any)
Marine forecast	Alaskan waters	1/day	5 days	Cyclone tracks, intensity	NWS, Anchorage	
Sea-ice advisory	Alaskan waters	M/W/F (20 GMT)	5 days	Ice conditions, changes	NWS, Anchorage	
Marine forecast tables	20 coastal sections	2/day	12 and 24 hrs	Winds, weather sea state, icing	NWS	Facsimile via Kodiak
Tsunami warning system	Gulf of Alaska	Warning if seismic sea waves confirmed Hourly bulletins		Wave arrival times for coasts	NWS Palmer, Alaska	

[a]Weather Service Forecast Observation Site

waters, the 5-day marine weather outlook, and the 5- and 30-day ice forecast maps. Numerical atmospheric forecast models need to be modified or developed for the Arctic. Most existing operational models were tuned to perform best at mid-latitude. Since the atmospheric models drive many other forecasts (e.g., waves, currents, and sea ice), they are critical to the safety and efficiency of decisions affecting many operations. Pressure data from the Arctic Ocean drifting buoys are critical for accurate synoptic analyses and forecast model initialization. Errors in the analyses in high latitudes have been shown to distort the forecast charts for Alaska and the contiguous mainland United States and Canada. Continuation of such data collection programs is of great importance.

Within their recognized limitations, forecast products are generally well regarded. They are essential for public safety and the successful operation of many aspects of commerce, industry, and government, particularly in the area of transportation. Nowcasting--short-term predicting--techniques appropriate for high latitudes are not yet developed for hazardous storm situations involving high winds and waves. The regional ice chart indicates a general level of forecast confidence. The feasibility of expanding this approach to other products, and to differentiate such levels according to geographical area, would seem worthwhile.

The daily, significant (deep water), wave height prognostic chart has serious limitations for continental shelf areas. A user assessment of observed sea conditions in 1981-1982 enabled NOAA's Anchorage office to make adjustments to the model predictions for the open ocean waves. The information is derived from a Navy-NOAA global spectral wave model, and the information refers to deep waters of the Gulf of Alaska and Bering Sea. Locally specific bathymetric data and input data are necessary to predict coastal wave conditions, such as the experimental Harbor Bar Forecast for Yakutat Bay.

Records show an annual global occurrence of one destructive tsunami, with one destructive event per decade in the Pacific basin. Subsea earthquakes off the Aleutians present the greatest potential for damaging tsunamis along the coasts of the Gulf of Alaska.

The tsunami warning system relies on seismograph data and teletype tide gauge reports (Witten, 1984). A fully reliable and prompt warning system needs telemetered data from West Coast stations and a back-up computer system. Instruments to monitor seabed seismic activity have been developed commercially and should be evaluated. Little attention has been given to computer modeling of potential coastal wave run-up heights.

Alternatives for Improvement of Processing and Dissemination

The identified deficiencies include some that can be remedied quickly at modest cost; other problems require major changes in structural arrangements. Some deficiencies will be met when new measurement systems already being planned become operational, providing, of course, that there are requisite resources to ensure data availability and delivery.

Ice Data

Current ice information data available to JIC are derived primarily from satellites. The AVHRR data from NOAA's polar orbiting satellites provide sufficient accurate information on cloud positions for meteorological forecasting, but are insufficient for determining the position of the ice edge. Errors of 10 to 20 nautical miles in ice edge are common, depending on the position of the ice edge relative to the satellite suborbital location on the earth's surface. Since clouds are often present, they tend to obscure the ice cover. Enhancement techniques using several channels occasionally provide a better delineation. Digitally processing the NOAA data could eliminate these serious shortcomings.

Another major satellite data source is NASA's scanning multichannel microwave radiometer (SMMR) data obtained from the NIMBUS-7 satellite. The SMMR, which has nearly an all-weather, day and night capability, provides global data on a 25 by 25 km resolution. Due to the lack of digital handling capability, this important data set for strategic ice information is severely underused. An example of its potential capability is shown in Figure 2-3. Combining different data products such as the AVHRR and SMMR would provide enhanced ice information, as shown in Figure 2-4.

The NOAA polar orbiting satellites to be launched about 1988 will operate a split-channel 1.6-μm sensor. This wavelength offers unique, demonstrated capabilities for snow and cloud discrimination. It is essential for the research community generally and for the Alaskan Arctic in particular that a data product be developed from this sensor. Optimally, this product might be combined with the data provided by the microwave sounder, which can also be used to delimit the ice conditions.

The needs for improved products require the following:

- Accelerated processing of existing satellite and other data streams by the JIC. Considerable time could be saved by installing state-of-the-art image processing capabilities at JIC to enable overlaying of varied data on different background grids.
- Improved data links between the NMC and JIC for the transmission of analysis and forecast products to JIC.
- Direct-facsimile reception of JIC transmissions for timely delivery to marine users in Alaska. Currently, various government agencies and some contractors receive regional ice charts by telecopier in exchange for providing local data.

Ice analyses are important to many users for planning and operations. Currently available data consist primarily of satellite imagery. The JIC has available DMSP and NOAA visible and infrared imagery, aircraft reconnaissance information, and ship and shore station reports. Limited SMMR data from NASA's NIMBUS-7 satellite are also available, but these do not utilize the full scope of the SMMR system. The use of NOAA/DMSP imagery for ice mapping is greatly limited by cloud cover and by the absence of daylight during the winter, which prevents the use of visible wavelength images. Regional

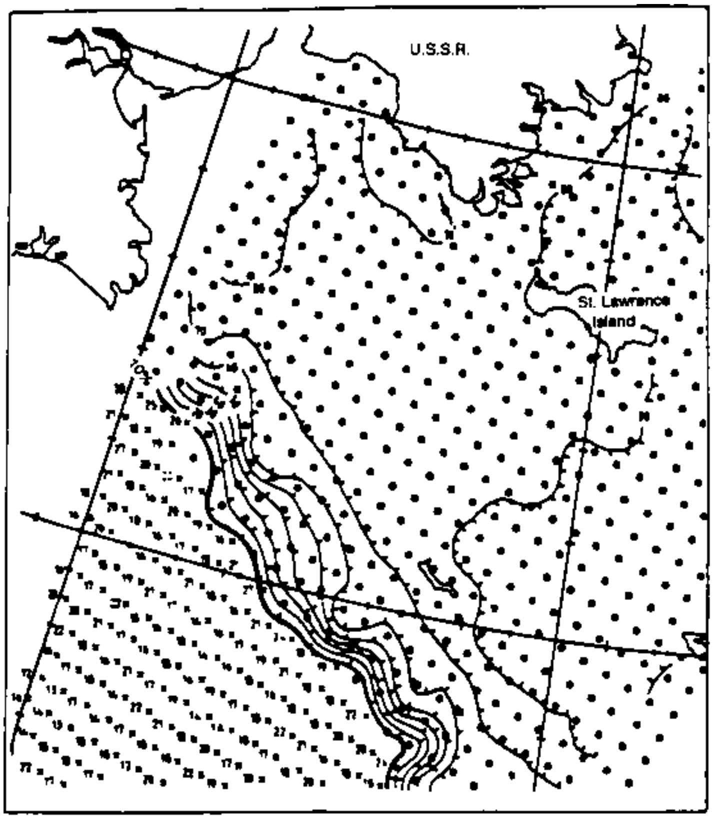


FIGURE 2-3 Bering Sea ice cover for February 7, 1984, derived from scanning multichannel microwave radiometer data; each dot or cross indicates the center of a picture element (pixel). Ice concentrations have been contoured at 10 percent intervals, with 10 percent representing the ice edge. Numbers in the open ocean represent wind speed in knots. SOURCE: Atmospheric Environment Service, Canada.

products use direct readout from NOAA polar orbiters, GOES-West, and the Japanese GMS as available, but the same limitations apply. Passive microwave sensors provide all-weather data, but they have only 25-50 km resolution, which is inadequate for mapping leads and landfast ice.

