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SPC Log No. 79-3371
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DATA REQUIREMENTS FOR OCEANIC PROCESSES IN THE OPEN OCEAN, COASTAL ZONE, AND CRYOSPHERE

(NASA-CR-162451) DATA REQUIREMENTS FOR OCEANIC PROCESSES IN THE OPEN OCEAN, COASTAL ZONE, AND CRYOSPHERE (System Planning Corp., Arlington, Va.) 70 p HC A04/MF A01 CSCL 08C
N80-12719
Unclas
G3/48 46098

September 1979

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Prepared under
JPL 955068

RECEIVED

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PREFACE

This study identifies and describes the relationships between the producers and users of oceanic, coastal, and polar information--with particular emphasis on NASA contributions. Although NASA activities serve as the study focal point, information networks are usually entwined and seldom follow simple, unilateral, or exclusive paths. The study, therefore, highlights NASA's involvement against a larger background of producers and users active in the ocean, coastal, and polar areas.

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DATA REQUIREMENTS FOR OCEANIC PROCESSES IN THE OPEN OCEAN, COASTAL ZONE, AND CRYOSPHERE

A. SUMMARY ISSUES

Over nearly two decades of environmental satellite missions and technology developments in support of these missions, NASA has produced and accumulated some very important and valuable information. With the exception of restricted or protected information, legislation has established laws that guarantee and protect the public's right to this information. In spite of such actions, and with no further implementing actions on the part of the government, information with high value to many users is often difficult to obtain. This study examines the type of information system that is needed to meet the requirements of ocean, coastal, and polar region users. The requisite qualities of this system are:

- Availability
- Accessibility
- Responsiveness
- Utility
- Continuity
- NASA participation.

Such a system will not displace existing capabilities, but will integrate and expand the capabilities of existing systems and resolve the deficiencies that currently exist in producer-to-user information delivery options.

At one end of the producer domain are information production and delivery systems devoted to scientific or proof-of-concept programs that serve scientific/investigative users. The output of these systems generally consists of customized, nonstandard data products. The program users served with information from these systems are most often a limited set of investigators, sometimes referred to as principal investigators, who naturally establish preferential and specialized data paths to their producers. Availability, accessibility, and general utility are low for nearly all non-program users; responsiveness and specific utility depend on whether continuity is part of the mission plan.

At the other end of the domain are operational or limited operational producers of information. These producers generate information for standard product forms that are used by a selected and sometimes small group with relatively stable, routine needs; consistent schedules and content are valuable commodities for this user group. The systems serving these producers usually develop along institutionalized paths with formalized access points. Availability and accessibility are improved for the specific subset of operational users for which the data are prepared. Utility is again dependent on the needs of this subset of operational users, but the formats and storage points in the processing chain make it difficult for the wider range of real users to achieve utility. Responsiveness is thus low as the operational systems are designed to turn out fixed-format-and-content data not amenable to change requests. Continuity is high since these systems tend to become institutionalized as part of a long list of federally provided services.

What then is to become of ocean, coastal, and polar region users whose needs fall somewhere in the broad range between proof-of-concept and operational systems? This set of users and their corresponding producers are currently at a critical decision point relative to the development of information systems with specific value to them. Their needs tie in directly with such proof-of-concept and investigative programs as the Nimbus series, GEOS-3, and Seasat, which are in the evaluation and analysis stage; and the National Oceanic Satellite System (NOSS) and the Defense Meteorological Satellite System (DMSS) Block VI upgrade, which are limited operational and continuing operational programs, respectively. It is therefore appropriate and essential to consider the relationships between producers and program users at this transitional juncture when alternative options still remain feasible. The key questions that should be addressed at this time are discussed below.

1. How can an awareness of the availability of all of the NASA and other data sets be made available to all of the NASA users?

At the core of better availability is the library function--one as complete and multidimensional as any major reference facility serving a university or other broad institution. Information created by NASA deserves this attention and merits the expense of such a system, which would serve as a focal point for the acquisition of data by providing a centralized and consistent way of cataloging and describing the contents of the data. Such a system should expand the current emphasis on land use and meteorological products to include ocean, coastal, and polar region information. The library should include data of past and current value and provide a referral service to other information bases that contain corollary or supporting information (e.g., aircraft and in situ data) for each subject area.

2. How can accessibility to these available data sets be improved for all classes of NASA users?

An information distribution system should be responsive to users with diverse needs and should provide for receipt of information, within schedule limits, that are compatible with the users' requirements. It is therefore imperative that the system functions be sufficiently dynamic to meet constantly changing needs. Many prior information systems have been discarded because they did not have adequate flexibility. A system should be able to serve one-time/no-repeat users as well as regular customers. As with a good reference library, a distribution system should be interpretive at the request interface to help determine which information matches the users' requirements. Many of these characteristics are best provided by a system with centralized entry and receipt functions.

In addition, for a system to have wide application and high value, it must provide fair and balanced support to all users. Preferential support to special interests must not create barriers to other users. For example, most present systems make data available either in the raw state or after the full chain of processing has taken place that converts the data into geophysical information or fully calibrated images. Most of the steps in this processing chain are noncontroversial in a user sense except for converting located and calibrated data into geophysical information or multispectral images. Thus, the final products often have limited utility to all but those who specifically require this last step. Most users cannot afford to reprocess from the raw data base and thus are continually trying to adapt an unsatisfactory final product to their specific use. Storage and accessibility of data at the stage just before the final user-specific processing functions would increase the data utility to a much wider range of users, all of whom could then afford their own unique final processing step.

3. How can responsiveness be increased for a wider range of users?

The achievement of system responsiveness may raise more questions than it answers. It is tied to the issues of where in the processing chain the data should be made accessible; to what level the data should be processed; what should be the range of formats, costs, and turnaround times; and how many tiers of handling from source to user can the system tolerate? Because a strong value versus timeliness relationship exists, it is necessary to consider costs, volume, and response time in relation to the full range of interested users. Science, agency, industry, and public users must all be considered in assessing responsiveness.

4. What kind of data utility should be built into the system?

The information system that is developed must attract and be viable to users ranging from scientifically curious, occasional requestors to users engaged in the process of determining the key features of future operational systems. These users must exercise any system before judgments can be made about the value of the system or adjustments made in its operation. If the system is deemed to be of value, users should be willing to pay for data. This is the most direct and only way to determine worth. The ability to adapt should be built into the planning so that high interest/volume areas can expand and low interest areas can contract. A purely subsidized system without any real measure of system worth can become self-perpetuating; this approach has led to the failure of many prior systems.

5. How important is it to provide continuity in the data base?

Continuity is an important requirement that must be met. Significant users, such as those engaged industrially in ocean, coastal, and polar regions, will not buy information until this condition exists. Other users will be wary of any temporary project or mission-unique information system. One major way to avoid this pitfall is to establish the system outside of the mission or project, but to gear project planning and execution to utilization of the system. To further help ensure continuity, NASA might also establish a measurement utility evaluation program that ties NASA research missions to operational agency needs. This would include the development of a standard process by which proven new techniques are more rapidly incorporated into operational programs.

6. How does NASA's role in the open ocean, coastal zone, and cryosphere change with time?

Through the 1990 time frame considered in this study, NASA's potential role relative to the operational agencies does not change significantly. There are many new sensors on the horizon which provide finer spatial and spectral resolutions than the present systems, and increased versatility and important new geophysical parameters. Consequently, NASA could have continuing evolutionary inputs into the operational programs through and well beyond the 1990 time frame. The present array of RTOP, AN, AO, ASVT, and other user interfaces are probably at least representative of future interfaces, and, unless policy decisions begin eliminating some of these classes of users from having NASA interfaces, the scope and extent of these user interfaces are bound to increase as more data types become available from a wider range of systems. Defining these specific interfaces as to quality, quantity, format, etc., is probably not particularly useful. Instead, it is important to group the users into different access classes and then ensure that each of the classes is provided in future systems. It is the various classes of access which must be planned for now rather than the projected total number of individual interfaces required at some assumed data rate and sensor mix.

B. INTRODUCTORY PERSPECTIVE

Creating and maintaining information describing the physical properties and climatic phenomena of ocean, coastal, and polar regions has been one of man's active endeavors for centuries. Navigation charts, pilot logs and diaries, and weather lore distilled from ships' logs have been selected, refined, and ultimately centralized and maintained by seafaring governments. The voyage of the *Challenger* was a major pioneering expedition sponsored by the British Government and organized by the Royal Society in collaboration with the University of Edinburgh, where the science of oceanography was born. Their ambitious aim was to chart the depths, movement, and content of the seas and to scour the oceans for marine life, for clues to climatic phenomena, and for minerals. Despite the advanced technology available today, in-situ measurements of these difficult-to-sample regions still provide the largest source of information on the polar regions.

Remote sensing systems are expected to make invaluable contributions to ocean, coastal, and polar region monitoring in the coming decades. With the exception of land-based over-the-horizon (OTH) radars, most remote sensing systems are generally carried on aircraft platforms and in some cases on satellites. Aircraft or satellite-based systems offer the unique advantages of broad area viewing and coverage of vast expanses in short periods of time. In fact, it is now possible to collect synoptically viable information matching or exceeding the expected diurnal or subdiurnal variations in phenomena of importance. Important discoveries have been made possible with this unique viewing capability, and the frequency of observations now support improved predictive processes. These data have been a boon to marine businesses and scientists alike. Businesses that extract resources from the ocean, coastal, and polar regions and transport materials through these regions can operate with greater efficiency and safety. Scientists are also learning more about the physical structure and processes involved in these difficult-to-monitor areas.

NASA has been and continues to be the pioneer in the development and "proof-of-concept" demonstration of space-based remote sensors and remote sensing systems. Although the operational deployment of satellite remote sensing systems may occur in other agencies such as the NOAA or DOD meteorological monitoring systems (Tiros/NOAA series and DMSS series, respectively) or NOAA geosynchronous satellites (SMS/GOES 1-5), NASA's contributions to the field of satellite and remote sensing technologies have provided the foundation and heritage for these missions (see Table 1).

Relationships between producers of information valuable to ocean, coastal, and polar region users will be limited to the recent past in which remote sensing, particularly satellite viewing, has made its mark and where NASA's role as a developer has been preeminent.

C. HISTORY OF DATA USE

The wide use and accent of remote sensing technologies reaches its apex in satellite applications, and these contributions signify the past and future role of NASA in this area. In particular, satellite remote sensing programs reveal the NASA contributions in their proper perspective as emerging developments of high technology applied to man's needs.

The number of satellites carrying sensors that yield data useful to ocean, coastal, and polar science and environmental monitoring is large, and the value of the data from them variable, as shown in Table 1. Recent representative sensor technologies of value to both aircraft and satellite platforms that are applicable to oceanic coastal and polar measurements are shown in Table 2.

Of the several satellites listed, the most useful are probably NOAA-3 and -4, ERTS-1/Landsat-2, Geos-3, the SMS/GOES quintuplets, Tiros-N, Seasat, and Nimbus-7. The data provided by these satellites are diverse. The last three satellites, which were launched in 1978, are of much interest, and their impact is currently being assessed. Tiros-N is the first of the new generation of operational meteorological and environmental polar-orbiting satellites.

TABLE 1. U.S. SATELLITES OF UTILITY IN OCEAN, COASTAL, AND POLAR MONITORING

Satellite	Launch Date	Orbit	Character	Sensors	Geophysical Measurement
Mercury Gemini Apollo Apollo-Soyuz	1962-1975	Variable	Exploratory	Cameras	Imagery
Nimbus-4 Nimbus-5 Nimbus-6 Nimbus-7	1970 1973 1975 1978	Polar	Experimental	IR and MW radiometers and bolometer; color scanner	Temperature, ice cover, radiation budget, wind, color
ITOS-1 through -4 ESSA-1 through -9 NOAA-1 through -4	1966-1975	Polar	Operational	Visible vidicon; IR scanner	Imagery, temperature
ATS-1 through -3	1966-1967	Synchronous	Prototype	Visible, IR scanners; data channel	Imagery, temperature, data relay
SMS/GOES-1 through -5	1974-1978	Synchronous	Operational	Visible, IR scanners; data channel	Imagery, temperature, data relay
Geos-1 through -3	1965-1975	Variable	Experimental	Laser reflectors; altimeter	Geoid, ocean geoid
ERTS-1 Landsat-2 Landsat-3	1972 1974 1978	Polar	Prototype Quasi-operational Quasi-operational	Visible, near-IR scanner; thermal IR scanner	Imagery, temperature
Skylab	1973	Low inclination	Experimental	Cameras; visible, IR scanner; spectroradiometer; MW radiometers; altimeter; scatterometer	Imagery, temperature, wave length, wind speed, geoid
Tiros-N/DMSS	1977-1978	Polar	Operational	Visible, IR and microwave scanners	Imagery, temperature
Seasat	1978	Near polar	Experimental	Altimeter; imaging radar; scatterometer; MW radiometer; visible/IR scanner	Geoid, wave spectra, wind speed, ice temperature