The principal shortcoming identified by users is the absence of near real-time information on ice edge location and ice motion. Questionnaires indicate a demand for increased resolution of current products to provide ice edge location (to 1 km), ice concentration (to 5 percent), and daily frequency. New products to display iceberg/floeberg location, size and movement, polynya location and size, and ice thickness are also requested by users of JIC products. Locating icebergs and mapping leads and polynyas would require coastal and airborne radar, until satellite radar data become available about 1990. The Soviet Cosmos satellite already carries an SLAR with 1-km resolution which was used to direct icebreaker activities when a merchant convoy was beset by ice in the East Siberian Sea in the fall

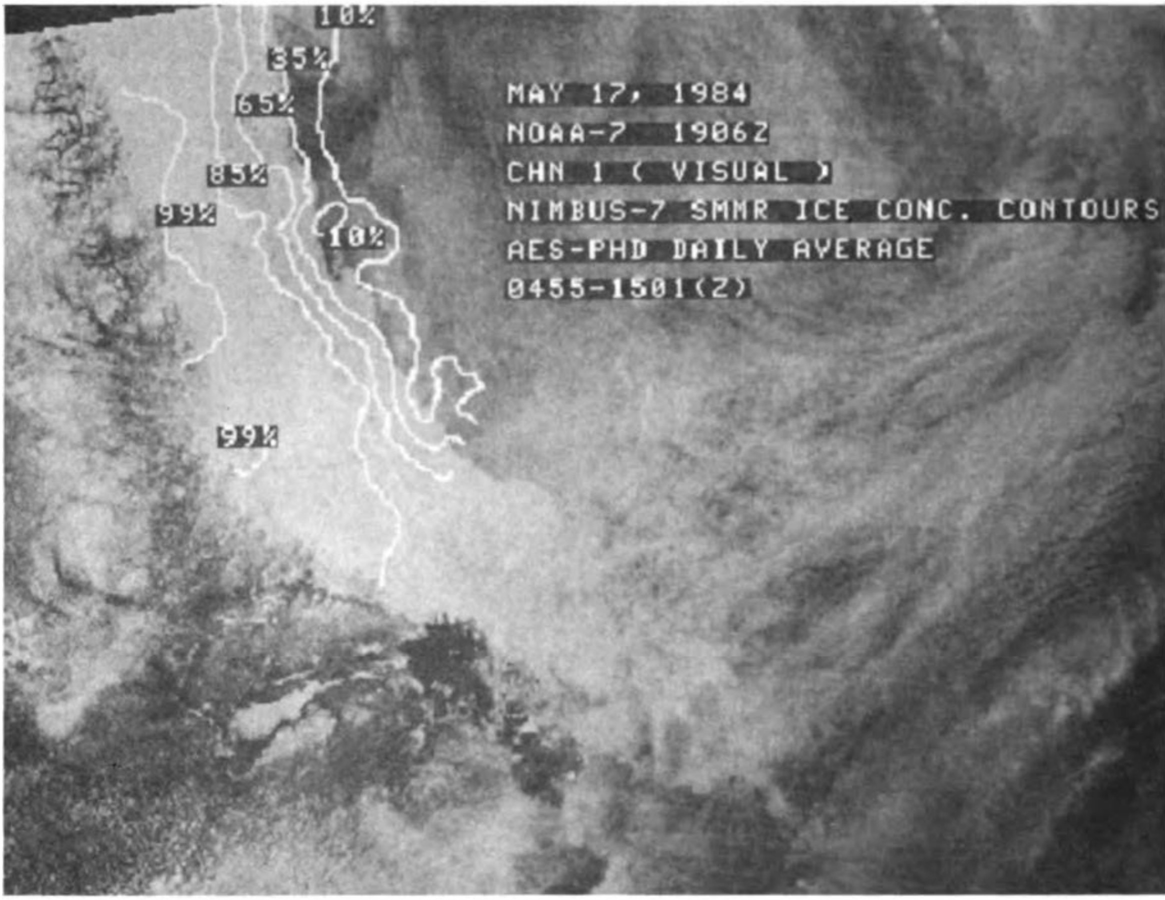


FIGURE 2-4 An enhanced ice information product.

of 1983. Ice thickness surveys by airborne systems are still experimental.

Some of the new products requested may fall within the gray area of specially tailored services. However, the facilities needed for satellite radar data processing, for example, will be extremely costly. Dissemination of information from such analyses will also require sophisticated data communication links, and it is not yet clear how such data delivery systems can best be implemented and what costs can be charged to users. It is worth noting that cost recovery for special forecast services is already a well-established practice in Canada (Atmospheric Environment Service), the United Kingdom (Meteorological Office, for long-range weather forecasts) and Sweden (Swedish Meteorological and Hydrological Institute [SMHI] for special forecasts in the Baltic Sea). In Sweden over half of the funding for the Marine Forecasting Services is derived from such revenue. Government regulations do not permit NOAA to recover costs from such activities and reallocate them to develop and improve the agency's environment data services.

Marine Analyses and Forecasts

The vital need for measurements in the open ocean has been noted. This general objective requires continuation and expansion of the proven data buoy technology and efforts to improve collection of ship-of-opportunity observations, especially during night hours. Additional buoys are needed in Gulf of Alaska coastal waters, where wave forecasting is a significant problem. In the Bering Sea the program of Exxon buoys ended in 1985, but two meteorological towers (one each on St. Matthew and St. Lawrence islands) have been continued and feed their data into the NWS system.

Future Processing Plans

Major advances in satellite data collection over the oceans are expected before 1990 (Joint Oceanographic Institutions, Inc., 1985). The systems planned for the DMSP, NROSS, Canadian RADARSAT, and European Space Agency's ERS-1 were identified earlier in this chapter. The potential of these advanced sensor systems will be realized only if there is timely data flow, processing, and product delivery to users. This requires adequate planning of organizational arrangements, algorithm development, hardware and software procurement, and data validation following launch. A second essential requirement is assured funding to initiate these procedures and to continue the data processing, archiving, and management over the 5- to 10-year lifetime of these systems. The continuing weak position of overall budgetary allocations for NOAA and the minimal success of new initiatives (e.g., the Ocean Satellite Services initiatives) for such activities is of utmost concern. It cannot be overemphasized that implementation of such plans requires 2 to 3 years' lead time prior to launch to enable fully operational processing systems to be put in place (i.e., Fiscal Year 1987 for Fiscal Year 1990 operations).