TABLE 2. SATELLITE SENSOR RECORDS OF INTEREST IN OCEAN, COASTAL, AND POLAR MONITORING

Short Form	Sensor Name	Wavelength or Frequency	Spacecraft	Spatial Resolution
SR	Scanning radiometer.	Visible and thermal IR	NOAA-1 through -4	7 km
VHRR	Very high resolution radiometer	Visible and thermal IR	NOAA-1 through -4	1 km
VISSR	Visible and infrared spin scan radiometer	Visible and thermal IR	GOES	1-7 km
AVHRR	Advanced very high resolution radiometer	Visible and thermal IR	Tiros-N	1 km
MSS	Multispectral scanner	Four channels, visible and reflected IR; thermal IR	ERTS/Landsat-1 through -3	75 m, 250 m (IR)
TM	Thematic mapper	Four channels, visible and reflected IR; thermal IR	Landsat-D	30 m, 100 m (IR)
CZCS	Coastal zone color scanner	Six channels, visible, reflected and thermal IR	Nimbus-7	825 m
ESMR	Electronically scanned microwave radiometer	19 GHz	Nimbus-5	15 km
SMMR	Scanning multichannel microwave radiometer	Five channels: 6.6, 10, 18, 21, 35 GHz	Nimbus-7, Seasat	15-140 km
ALT	Short pulse altimeter	13.9 GHz, 13.5 GHz	Skylab, Geos-3, Seasat	2 km
SASS	Radar wind scatterometer	13.4 GHz, 14.6 GHz	Skylab, Seasat	100 km
SAR	Synthetic aperture radar	1.3 GHz	Seasat	25 m range - 9 m azimuth
MSU	Microwave sounding unit	4 or 7 channels 50 to 58 GHz	Tiros or DMSS BLK V-D-2, respectively	100 km

Seasat is dedicated to pioneering new radar remote sensing for oceanography. Nimbus-7 is designed to serve experimental ends for both pollution monitoring and oceanography. Intentional avoidance in this text of Air Force or DOD monitoring systems, such as the Defense Meteorological Satellite System, is due to the confined special interest use and distribution of these data. Scientific and commercial users have a difficult time acquiring this important data set. In fact, spacecraft data of use in ocean, coastal, and polar regions presently available on any basis other than a primarily experimental one are limited and are effectively confined to low- and medium-resolution visible, infrared and microwave sounding and imagery (NOAA, GOES) and small amounts of high-resolution (≈ 80m) Landsat images. However, the near future promises a large increase in the quantity, quality, and coverage of higher resolution data.

The answer as to who needs what information from spacecraft obviously depends both on the need and on the type of information that is obtainable or that producers can provide. In research areas, the disciplines currently served with some degree of usefulness are marine geodesy and gravity; physical, geological, and biological oceanography; glaciology; boundary layer meteorology; and climatology. Various maritime operations, i.e., shipping, offshore mining, oil drilling, and fishing, all require an improved and expanded data base and more accurate marine forecasts. The ever-increasing fraction of the population living along the seacoasts has a need for improved forecasting and warning services for protection of life and property. However, because of the great length and breadth of the subject areas, the difficulties in obtaining timely detailed information of sufficient observational density have prevented the establishment of an effective operational monitoring and forecasting system that is able to serve the full range of interested users.

In addition, many universities, NOAA environmental research laboratories, industry consortiums, NASA centers, the Coast Guard, the Navy, and others collect remote sensing data from airplanes and from ships and data buoys as part of research programs. NOAA and the Navy also collect ship reports and some data buoy reports on a regular, twice-a-day basis as part of the input data base for ocean and weather forecast models. Most of this aircraft and in-situ data are at least conceptually accessible by others and some of this data is traded about in non-real time. Some coordinated library function could aid access to and utilization of these valuable data bases. Measurement quality in these data bases is quite variable.

D. USER BENEFITS

The ocean coastal and polar areas play as fundamental a role in the natural scheme of things as does the atmosphere, although their influence and functions, being considerably more varied and diffuse, are neither as well appreciated nor as well understood. The sea profoundly affects the weather and climate and, in turn, is affected by the atmosphere; it acts as both a heat reservoir for storing, distributing, and releasing solar energy and as the source for most atmospheric moisture. The sea interacts with the bounding land and air over times ranging from minutes to millennia. Geological activity on all time and space scales takes place in and under the seas, which serve as the repository for the detritus of man and nature and, just as importantly, as practicable sources of petroleum and a few useful minerals. The sea's currents and dilutant powers are called upon to disperse sewage, poisonous and nonpoisonous wastes, solid trash, and excess heat, while it maintains a role as the *aqua viva* for an extremely complicated and commercially important food chain and as a means of recreation and refreshment for people. In the estuaries and the coastal zones, these conflicting demands are especially severe. After nearly two decades of activity in space, it is becoming obvious that for several limited but nevertheless important classes of phenomena it is possible to make observations and measurements from spacecraft of considerable usefulness. In a few isolated instances, it even appears one may do so with a breadth and accuracy exceeding that attainable using ships or buoys. The satellite represents a new tool of great power, and the information on physical and biological processes obtained from it will be worthy of widespread operational use and inclusion in the data banks and in the minds of researchers. By and large, current satellite sensing is confined to surface and near-surface phenomena. This constraint is not as severe as it appears at first glance, because data taken from spacecraft will be appended to other, conventionally derived surface and subsurface measurements of ocean and ice parameters in order to construct a more three-dimensional view. In addition, near-surface data are useful in their own right, since the coupled nonlinear interactions between surface and atmosphere largely take place in the few tens of meters above and below the sea-air interface, at least for shorter time scales. Man's activities are mostly confined to near-surface conditions as well, so that the kind of data that one can pursue from spacecraft is clearly highly relevant.

Space systems such as the ones pioneered by NASA provide an opportunity to implement a global assessment of the environment and of man's effect on it. Considerable effort has been spent for more than a decade on quantifying the economic and scientific benefits of such remote sensing activities. Some of this process is shown in Figure 1.

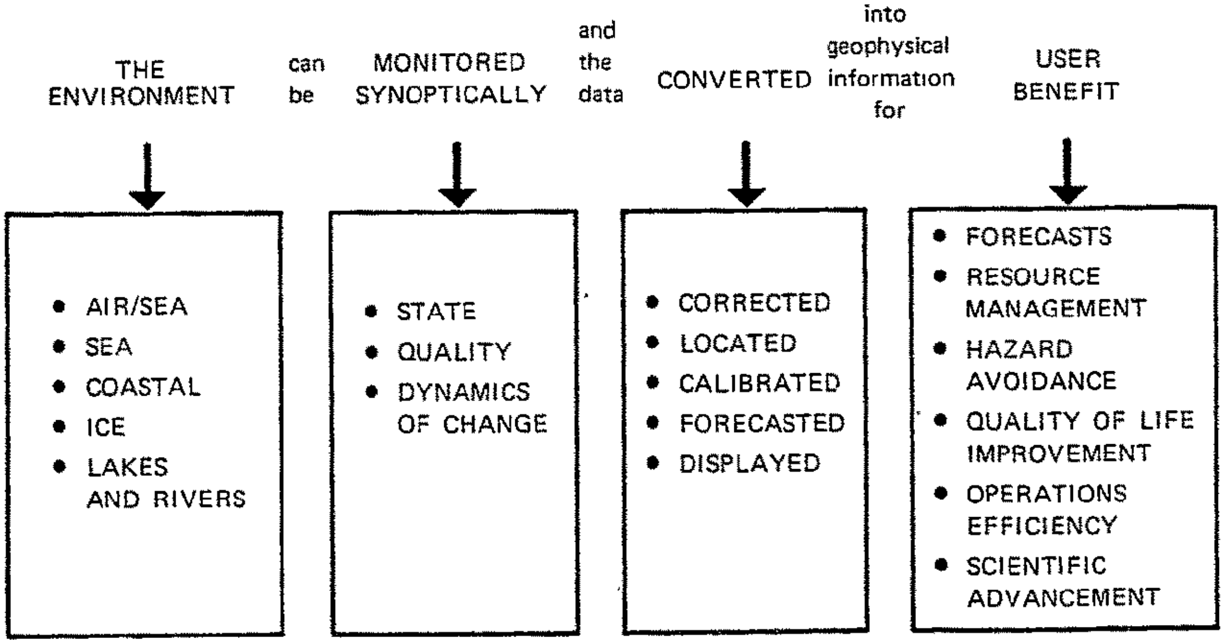

FIGURE 1. CONVERTING ENVIRONMENTAL DATA INTO USER BENEFIT

Extensive efforts have been undertaken to collect a large amount of data on user needs (Refs. 1, 2, 3, 4, 5). In this report, an attempt has been made to cross-correlate the gross requirements of the alternative user communities. This allows some generalizations to be made concerning which sensors have the greatest potential for combined use for specific missions and users.

Satellites are particularly useful in providing global and regional environmental information on a regular basis. Economic benefit comes from monitoring the environment, making predictions based on synoptic global data sets, and making decisions in operations and resource management. Reduction in loss of life and property accompanies such a monitoring effort and provides additional social benefit. In addition, there is significant scientific benefit in that the scope of the information-gathering capability provides a hitherto unobtainable information source. It is a fact that a simplified tie between the snynoptic data collected from a satellite and real users is possible. This has been demonstrated already on operational meteorological systems providing two to four times daily coverage of the globe. The same kind of capability will occur with ocean, hydrologic and polar measurement systems in the 1980s.

Another way of stressing the importance of satellites is by assessing the type and range of the probable economic benefits directly traceable to the synoptic ability of space platforms to provide geographically dense and short-time-period (within subdiurnal cycles) information. Table 3 illustrates some of the important areas.

An essential link between the monitoring systems and their benefits is the proper use of data, including nowcasts and forecasts. Several ocean data economic benefit studies were performed as part of the Seasat program.[1] These studies were based on a projected operational system with even more capability than the current NOSS description, but serve to emphasize the

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[1] Detailed information on the economic benefit assessment study results are available from ECON, Inc., Princeton, New Jersey.

TABLE 3. ENVIRONMENTAL DATA WITH USER UTILITY

		Ocean	Coastal	Polar Ice/Snow
Environmental Monitor	State	Temperature Salinity Waves Geoidal surface	Temperature Salinity Roughness Water resource availability	Temperature Extent Thickness Age and salinity
	Quality	Pollutants Nutrients Sediments	Chlorophyll Pollutants Nutrients Disease monitor Over-use Turbidity	Morphology Surface roughness Pollutants Water equivalency
Benefits	Energy Transfer	Currents/Circulations Tides Radiative exchange Evaporative exchange Surface wind shear/Transport Pressure/Wind surges	Currents/Circulations Evaporative exchange Radiation exchange Tides Surface wind shear/Transport Upwelling	Breakup dynamics Evaporative exchange Sublimation exchange Radiation exchange Ice motion and rotation
	Resource Yield Management	Resource location Resource use surveillance Yield estimation Operations support Navigation	Resource location Resource use surveillance Yield estimation Operations support Navigation	Resource Location Resource use surveillance Operations Support Navigation
	Hazard Avoidance	Freak waves High seas	Waves Winds	Icebergs Ice edge motions Ice leads

economic benefits derivable from space-based operational monitoring of the earth's environment. They indicated the large potential benefits resulting from NOSS-type missions in several commercial areas. Other social and economic benefits, probable, but difficult to quantize, are sure to occur, but the range of conservative benefits that appear reasonable is already large. These studies were performed in concert with commercial users interested in NOSS-type data, and initial use of pilot data products is now occurring using Seasat-1 data.

E. USER NEEDS

There are a diverse list of features, or observables, that comprise the geophysical measurements of importance in coastal, polar, and oceanic processes. A general summary of these needs and requirements is given in Table 4. In listing these parameters, it is convenient to begin at the level of the action of the atmosphere upon the sea, and then follow the ocean's response in terms of waves and currents and its effects upon the shore. Other coastal interactions are then listed, including identification of water mass properties established by natural and man-made influences. Ice cover, dynamics, and iceberg transport are discussed next, and finally, some estimates of the role of the ocean in establishing climatology are given. A summary listing of ocean, coastal, and polar region needs and the specific users identified with each of these needs is provided as part of this section.