Defense Meteorological Satellite Program (DMSP)

A new DMSP satellite is incorporating for the first time a new operational SSM/I, and is scheduled for launch in mid-1986. It will provide data for ocean surface wind speed, precipitation, water vapor, cloud water, liquid water, and sea-ice parameters. It will enter the Shared Processing Program data link from the Fleet Numerical Oceanographic Center (FNOC) and Air Force Global Weather Center (AFGWC) to NESDIS in near real-time. Orbital data will be archived by SDSD;

orbital and gridded brightness temperatures for polar regions and gridded sea-ice products will be archived by the National Snow and Ice Data Center (Weaver and Barry, 1985). NWS and NOS will provide data to the civil marine community (Sherman, 1985), but the details of implementation are not yet available.

Navy Remote Ocean Sensing System

The Navy Remote Ocean Sensing System, NROSS, is scheduled for launch in mid-1989. It will provide data from the DMSP SSM/I, together with global wind velocity (scatterometer), all-weather sea-surface temperature (low-frequency microwave radiometer) and ocean waves, and sea ice edge (altimeter). The plan for data distribution is as noted for DMSP (Sherman, 1985).

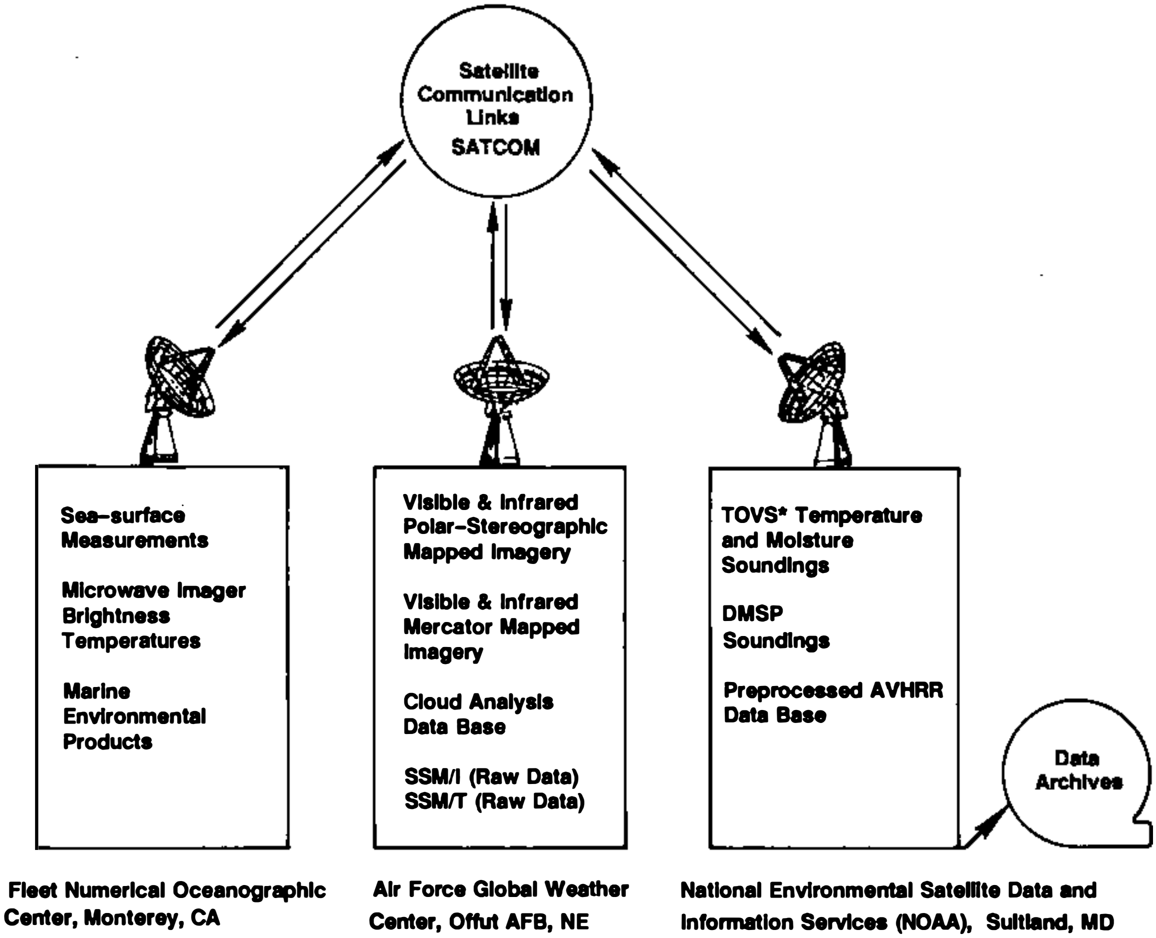
European Space Agency Satellite ERS-1 and Canadian RADARSAT

The European Space Agency ERS-1 (1989-1990) will carry sensors similar to those on NROSS. In addition, SAR data will be collected over most of the Arctic by direct readout to receiving stations at Kiruna, Sweden; Ottawa, Canada; and Fairbanks, Alaska (PIPOR, 1985). Present plans indicate that the European Space Agency will provide 5 to 10 minutes per day of high-rate digital SAR data to NASA, which will develop an SAR receiving and processing station at the University of Alaska Geophysical Institute in Fairbanks. An agreement between the university and NASA is being worked out for this activity and for the development of data archiving for research purposes. NASA and NOAA must complete and implement coordination to enable NOAA to meet near real-time user needs for operational requirements.

The Canadian RADARSAT (1990 launch) is also planned to have an SAR and scatterometer, but at present NOAA has no plans to receive any of those data.

Data Integration

An arrangement for shared processing of interagency meteorological satellite data has existed between the Air Force, NOAA, and the Navy since 1975. This concept will be implemented in 1986 with data from the DMSP and NOAA polar orbiters, followed by oceanic data from NROSS in 1990 (OAO Corporation, 1985). NESDIS will produce atmospheric sounding data, FNOC sea-surface measurements and microwave imagery (antenna and brightness temperatures) products, and AFGWC visible and infrared map imagery and cloud analyses. Transmission of data exchange eventually will be accomplished through a dedicated satellite wide-band communications system. NESDIS will also archive the data produced under this agreement (OAO Corporation, 1985) and will transmit the five channels of AVHRR Global Area Coverage preprocessed orbital data. Figure 2-5 provides an overview of the shared processing arrangement.



*Tiros Operational Vertical Sounder; other acronyms are listed in Appendix C.

FIGURE 2-5 Shared processing overview.