1. Oceanic Monitoring

The transport of matter, momentum, and energy across the air-sea interface is chiefly due to solar radiation and atmospheric stress. Parameters such as the air-sea temperature difference, exchange of latent and sensible heat, and the vector surface wind field are important observables for climatological, meteorological, and oceanic purposes. For spacecraft, the measurement goals shown in Table 5 have been established for the NOSS and DMSP Block 6 programs. Expanded discussion of each measurement is provided below.

TABLE 4. NEEDS AND REQUIREMENTS

Area	User
Ocean Engineering Hazards	
Accurate 3-day forecasts, twice daily, for the continental shelf exploration	USGS, Industry
Detection and monitoring pollutants	EPA, CG, USGS
Better estimates of sea floor erosion	USGS, Industry
Improved wave force calculations for structures	Industry, USGS, USACE, NOAA
Coastal Protection and Land Use, Offshore Development	
Reduce and predict coastal erosion	USACE, USGS
Forecast extreme events (storm surges, tsunamis)	NOAA, USGS, USACE
Predict pollutant transfer	EPA, USGS
Improved warning/evacuation procedures in low-lying areas	NOAA, FDIA
Land use inventories, monitoring, planning, and management	NOAA, BLM, States
Rain prediction and numerical estimates of precipitation	USDA, NOAA
Environmental assessments and monitoring	FED, State, Local Fisheries, Oil, and Gas Mining Interests
Military Strategy	
Sea surface topography and sea state knowledge	Navy, NOAA
Improved surface vessel design	Navy
Logistics of fleet deployment and routing	Navy
Weapon system design	Navy, USAF, Private Sector Transport
Operational Meteorological and Maritime Forecasts	
Improve North Pacific and North Atlantic numerical sea/state wind forecasts	Navy
Generate data for South Atlantic, South Pacific and Indian Ocean models	Navy, Universities
Track major storms	DOD, NOAA
Improve continental weather forecasts	DOD, NOAA, All Marine Industry Groups
Navigation Hazards	
Improve and/or extend iceberg patrols	CG
Ship routing around storms	DOD, NOAA, AIMS
Improved ship design from global ocean data	Navy, Marad, AIMS
Ship routing in sea ice and lake ice	CG, Private Sector Transport
Economical Navigation	
Reduce Merchant Marine transit times	Private Sector Transport
Route fishing fleets	NOAA

TABLE 5. OPERATIONAL MEASUREMENT GOALS

Parameter	Precision	Absolute Accuracy	Range	Frequency	Delay	Model Grid Size	Horizontal Resolution
Wind							
Speed	0.5 m/s	2 m/s	0 to 50 m/s	12 hr	3 hr	200 km	25 km
Direction	5°	10°	9° to 360°	12 hr	3 hr	200 km	25 km
Sea Surf Temperature							
Global	0.25°C	1.0°C	-2°C to 35°C	3 days	12 hr	200 km	25 km
Local	0.10°C	0.5°C	-2°C to 35°C	1 day	12 hr	10 km	10 km
Waves (Sea State)							
Sign wave height	0.3 m	0.3 m	0 to 25 m	12 hr	3 hr	100 km	25 km
Amplitude components	0.7 m	0.7 m	1 to 8 m	12 hr	3 hr	100 km	25 km
Wavelength components	10%	10%	6 to 1,000 m	12 hr	3 hr	100 km	25 km
Direction	10%	10%	0° to 360°	12 hr	3 hr	100 km	25 km
Ice							
Cover	15%	15%	0 to 100%	3 days	12 hr	20 km	20 km
Thickness	2 m	2 m	0.25 to 50 m	3 days	12 hr	50 km	50 km
Age	New, 1st yr multi-yr	New, 1st yr multi-yr	0 to 3 yr	3 days	12 hr	20 km	20 km
Sheet height	0.1 m change	0.5 m change	-5 to +5 m/yr	1 yr	30 days	TBD	10 km
Bergs	N/A	+2 km of true location	N/A	2 days	12 hr	N/A	0.1 km
Water Mass Definition							
Chlorophyll	10% (mg/m^3)	Within factor of 2	0.1 to 100 mg/m^3	2 days	8 hr	TBD	0.4 km
Turbidity	0.1 ppm	Lo, med, hi	0 to TBD	1 day	10 hr	TBD	0.4 km
Horizontal Surface Currents							
Speed	5 cm/s	5 cm/s	0 to 250 cm/s	1 day	1 day	100 km	20 km
Direction	10°	10°	0° to 360°	1 day	1 day	100 km	20 km

Source: NOSS and DMSP BLX VI Measurement Goals.

a. Sea Surface Temperature Measurement

In cloud-free areas, it should be possible to determine absolute temperature accuracy to an order of 0.8°C and precision or relative accuracy to approximately ±0.3°C. The current sensors contributing to these measurements are the Advanced Very High Resolution Radiometer (AVHRR) from the NOAA/TIROS meteorological satellites, the Operational Line Scanner (OLS) from the Air Force Defense Meteorological Satellite Program, and the Coastal Zone Color Scanner from NASA's Nimbus-7 program. In cloudy areas or in light rain, a temperature precision of ±1.5° to 2.0°C and accuracy of 2 to 3 deg should be possible with 100 km resolution and few-day averages away from coasts by using microwave radiometric technologies such as the Scanning Multichannel Microwave Radiometer from Seasat and Nimbus-7. To the satellite-derived temperatures should be appended surface and vertical temperature profiles obtained by more direct or in-situ means to the maximum extent possible. A profile of vertical temperature and moisture is important to meteorological forecast improvement and is a corollary advantage gained by accurate measurement of air/sea interactions and the planetary boundary layer dynamics that are revealed by these measurements.

b. Surface Vector Wind Field

The scatterometer on Seasat has measured surface wind speed referenced to what is referred to as a level 9 ≃ 20 m height from a 3 m/s to a 28 m/s wind speed with a precision of ±2 m/s and a wind direction to ±20 deg through clouds and light rainfall with 100 km resolution over a 1000 to 1500 km swath width. Normalized radar backscatter cross sections of the ocean per unit area, σ°, as a function of wind speed and radar angle of illumination is the measurement parameter. This effect forms the basis for the wind speed measurement with the radar wind scatterometer. For higher winds, current Seasat data indicate that it is possible to determine speed from 5 to perhaps 50 m/s within ±25 percent of actual speed over a several hundred kilometer swath through clouds and light rain by using the SMMR. This measurement is derived from emittance-related variations in brightness temperature in two widely different spectral bands due to the varying presence of wind-generated foam on the surface.

c. Surface Wave Field

There is a strong coupling between the surface wind field and ocean waves. The surface wind field is used by the Navy's Fleet Numerical Weather Central (FNWC) as the major input to their spectral wave forecasting model. This model is used and relied on operationally by the U.S. Navy as well as by many marine commerce users. The wind initially generates short-length capillary waves, which then cascade toward longer wavelengths and larger amplitudes, dependent upon the strength, direction, duration, and fetch of the wind. Significant wave height $H_{1/3}$ is a one-parameter specification of sea state.