It is planned that the NESDIS/SDSD will distribute the shared processing data on a cost-recovery basis to near real-time and retrospective users. The sea-ice parameters produced from the SSM/I by FNOC will be transmitted via NESDIS/SDSD to JIC for near real-time use. The details of these proposals have not yet been specified. In addition, the National Snow and Ice Data Center at the University of Colorado will process SSM/I brightness temperature data received from SDSD into gridded sea-ice products using the Science Working Group (1984) algorithm and distribute the processed data to retrospective users (Weaver and Barry, 1985). However, funding for this activity has not been committed beyond the development phase.

A separate agreement is being prepared between NOAA and NASA on space-related programs. For data management, this will establish a mechanism for providing NOAA with NASA experimental remote-sensing data sets and derived products, and facilitate NASA access to NOAA operational data for this research program. Specific cooperation is expected to include processing and managing sea-ice data by NSIDC, and applying the JPL Pilot Ocean Data System (PODS) image processing technology to combine satellite and in situ ocean data. No arrangements have yet been made for the provision of ERS-1 SAR data from the planning facility at Fairbanks, Alaska, to NOAA.

Projections of satellite and other data collection indicate that NESDIS data holdings will double by 1990. Existing NOAA data management systems will be unable to handle this growth as well as the user needs for improved data products and data access. Moreover, the present system cannot adequately provide access to NOAA's existing data holdings needed by retrospective users. Access is indirect, and the data are usually provided on tape or diskette with a turnaround of days to weeks. There is a recognized need to selectively archive the increasing streams of satellite data in near real-time and to provide access via direct computer links. Another possible trend is data management decentralization resulting from the spread of micro- and mini-computer systems and high-density digital storage systems. Adequate quality control would have to be ensured in such a case.

It is essential that NOAA provide adequate planning and funds to upgrade its systems for managing archival data and for the high volumes of satellite data anticipated for the late 1980s and 1990s. The data input to NESDIS between now and 1992 will exceed by more than twofold the total data acquired over the last century. Moreover, NOAA currently archives only 20 percent of all the nation's atmospheric and oceanic data. NOAA's satellite services (including data management) have remained at almost level funding since 1980, while there have been rapid increases in POES and GOES expenditures. A NOAA budget initiative to remedy this situation was only partially successful for Fiscal Year 1987. An initiative for a National Oceanic and Atmospheric Data Network to upgrade the environmental data accessibility is under consideration. However, even this proposal is modest compared with resources committed to NASA's Pilot Data Systems. Failure by NOAA management to address this problem will seriously hamper many commercial and industrial developments in arctic offshore areas and would constitute a serious waste of the resources invested in the new satellite systems.

The availability of faster computers, augmented data storage, and flexible image processing systems can be exploited over the next 5 years to significantly improve NOAA's arctic environmental products and services. Until now, laborious manual procedures have been used to overlay data displays from different sensors or measurement platforms. Sophisticated systems, such as those available in the Prototype Regional Observation and Forecast System (PROFS) of NOAA-ERL, NASA's Pilot Climate Data Systems (NASA, 1985), and NORDA's Interactive Digital Satellite Image Processing System (Hawkins et al., 1985), illustrate the scope of state-of-the-art technology. Beyond these data display techniques, however, there is a need for more research on the best ways to analyze and combine data on surface winds, waves, sea-surface temperatures, and ice conditions measured from ships and buoys with satellite measurements. Likewise, forecast models should be able to directly integrate satellite-measured parameters as well as derived variables.

The data collection and management issues raised here for the Arctic form only one part of the broad problem of earth sciences research recently addressed by the Senior Interagency Group on Space of the Office of Science and Technology Policy (1985). Its report identifies NOAA's primary responsibility for long-term environmental data bases to assess mankind's global impact or potential impact on the oceans, atmosphere, and land. The Arctic represents a special concern in this context because of the key role of space-based remote sensing. The OSTP report recommends that budgetary planning consistent with the earth sciences research plan be initiated immediately by the relevant agencies.

3

CONCLUSIONS AND RECOMMENDATIONS

The Committee on Arctic Integrated Ocean Information Systems presents the following general conclusions about NOAA's oceanographic and meteorological products and services.

- NOAA's oceanographic and meteorological products and services largely satisfy the present public and private needs of the maritime, fishing, and offshore oil and gas industries operating in the arctic and subarctic seas adjacent to Alaska.
- NOAA's emphasis on acquiring, processing, and disseminating long-term global and regional environmental data for arctic engineering applications, operations, and research is basically responsive to its mission.
- Improvements are needed at present in forecasting the rapid development of extreme weather and sea conditions, particularly in Bering Sea areas where the safety of coastal inhabitants and fishing operations may be threatened.
- NOAA needs to improve accessibility to real-time and archived data systems and capabilities now in place or planned for operation during the next 5 years.

The committee has identified the following specific areas where improvements are needed and actions should be taken:

Planning for New Satellite Data Products and Services

- Planned operational satellites and sensors will be adequate for generating needed surface, ocean, and meteorological remotely sensed data through the mid-1990s. However, plans for data processing, archiving, cataloging, and disseminating systems to deal with the data flow expected to be generated in the next 5 to 10 years by new sensing systems are inadequate. Further planning and initiation of expanded data processing and storage capabilities under the government's meteorological satellite Shared Processing Program are dependent on long-term program commitment and funding by NOAA as well as by the Department of Defense (DOD). Timely implementation is a major concern to the committee. This program is national in scope and effect; its full implementation will be essential to the provision of basic arctic environmental services.

• Data from the proposed new polar orbiting satellites will be beneficial to the offshore and marine industries provided the data are assembled in manageable form and made available in near real-time. These data will also be useful to research if they are appropriately archived.

Recommended:

Ensure necessary planning and funding to process and archive data and disseminate the products derived from satellite sensor systems over the next 5 to 10 years for the Arctic. NOAA's firm long-term commitment to the NOAA-DOD Shared Processing Program is an essential element in this strategy.

Improving Access to Real-Time Satellite Data

• Existing satellite systems are not adequate to support expected future ice data needs of fisheries, marine commerce (tactical navigation), and offshore cargo transfer activities. Although new satellites are scheduled to be launched during the next 5 years (DMSP, ERS-1, NROSS and RADARSAT) to provide such a capability, the committee lacks confidence that the necessary planning will be completed and funding obtained to implement the tactical ice data needed to support fishing, government, and industrial operations in which vessels must transit ice-frequented or ice-covered waters.

Recommended:

With the U.S. Coast Guard and the U.S. Navy, develop and implement a plan that demonstrates application of tactical ice navigation information using processed data and imagery from new satellite systems having synthetic aperture radar (SAR) sensors.

• Deficiencies exist in the present real-time data delivery system. Specifically, because of limited on-board satellite data storage capability, a ground receiving station in Alaska for synthetic aperture radar and a real-time information dissemination system are essential to meet near real-time data needs.

Recommended:

Ensure the construction of a ground receiving station in Alaska for SAR and other data, and provide the capability for subsequent dissemination of data in near real-time.

Improving Archived Satellite Data Services

• Satellite data are not being inventoried and archived to the extent the committee believes will be needed for future analysis and planning for arctic activities. Also, there is a need to improve access to archived data.