The proper description of a homogeneous surface wave field is more detailed, requiring a two-dimensional power spectral density as a function of surface wave vector. A reasonably complete determination of this function near storms, when used as input data to numerical models, would allow wave forecasts to be made at a distance of several hundred kilometers from the high wind regions. Where the field is nonhomogeneous, as it is near coastal regions and shorelines, intense low pressure systems, or in shoaling water, an image of the surface field is more important to determining state and conditions than a spectrum.

Based on early Seasat results, it appears possible to measure significant wave height $H_{1/3}$ with a precision of ± 1 m or ± 10 percent of the actual height over a range of 1 to 20 m along the subsatellite track on a near-all-weather basis by using a short-pulse altimeter. The rough ocean broadens a radar altimeter pulse (as shown in Fig. 2), the measurement of which forms the basis for the determination of $H_{1/3}$. $H_{1/3}$ is the average height of the highest 1/3 of the measured wave spectrum.

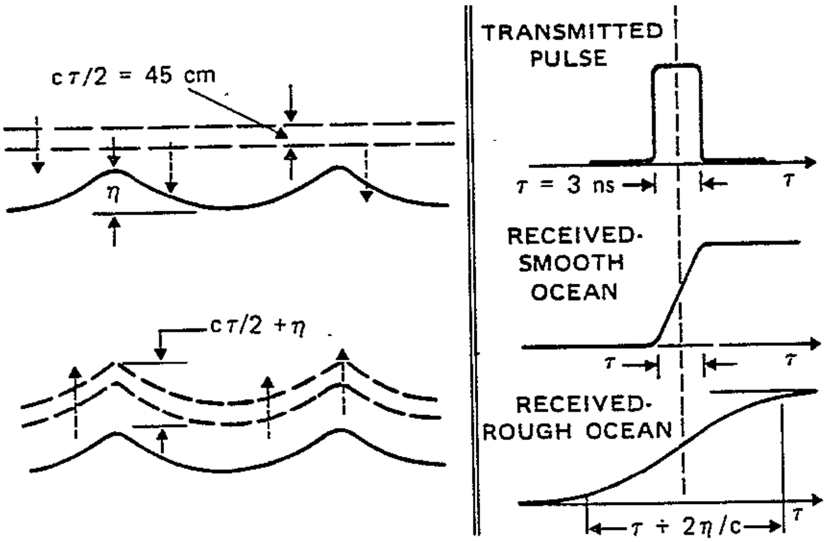

FIGURE 2. SHORT-PULSE METHOD FOR DETERMINING SIGNIFICANT WAVE HEIGHT

For the surface wave power spectrum, the synthetic aperture radar (SAR) used on Seasat indicates that it will yield square amplitude measurements consistent with the precision for $H_{1/3}$ for all wavelengths between 50 m and the largest observable length, measured at 10 deg intervals for all angles of propagation; the spatial and temporal resolution is limited to small samples taken near the United States or to more intensive spectra in selected regions. An instrument at L-band appears to have an all-weather capability unaffected by atmospheric scattering similar to that of the X-band wind field scatterometer.

d. Currents

Ocean currents are driven by wind stress, tidal forces, uneven temperature, and salinity distributions in the body of the sea. On the rotating earth, a moving fluid tilts its surface relative to the geoid with a slope proportional to the fluid velocity; this is called geostrophic flow. In the case of western boundary currents (e.g., the Gulf Stream), the slopes are of order 10^{-5} or less; the resultant topographic elevations across the Gulf Stream, measured with respect to the geoid, are about 1.5 m or less. However, the location and meander of currents are important to ocean transportation and resource extraction as well as scientific investigation.

For upwellings, it appears feasible to determine position, temperature, and areal extent of an upwelling event to 5 km within 1 to 2 days of its onset and to obtain estimates of the near-surface chlorophyll concentration by using combined temperature and color imaging devices such as CZCS (NASA, 1975).

e. Tides: Open Ocean and Shelf

Deep-sea tides, being largely astronomically driven by the moon and sun, occur at precise frequencies. Five of these tides contain about 95 percent of the tidal energy. Their amplitudes in the open ocean are typically 0 to 1 m. Open ocean and shelf tides are difficult and time-consuming to measure, and their relationships to coastal tides are hard to establish. Worldwide deepsea tidal measurements would aid in the theoretical understanding and prediction of tides at arbitrary locations along the coastlines.

By using precision altimetry in the way described earlier, it appears that one may determine tidal range to ±25 cm (relative to mean sea level) and phase to ±20 deg for diurnal and semidiurnal periods. The required spacings are 25 km on continental shelves and 100 km globally.

2. Coastal Monitoring

a. Surface Wave Attenuation

Surface waves reflect, refract, and diffract under the influence of coastal or shoal water and may converge or diverge, depending on bottom topography. Heavy wave action moves shoals and channels about and damages ocean structures such as jetties and offshore platforms. Wave refraction studies for a given region assist in shoreline protection, channel maintenance, and understanding of wave-driven circulation. Under these conditions, images rather than spectra are required. The SAR produces image wave refraction patterns for wavelengths greater than twice the resolution cell size or 50 m over swath widths of up to 100 km on a selected basis, as evidenced by the 25 m range dimension radar flown on Seasat.

Upwellings and downwellings are slow vertical flows usually brought about by wind stress and coastal topography. Upwellings in particular are of interest because the cold subsurface water often has a high nutrient level that may lead to a plankton bloom and ultimately an enhanced fish population important to marine fishery. From the standpoint of spacecraft data, the speed of the current in an upwelling is not observable, but timely identification and location of the event are possible.

In order to determine the complete current velocity field, one must measure speed and direction as a function of position and time. In addition, the vertical distribution of current velocity throughout the water column is needed for measuring total transports of water, dissolved chemicals, nutrients, etc. This is currently impossible from satellites, and, therefore, subsurface current profiles taken by conventional means must be appended to any surface current measurements made from spacecraft.

Present estimates validated or confirmed by the Seasat experiments give roughly ±20 cm/s as the ultimate achievable precision in the determination of surface geostrophic speeds from spacecraft by way of surface slope measurements using a radar altimeter and perhaps several kilometers as the time-averaged error in the position of the current measurements along the subsatellite track only. Nevertheless, surface current speeds considerably below 20 cm/s are found in the ocean and are of interest. No apparent means yet exist for remotely determining such low speeds from spacecraft.

When drifting buoys are equipped with satellite positioning devices and data collection systems, they become extremely valuable adjuncts to the remote sensors on board the spacecraft, especially in the area of fisheries management and prediction. Spacecraft remote sensors alone can by no means deliver all of the required information. The hope is that satellite altimetry will become sufficiently precise so that this dynamic topography, and hence surface current speed, can be determined by using it. This requires that both the background geoid and the topographic departures from it be determined with precisions approaching ±10 cm in the vertical. The requirement inextricably links oceanography and marine geodesy if such schemes are to be pursued.

b. Storm Surge and Wind Setup Along a Coast

Storm systems pile up water ahead of them as they approach a coastline from seaward. In the case of hurricanes, this surge is often directly responsible for more damage and loss of life than is the wind. Hurricane surges are confined to a few tens of kilometers and a few hours of time during the landfall; amplitudes can exceed 9 m. Wind setup is the accumulation of water along a coast due to long-term stresses such as trade winds; a typical elevation is about 1 m.

By altimetric means, it should be possible to measure storm surge elevations to ±1 m in a storm system on a target-of-opportunity basis along a single subsatellite track. It was estimated that the space-time coincidence of storm and satellite would be a low probability event. However, based on 100 days of Seasat evidence, during which several Atlantic and Pacific storms were monitored extensively, this was not the case. A special Seasat/STORMS Workshop has been convened to evaluate these data.

c. Beach and Shoal Dynamics

Waves and currents erode and build shorelines and shallow water features. Baseline data on shoreline and shoal configurations allow assessment of changes due to wave action. By using an imaging radar, it is possible under storm conditions to image shorelines and shoal waters with high resolutions over adequate swath widths on a selected basis near the continental United States. High-resolution optical and near-infrared imagery taken under cloud-free conditions at several wavelengths (such as will be available from Landsat's thematic mapper) can yield some subsurface data.

d. Shallow-Water Charting and Bathymetry

The positioning of newly formed or poorly charted shoals and some assessment of their topography can be obtained by using multispectral imagers such as MSS or CZCS. It is possible to image shoals of depths less than 10 to 15 m where the water is clear, with vertical resolutions of 2 to 5 m and horizontal resolutions on the order of 70 m and image centers located to a few meters on a selected basis. Synthetic aperture radar imagery is also capable of evaluating subsurface effects by sensing surface wave modifications related to such effects.

e. Near-Surface Sediment Transport

Wave action, river discharges, tidal flushing, and advection by current systems result in transport of sediment and sand throughout the ocean. Surface sediment patterns and particulate concentrations are indicators of transport of material, which can be viewed at several optical wavelengths with 800 m resolution over swath widths of up to 700 km (MSS, CZCS). By designing algorithms that use image brightnesses at these wavelength bands, it may be possible to determine concentrations from approximately 0.2 to 100 mg/m^3 on a selected basis.

f. Water Mass Properties

Variations in the physical or chemical composition of water mass leads to variations in its color or reflectivity. Such changes can be natural or man-made; in either case, they tend to be more pronounced near coastal regions. The color is determined primarily by molecular scattering and secondarily by nutrients (e.g., cholorophyll A in plankton and algaes, suspended sediment load, pollutants) and, where water is sufficiently shallow, by water depth and bottom type. Other environmental factors such as atmospheric conditions, sun and viewing angles, surface winds, and waves also influence the measurement of ocean color.

Surface measurements of upwelling spectra from three types of water masses illustrate the increase in energy in the green and red regimes of the spectrum as the transition from Gulf Stream to estuarine water is made.

The CZCS on Nimbus-7, which is also planned for NOSS, will image the ocean surface and near surface in multiple wavelengths of visible light and reflected and thermal infrared radiation with 825 m spatial resolution over swath widths of 700 km under controlled illumination conditions. The choice of wavelength bands was dictated by the requirement for making qualitative measurements relating to chlorophyll and sediment concentrations.

Measurement of ocean color from radiometric quality imagery of the desired area in several spectral intervals will perhaps allow measurement, at least under certain limited conditions, of the following features: suspended near surface sediment distribution and concentration; chlorophyll distribution and concentration between perhaps 0.1 and 20 mg/m^3; fish stock location via relationship to biosignificant observables; and pollutant distribution and concentration. The CZCS sensor can be used to make most of the measurements.

By viewing toward rather than away from the sun, it is possible to observe surface features in the sun glitter owing to the changes in surface reflectivity. A variable viewing angle is required to measure either color or reflected sunlight; viewing up-sun allows determination of oil spills, internal waves via surface slicks, and variations in surface roughness. Salinity levels have also been derived from glitter variations.

3. Polar Region Monitoring

Ice cover and ice movements vary greatly with the time of year and surface wind conditions. The percentage of ice cover in polar regions governs much of the weather there, owing to the large exchange of heat between air and water occurring through open water areas, especially in narrow leads and polnyas. In coastal areas and lakes, shipping depends upon an accurate assessment of ice conditions throughout the navigable waters. Iceberg tracking and forecasting are vital for shipping protection and navigation. The observation of ice from satellites is complicated, however, by the persistent cloud cover found in polar and subpolar regions. Thus, the synthetic aperture radar is very useful for imaging ice cover and very large icebergs on a near-all-weather selective basis. With the NOSS or DMSS advanced SMMR at a 94 GHz frequency, it is possible to image ice cover with good resolution (1 km) over the entire polar caps with swaths of 1,000 km on a near-all-weather basis.