• An overall plan is needed that addresses the needs of all users of data from sensors on current and future satellites, provides for formatting data in a useable form, and disseminates and archives the data.

Recommended:
Give high priority to developing improved means of accessing archived data. Particular emphasis should be given to quality control, data volume, cross referencing, telemetery, and data base management.

Validating Satellite Data

• There is insufficient effort to validate orbiting satellite sensor data.

Recommended:
Maximize the potential benefits from the new and costly satellite sensors by providing funds, planning, and program leadership to obtain surface-based and airborne measurements to validate satellite sensor data and the algorithms used.

Integrating Earth and Satellite Data

• There is need for further investigation into ways to enhance information services by combining data obtained from various satellite, earth, and airborne sensors.

Recommended:
Develop appropriate hardware/software systems to combine data from various satellite and surface-based sensors to utilize more fully the current and future data from the arctic and subarctic ocean areas. This action must be taken jointly by both operational and research elements within NOAA.

Automating Satellite Data Processing

• The routine exchange of data in the meteorological satellite Shared Processing Program is vulnerable to human error. This represents a major weakness in the planned acquisition-interpretation-dissemination process.

Recommended:
Automate the exchange of data among the three Centers of Expertise designated in the meteorological satellite Shared Processing Program.

Expanding Oceanographic Baseline Data Acquisition

• Satellite sensors can provide adequate atmospheric and surface data, but the essential needs of all users for long-term subsurface oceanographic data are not satisfied. Baseline fishery and oceanographic data in the Bering Sea and parts of the Gulf of Alaska are inadequate, especially time-series data for the water column structure. Recent developments in automated data acquisition systems can help satisfy these needs.

Recommended:
Obtain and maintain a long-term time-series of subsurface arctic and oceanographic data for fisheries application and research. Particular attention should be given to the possibility of using automated data acquisition systems such as systems placed on ships-of-opportunity, drifting buoys, and moored instruments in subarctic ocean areas.

Improving Forecasting Services, Data Sources, and Models

• Nowcasting of small-scale severe weather and ice movement for arctic marine and coastal areas is needed but is not being done. While local specialized services are expected to be provided by private industry, better access to NOAA's environmental data base is needed.

Recommended:
In concert with private information services, improve the acquisition and dissemination of locally detailed arctic meteorological and oceanographic information to the fishing industry, local communities, and commercial vessels and ports, and develop and implement a plan that:

- Resolves with the user communities additional needed satellite data, weather observations, and ice monitoring sites in the Arctic;
- Provides a means of putting the data in a useable form;
- Disseminates and archives appropriate data.

• Dedicated meteorological buoys for weather forecasting in the Arctic are lacking, and coverage of the arctic coast is inadequate in regard to rapid sensing and reporting of developing arctic lows and other severe weather conditions.

Recommended:
Ensure the availability of buoys for obtaining meteorological as well as oceanographic data.

• There are no numerical atmospheric forecast models designed specifically for the Arctic. Most existing operations models are tuned to perform best at mid-latitudes.

Recommended:

Conduct research to develop and improve operational atmospheric forecast models to:

- Provide nowcasting techniques for arctic applications.
- Enhance current National Weather Service (NWS) marine forecasts.
- Provide a long-term hindcast (such as 20 years) of meteorological and oceanographic conditions in the Bering Sea using an appropriate model. Until this model is developed, NOAA should archive synoptic charts derived by the NWS in Alaska.
- Improve ice edge predictions.

Providing Adequate Fisheries Data

• NOAA, under the requirements of the Magnuson Fishery Conservation and Management Act of 1976, is responsible for management of fishery resources in the U.S. ocean areas in the Arctic. NOAA data and products that fishermen and fisheries managers use to forecast fish abundance and distribution in arctic waters are marginally adequate.

• Arctic ocean fishery management depends, to a large extent, upon data collected by observer programs funded either directly by foreign governments, or indirectly through the collection of fishing fees. A shift to domestic harvesting will require a similar domestic observer program.

Recommended:

Develop an adequate fishery data collection system for domestic fisheries in the Arctic. This action will require funds to replace the loss of foreign-financed observers who now provide much of the fisheries data. In the interim, NOAA should continue to investigate the possibility of placing automatic reporting devices aboard foreign and domestic fishing vessels to acquire real-time weather, sea state, and fishery catch data.

Upgrading the Tsunami Warning Service

• Tsunamis pose a severe risk for coastal locations in the Gulf of Alaska. Systems for reliable detection of seabed seismic events and early detection of ocean seismic waves, as well as satellite communication of this information, are essential to issue timely warnings. Accurate bathymetric and coastal surveys would greatly improve the basis for predicting tsunami effects. Improved records of past events, travel times, and effects are essential to research concerning mechanisms, characteristics, and predictability.

Recommended:

Upgrade the system for providing timely warnings of infrequent, but potentially devasting, tsunamis along the coastline of the Gulf of Alaska by deploying and testing improved seabed seismic detection devices and fail-safe satellite transmission of data on ocean level and seismic waves to the NWS Alaskan warning center. Improve modeling of travel times and coastal run-up of tsunami waves.

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APPENDIX A

NOAA ACTIVITIES AND NEEDS FOR OCEANOGRAPHIC AND METEOROLOGICAL DATA FOR ARCTIC MARINE OPERATIONS

This appendix summarizes programs of the National Oceanic and Atmospheric Administration (NOAA) and indicates some needs for acquisition of oceanographic and meteorological information to support its own operations. These summaries are based on material provided by NOAA at the request of the committee.

NATIONAL OCEAN SERVICE

In December 1983 NOAA Administrator Dr. John V. Byrne instructed the National Ocean Service (NOS) to take the lead in integrating oceanographic and meteorological services to the marine community. This mandate was added to a growing list of responsibilities placed on the NOS predecessor agencies by Congress and the executive branch since 1807. Consequently, NOS has long-standing responsibilities in marine mapping, charting, and geodesy, as well as documenting fluctuations in lake and ocean levels caused by lunar and atmospheric forces.

In the Arctic, NOS has been particularly active in assisting the State of Alaska in surveying its coastline and waterways. Accurate surveys were required because of the potential royalties from tideland oil and minerals leases. NOS has also assisted the Minerals Management Service by mapping areas of the continential shelf slated for offshore oil and gas leasing.

Since weather and climate impose harsh effects on all ship and aircraft operations in the Arctic, and because NOS has a long-term need for continuous observations to support the NOAA field service, it will play a leading role as the integrator and coordinator of ocean environmental products and services. In this regard, NOAA Administrator Dr. Anthony Calio and the oceanographer of the Navy, Rear Admiral Richard Seesholtz, requested NOS to prepare a Technical Improvement Plan for the Navy/NOAA Joint Ice Center for submission to both organizations in the fall of 1985.

NATIONAL WEATHER SERVICE

The National Weather Service (NWS) makes atmospheric observations as required to provide meteorological forecast and warning services. NWS products include weather forecasts and severe storm and adverse weather warnings for the protection of life and property. NWS also makes observations and measurements of ocean conditions as required by marine interests. These observations are used to distribute forecasts and warnings of waves, tsunamis, sea ice, and other ocean conditions for the protection of life and property and to enhance the efficiency of marine operations. NWS is also responsible for developing meteorological, climatological, hydrologic, and ocean service systems to meet user requirements.

General long-range NWS data objectives include an all-weather satellite system with a complementary network of surface observation stations (on both land and water). Data products that are, or soon will be, obtained from the satellite system include:

- visual and infrared cloud cover
- surface wind speed and direction
- sea state
- sea-surface temperature and current speed and direction
- vertical atmospheric temperature and humidity profiles
- sea-ice type, extent, and concentration

Surface observations needed to provide ground truth calibration for the satellite data are:

- wind velocity and gusts
- spectral energy, wind, wave, and swell
- barometric pressure and pressure tendency
- air temperature
- visibility
- relative humidity or dew point temperature
- sea-surface temperature and subsurface temperature profiles
- sea-ice drift
- ocean current velocity

To obtain such baseline information, reporting hourly is required from a network of fixed stations. These stations also be capable of reporting more frequently when certain threshold values are exceeded. This network should provide data in a time-series selected to detect rapidly moving or intensifying storm systems. This capability would be used to alert forecasters to trends and thresholds for early warnings, and such a network would permit interpolation and timing of events between points. In addition, an effective synoptic network would produce weather condition "snapshots," and provide improved data having continuity without breaks or voids in the data record. After several years of operation, the satellite observational inputs will improve the data base for climatological archives. This synoptic network will also provide inputs to forecast models and private sector users.

NATIONAL MARINE FISHERIES SERVICE

The National Marine Fisheries Service (NMFS) administers a marine fisheries program that promotes the conservation, management, and development of living marine resources for commercial and recreational use. The program includes services and products that support fisheries management operations (domestic and foreign), fisheries development and industry assistance activities, protected species and habitat conservation operations, and the scientific and technical aspects of NOAA's marine fisheries resources program.

One of the fundamental internal needs of NMFS for arctic environmental information is the safe operation of NOAA and chartered research vessels--a requirement shared by all arctic seafarers. Timely environmental information is needed on sea-ice location, bottom topography, and weather conditions and forecast.

Beyond these critical fundamental requirements is the desirability of supplemental information on subsurface physical and chemical properties of arctic waters. These data are most frequently acquired by the fisheries research vessels themselves, although numerous other governmental agencies and nongovernmental institutions have contributed extensively to the arctic oceanographic data base. The acquisition of more extensive subsurface oceanographic information in arctic waters, while desirable, may be prohibitively expensive. This situation could be ameliorated by initiation of a ship-of-opportunity effort in arctic waters to collect basic data, such as temperature profiles and surface winds. Additional measurement of salinity, oxygen, and nutrients might be handled in a similar manner.

Unfortunately, present high-resolution satellite-derived oceanographic parameters from NOAA satellites are considerably restricted in high latitudes by cloud cover. Some parameters--such as sea-ice coverage, sea-surface temperature, and chlorophyll concentration--is measurable, but not on a routine basis. Of the data to be provided by newer satellites (DMSP and future NOAA and Navy satellites), sea-surface temperature, chlorophyll concentration, surface winds, and ice edge position, will be of greatest use to fisheries research.

NORTHWEST AND ALASKA FISHERIES CENTER (NWAFC), RESOURCE ASSESSMENT AND CONSERVATION, ENGINEERING DIVISION

The Northwest and Alaska Fisheries Center (NWAFC) has a continuing program to assess groundfish and crab resources of the Eastern North Pacific Ocean and the Bering Sea. These surveys provide information on composition, distribution, abundance, and biological characteristics to the North Pacific Fishery Management Council, the International North Pacific Fisheries Commission, the State of Alaska, and environmental management agencies. The strategy for collecting this information is based on annual and triennial surveys that include international research cooperation with Japan and the Soviet Union. The data base begins in 1955 for king crab and 1972 for groundfish in Bristol Bay. The surveys were expanded in 1975-1976 to support fishery management in the new Fishery Conservation Zone implemented by the Magnuson Fishery Conservation and Management Act (MFCMA) of 1976, which extended U.S. jurisdiction over commercially important resources extending from Unimak Pass to the U.S.-Soviet Union Convention Line. These surveys document variations in abundance of more than an order of magnitude for king and Tanner crab, and cod and other groundfish species. Short-term predictions of resource availability (1 to 3 years) are provided regularly to management agencies and to the domestic fishing industry.

NATIONAL MARINE MAMMAL LABORATORY, NMFS

The Marine Mammal Laboratory conducts research on the interaction of marine mammals with fisheries and industrial development, particularly how these interactions affect growth and population recovery. Of particular concern to NMFS management are declines in northern fur seas and sea lion populations in the southern Bering Sea. Effects of prey (fish) availability on feeding patterns, fishing operations (debris entanglement is a particularly grim threat to pinnipeds), environmental factors (e.g., ice, water temperature, and currents) haulout and breeding habitat, reproduction, and diseases are all key subjects under investigation.

There are two major management issues for NMFS concerning cetaceans. The first is the effect of the incidental take of Dall's porpoise in the Japanese, high seas, salmon gillnet fishery in the Bering Sea and North Pacific. Japanese salmon fishing and research vessels are used to collect samples of landed marine mammals for biological studies, population enumeration, and determination of the rate of incidental take. The second issue is recovery and maintenance recruitment rates in the U.S. arctic seas of bowhead whale populations and some bowheads are taken by Alaskan Eskimos in a subsistence fishery, and their habitat may be threatened by offshore oil and gas development. NMFS conducts aerial surveys in the spring to photograph the whales. Photogrammetric analyses are then performed to assess the size distribution (length) of individual whales in order to estimate recruitment, to determine overall population size, habitat use, and life history.

NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SERVICE

NESDIS conducts an integrated program to develop and use civilian satellite-based environmental remote-sensing systems; administers national and international acquisition, processing, dissemination, and exchange of environmental data; and develops and operates civilian satellite systems. It requires arctic environmental data to support its participation in the NAVY/NOAA Joint Ice Center (JIC) and its other forecasting responsibilities. Operational products that result from JIC include arctic ice analyses; sea-ice edge, concentration, and age; forecast dates for sea-ice break-up and freeze-up at high, medium, and low resolutions; and sea-surface temperatures. Ice atlases and a digital data base are also prepared independently by the JIC.

To conduct its mission, NESDIS requires real-time access to advanced very high resolution visible and infrared satellite imagery (1 km resolution), global-area coverage visible imagery (4 km resolution), and geostationary (GOES) visible imagery (1 km resolution). (Raw data ingestion should be within 3 hours of observation to permit its use in analyses.) These satellite data are supplemented by conventional and special environmental reports from shore stations, ships, and Canadian ice reconnaissance flights that provide sea-ice concentration, ice-type distribution, and ice edge information. Scanning multichannel microwave radiometer-based sea-ice-edge charts (60 km "coarse" resolution) are also required to "fill-in" holes in operational charts which result from persistent cloudiness.

Digital image processors have been proposed to replace current manual methods of producing operational sea-ice analyses. These processors would manipulate high-volume data sets and merge different format data sets using interactive techniques. Beginning in 1987, special sensor microwave imager data and high-resolution visible and infrared images will become available from the DMSP, and will be part of the Shared Processing Program. NESDIS will implement an on-line users service in 1987 to provide access to GOES, polar orbiter, and Shared Processor metsat data bases.

OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH

The Office of Ocean and Atmospheric Research (OAR) conducts an integrated NOAA research and development program. The program consists of NOAA laboratory and extramural research projects that are relevant to NOAA services and resource management. OAR's projects use routinely collected conventional environmental data products (both real-time and archival). Research projects that require nonroutine environmental observational data must collect those data as a special part of the project separate from the routine findings.

OAR arctic projects address three problem areas which have an influence on NOAA's mission:

- rapid encroachment of sea ice into ice-free areas;
- sea-ice concentration, movement, and convergence and divergence; and
- arctic weather forecasting.

APPENDIX B

THE STATUTORY BASIS FOR NOAA ACTIVITIES

At least 38 laws, resolutions, and executive orders form the statutory basis for NOAA's current activities. These are listed at the end of this appendix and referenced in the paragraphs to follow. For convenience, the statutory authorities have been divided into six categories. The following is a very brief summary of the most important requirements and authorizations in each category.

WEATHER

• NOAA is required to take needed data and measurements, forecast weather, develop international meteorological reporting networks (including ones in the Arctic), coordinate U.S. meteorological data requirements, support development of meteorological science and research;[1] a related law repeats the requirement that NOAA develop an international reporting network.[2]

• NOAA is also required to establish a continuing research program to monitor stratospheric changes and determine resulting climatic effects.[3]

• NOAA must prepare comprehensive 5-year plans for ocean research, development, and monitoring so that national priorities can be set.[4]

• NOAA is authorized to make meteorological observations,[2] to study severe disturbances in the atmosphere,[5] and to participate fully in the 5-year National Climate Program.[6]

• NOAA is directed by executive order to perform the functions of the National Oceanographic Instrumentation and Data Centers and the National Data Buoy Development Projects;[7] these functions were transferred from the Navy and the Coast Guard, respectively.

• A Senate resolution expresses the sense of Congress that NOAA represent the United States in participating fully in a worldwide weather program or system.[8]

FISHING AND WILDLIFE

• NOAA is required to make Fishery Management Plans available to the public and to carry out a comprehensive fishery research program to support preparation of such plans.[9] An annual report to Congress on allocation levels is required.

- NOAA must be consulted on protection of fisheries resources from damage caused by subsea mining operations.[10] The Secretary of the Interior must cooperate on fish and wildlife research, and the results must be made public;[10] and the State Department must consult with the Commerce Department in developing fishery schedules and guidance materials.[11]
- NOAA is authorized and directed to provide grants to states concerning sports fishery problems.[12]
- NOAA must enforce the International Convention for the High Seas Fisheries of the Pacific Ocean.[13]
- NOAA is required to implement the convention between the United States and Canada outlining research to be carried out on sockeye and pink salmon in the Fraser River.[14]
- NOAA is required to carry out seal research in accordance with the Fur Seal Convention.[15]
- NOAA is authorized to enter into joint projects with states to protect anadromous fish and to conduct related research.[16] A similar act authorized NOAA to cooperate with states on fishery research.[17]
- NOAA is authorized to carry out studies and investigations on broad aspects of fishery resources, including production and sale of fish, abundance of resources, and related statistical data.[18] Again, NOAA is authorized to protect fishery resources.
- NOAA is authorized, by several general laws, to study migratory sport fishes,[19] cooperate in whaling studies,[20] cooperate with state and federal agencies to study salmon stocks in the North Atlantic,[21] establish a salmon and steelhead research program,[22] and conduct joint research with Japan on salmon fisheries and marine mammals in the Pacific.[13]
- NOAA is authorized to support a broad research program for the protection of marine mammals and to publish results in the Federal Register.[23] (This law also bans the taking and exporting of marine mammals, with some exceptions.)
- The Secretary of Commerce is authorized to study endangered species and list them publicly.[24]
- NOAA is permitted to report[25] on the fishery and wildlife aspects of water development projects.
- NOAA and the State Department are allowed to set the allocation levels of fishery resources to be removed by foreign nations.[9]
- NOAA is allowed to enforce the Halibut Fishing Convention between the United States and Canada.[26]

ENVIRONMENTAL CONSERVATION

- NOAA is required to prepare an Environmental Impact Statement whenever any proposed action of the agency will significantly affect the quality of the human environment.[27]

- NOAA is required to initiate a broad research program on the effects of pollution (including ocean dumping), overfishing, and ecosystem changes.[28]
- The Secretary of Commerce is authorized to designate marine sanctuaries of ocean, coastal, and Great Lakes waters. The Secretary must consult with other federal departments and state officials. The Secretary of Commerce shall issue appropriate regulations that are subject to review and approval by the governors. NOAA is authorized to cooperate with other nations in such studies.[29]
- NOAA is authorized to carry out research on the effects on the marine environment of seabed mining and mining waste disposal at sea.[30]

EARTH SCIENCES

- NOAA is designated the central agency to collect geomagnetic data and to make it available to others.[31] The same law authorizes NOAA to make geodetic, topographic, and hydrographic studies: measure tides and currents; and to make other field surveys to collect basic data and develop navigation charts for a broad range of users.
- NOAA is also authorized to conduct research in the geophysical sciences and to enter into joint projects to do surveying "in the public interest."[31]

SUBSEA MINING

- NOAA is required to be consulted on preparation of any subsea mining plan.[10]
- NOAA is authorized to carry out research on subsea mining, particularly on matters such as health, safety, pollution, and economics.[32] (It was this legislation which transferred the Minerals Technology Center to NOAA from the Bureau of Mines.[32])
- NOAA is permitted to accelerate studies of how mining and other commercial activities affect the marine environment.[30]

COASTAL ZONE MANAGEMENT

- The Secretary of Commerce is authorized to make grants and contracts with any coastal state to develop and implement a management program for the coastal zone and for acquiring and operating estuarine marine sanctuaries.[33]

GENERAL AND MISCELLANEOUS

- NOAA has responsibilities for remote sensing, including the storage and maintenance of satellite data and the requirement that data be made available on a nondiscriminatory manner to civilian users.[34]

• NOAA is mandated to participate in reorganization inside the federal government. For example, NOAA now has the U.S. Army Corps of Engineers' former responsibility for conducting basic research on water, ice, and snow.[35] This law also gives NOAA most of the functions of the Marine Minerals Technology center and all functions of the National Sea Grant Program.

• NOAA is authorized to support a variety of programs to enhance broad understanding of ocean and coastal processes and resources and to support research on national needs which have been identified.[36]

• NOAA is authorized to support research and development of diving, particularly in hostile environments.[37]

• One of the oldest relevant laws authorizes all agencies within the Commerce Department to carry out special studies and make them available at cost and to undertake joint research projects with others in areas of mutual interest.[38]

RELEVANT LAWS, RESOLUTIONS AND EXECUTIVE ORDERS

1. Federal Aviation Act of 1958--49 U.S.C 1463
2. Weather Bureau Act--15 U.S.C. 313,313a
3. The Clean Air Act--42 U.S.C. 7454
4. National Ocean Pollution Planning Act--33 U.S.C. 1704,1705
5. Act of June 16, 1948--15 U.S.C. 313 nt. Stat. 70
6. National Climate Program Act--15 U.S.C. 2904,2907
7. Executive Order No. 11564--15 U.S.C. 1517 nt.
8. Senate Concurrent Resolution 67--World Weather Program, May 29, 1968, 82 Stat. 1443 (not independent authority)
9. Magnuson Fishery Conservation and Management Act of 1976--16 U.S.C. 1801, *et seq.*
10. Alaska National Interest Lands Conservation Act--16 U.S.C. 3101
11. Fishery Attache Program--Executive Order No. 10249, June 4, 1951, 16 F.R. 5309 (3 C.F.R. 1949-1953) and Memorandum of Understanding between the Departments of State and the Interior (NMFS Attache program operates under the terms of the May 5, 1959 MOU) with respect to the Minerals and Fisheries Officer Program, dated May 5, 1959. 15 U.S.C. 742d,742e(c), 22 U.S.C. f 846 note
12. Federal Aid in Fish Restoration Act--(Dingell/Johnson Act), 16 U.S.C. 777-777k
13. North Pacific Fisheries Act of 1954--16 U.S.C. 1021, *et seq*.
14. Sockeye Salmon or Pink Salmon Fishing Act of 1947--16 U.S.C. 776 *et seq*.
15. Fur Seal Act of 1966--16 U.S.C. 1151, *et seq*.
16. Anadromous Fish Conservation Act--16 U.S.C. 757a-757g
17. Commercial Fisheries Research and Development Act of 1964--16 U.S.C. 779-779f
18. Fish and Wildlife Act of 1956--16 U.S.C. 742a-742k
19. Migratory Game Fish Study--16 U.S.C. 760e-760g
20. Whaling Convention Act of 1949--16 U.S.C. 916, *et seq*.
21. Atlantic Salmon Convention Act of 1982--16 U.S.C. 3601, *et seq*.

22. Salmon and Steelhead Conservation and Enhancement Act--16 U.S.C. 3301, et seq.
23. Marine Mammal Protection Act--16 U.S.C. 1361-1407
24. Endangered Species Act--16 U.S.C. 1531 et seq.
25. Fish and Wildlife Coordination Act--16 U.S.C. 661-666c
26. Northern Pacific Halibut Act-16 U.S.C. 773 note
27. National Environmental Policy Act (NEPA)--16 U.S.C. 4321, et seq.
28. Marine Protection Research and Sanctuaries Act--33 U.S.C. 1441,1442
29. Marine Protection, Research, and Sanctuaries Act of 1972 (Marine Sanctuaries)--16 U.S.C. 1431
30. Deep Seabed Hard Minerals Resources Act--30 U.S.C. 1419(a)
31. Coast and Geodetic Survey Activities Act--33 U.S.C. 833a et seq.
32. Act of May 16, 1910--30 U.S.C. 3; Reorganization Plan No. 4 of 1970, U.S.C. 1511 nt., section 1(c)
33. Coastal Zone Management Improvement Act--16 U.S.C. 1451 note, 16 U.S.C. 1801
34. Land Remote Sensing Commercialization Act of 1984--P.L. 98-365
35. Reorganization Plan No. 4 of 1970--15 U.S.C. 1511 nt., section 1(e)
36. National Sea Grant Program Act--33 U.S.C. 1124,1125
37. OCS Lands Act--43 U.S.C. 1347(e)
38. 15 U.S.C. 1525

GLOSSARY OF ACRONYMS

AEIDC	Arctic Environmental Information and Data Center, University of Alabama
AES	Atmospheric Environment Service, Canada
AFGWC	Air Force Global Weather Center
ALT	Altimeter
AMSU	Advanced Microwave Sounding Unit
AOGA	Alaska Oil and Gas Association
AVHRR	Advanced Very High Resolution Radiometer
CAC	Climate Analysis Center
C-MAN	Coastal Marine Automated Network
DCS	Data Collection System (part of the GOES satellite system)
DMSP	Defense Meteorological Satellite Program
ERL	Environmental Research Laboratory (NOAA)
EEZ	Exclusive Economic Zone
FCZ	Fishery Conservation Zone
FNOC	Fleet Numerical Oceanography Center
GMS	Geostationary Meteorological Satellite (Japan)
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GTS	Global Telecommunications System
HIRS	High-Resolution Infrared Radiation Sounder
JIC	Joint Ice Center (Navy/NOAA)
LFMR	Low Frequency Microwave Radiometer
MESSR	Multispectral Electronic Self-Scanning Radiometer
MFCMA	Magnuson Fishery Conservation and Management Act
MMS	Minerals Management Service
MSR	Microwave Scanning Radiometer
NCDC	National Climate Data Center
NEDRES	National Environmental Data Referral Service
NESDIS	National Environmental Satellite, Data, and Information Services
NGDC	National Geophysical Data Center
NMC	National Meteorological Center
NMFS	National Marine Fisheries Service (NOAA)
NODC	National Oceanographic Data Center (NOAA)
NODDS	Navy Oceanographic Data Distribution System
NORDA	Naval Ocean Research and Development Activity
NOS	National Ocean Service (NOAA)

NROSS	Navy Remote Ocean Sensing System
NSIDC	National Snow and Ice Data Center
NWAFC	Northwest and Alaska Fisheries Center (NMFS, NOAA)
NWS	National Weather Service (NOAA)
OAR	Office of Oceanic and Atmospheric Research
OCSEAP	Outer Continental Shelf Environmental Assessment Program
ONR	Office of Naval Research
OSTP	Office of Science and Technology Policy
PMR	Passive Microwave Radiometer
PODS	Pilot Ocean Data System
POES	Polar-Orbiting Operational Environmental Satellite
SAR	Synthetic Aperture Radar
SCAT	Scatterometer
SDDS	Satellite Data Distribution System (replaced by NODDS)
SDSD	Satellite Data Services Division (of the National Climate Data Center)
SEDAS	Shipboard Environmental Data Acquisition Systems
SLAR	Side Looking Airborne Radar
SMMR	Scanning Multichannel Microwave Radiometer (on NASA's NIMBUS-7 satellite)
SOWM	spectral ocean wave models
SPOT	Satellite Pour l'Observation de la Terre
SSM/I	Special Sensor Microwave/Imager
SSMO	Summaries of Synoptic Meteorological Observations
SSM/T	Special Sensor Microwave/Temperature
VNIR	Visible and Near-Infrared Radiometer
VTIR	Visible and Thermal Infrared Radiometer
WMO	World Meteorological Organization (GTS)