It is expected that in the future the Arctic Ocean will be utilized more for navigational purposes, particularly as oil sources are located there. Naval operations in the Arctic depend on up-to-date information on the extent, position, thickness, and breakup characteristics of sea ice, which requires mapping large areas. The all-weather, day-night operational capability of radar systems is particularly useful in this regard, since light and weather conditions are uncertain most of the time.

Past research has demonstrated to some extent the ability of radar systems to discriminate sea ice types and thickness. However, before a radar system of general utility for ice discrimination can be developed, a need exists to understand the nature of radar returns from ice and the effect of different operating parameters. It will be helpful to design an optimum sensor system that can discriminate ice types and thickness. To specify optimum parameters for such a system, the effect of frequency, polarization, angle, and resolution in discriminating sea ice types has to be understood. This information can be achieved in part from the radar scatterometer data and radar images. A small measurement program would be sufficient to understand the nature of radar scatter from ice given the availability of adequate theoretical methods.

The ability of radar to discriminate sea ice types and their thickness has been extensively studied. Radar backscatter measurements at 400 MHz (multi-polarization) and 13.3 GHz (VV polarization) obtained from NASA Earth Resources Aircraft Program Mission 126 were analyzed in detail. The mission was conducted in April 1970 off the coast of Alaska near Pt. Barrow. The scatterometer data were separated into seven categories of sea ice according to age and thickness as interpreted from stereo aerial photographs. The variations of radar backscatter cross section with ($\sigma°$) with sea ice thickness at various angles are presented at the two frequencies. There is a reversal of angular character of radar return from sea ice less than 18 cm thick at the two frequencies. Multi-year ice (sea ice greater than 180 cm thick) gives the strongest return at 13.3 GHz. First-year ice (30 cm to 90 cm thick) gives the strongest return at 400 MHz. Open water can be differentiated at both frequencies.

Four-polarization 16.5 GHz radar imagery was obtained from Mission 126. Open water and three categories of sea ice can be identified on the images. The results of the imagery analysis are consistent with the radar scatterometer results. There is some indication that cross-polarized return may be better in discriminating sea ice types and thus thickness. Further work must be done, however, before conclusions can be reached.

An analytical theory of radar scatter from sea ice was developed. Sea ice was considered a nonhomogeneous medium in which the dielectric properties vary continuously in the vertical direction. In addition, a small random horizontal variation was considered. Polarized radar backscatter cross section ($\sigma°$) was computed for six ice types at 400 MHz and 13.3 GHz by taking surface roughness into account. The results thus obtained were in general agreement with the experimental results.

Automatic classification techniques were applied to scatterometry data. Using the four categories (as in the SLAR analysis), a correct classification of 85 percent can be achieved. The results presented here may be important in understanding the nature of radar returns from sea ice and in design of ice-mapping imaging radars.

4. Marine Geoid Monitoring

The marine or ocean geoid is defined as the surface assumed by a motionless uniform ocean under the influence of gravitational and rotational forces only. Geostrophic currents, tides, storm surges, setup, and waves lead to an ocean surface that departs from the geoid; the latter must then be known on a spatial grid with precision at least as fine as that with which the observable is to be determined. Although only preliminary Seasat data have been evaluated it appears possible to measure relative short-scale vertical variations in the marine geoid to ±20 cm and long-scale variations to perhaps ±100 cm along the subsatellite track over a grid spacing of the order of 25 km over all open ocean areas by using the altimeter and precise orbit determination.

5. Climatology Monitoring

The role of the ocean in climatic change is not completely understood, but it is clear that the transformation of absorbed sunlight into thermal energy in the upper layers of the sea is an important one, as is the poleward transport of this heat by western boundary currents. Variations in the positions of major ocean currents in part appear to be induced by changing wind stress, which apparently lead to the El Nino phenomenon, for example. The appearance of anomalous large areas of warm water in the Pacific Ocean has been hypothesized as the origin of warm waters in the eastern United States through poorly understood processes involving motions of the upper atmosphere.

The contributions of spacecraft to ocean climatology monitoring are mainly in the areas related to global determination of sea surface temperature and heat transport.

Due to the long-term experimental time period required to gain evidence supporting the use of satellites to collect data useful to climatology, it will be some time before we know how valuable their contribution may be.

F. SENSOR MEASUREMENT AND SYSTEMS CAPABILITIES

In addition to User Needs Compilations, NASA has compiled data pertaining to current and projected system capabilities to aid in design efforts. Their work in this area includes the following publications:

- NASA Special Programs Office, Satellite Capability Handbook and Data Sheets, #624-3, July.1976
- NASA Special Programs Office Sensor Capability Handbook and Data Sheets, #624-2, July 1976

Most of this information is in a format which can be easily tapped for quick mission and system design help and for a rapid guide to requirements that cannot at present be satisfied with current sensor technologies.

Table 6 provides a summary illustration of the various parameters discussed in Section E and lists the current generic sensor types contributing to their determination. The estimates of sensor usefulness are also designated by primary (1), secondary (2), and tertiary (3) designations, and by calibration support designations (C).

Carrying this description one step further, Table 7 shows the current consensus about real sensor capabilities and accomplishments. Although

TABLE 6. SENSORS AND OBSERVABLES.

Observables	Imaging Radiometers			Short-Pulse Altimeter	Imaging Radar	Scatterometer
	Visible	Thermal IR	Microwave			
Chlorophyll and algaes	1	-	-	-	-	-
Current position	2	1	1	1	1	-
Current speed	-	-	-	1	2	3
Estuarine circulation	2	1	-	-	2	3
Fog	1	1	-	-	-	3
Ice cover	1	2	1	1	1	3
Icebergs	-	-	-	-	1	-
Internal waves	1	-	-	-	1	-
Marine geoid	-	-	C	1	-	-
Oil spills	1	-	-	-	1	-
Pollutant identification	1	2	2	-	1	-
Salinity	-	-	1	-	-	-
Sea state and swell	2	-	2	1	1	2
Sediment transport	1	-	-	2	2	3
Setup	-	-	-	1	-	-
Shallow water bathymetry	1	-	-	-	1	-
Storm surges	3	3	3	1	2	3
Surface winds	-	-	1	2	2	1
Temperature	-	1	1	-	-	-
Tides	-	-	-	1	-	-
Upwellings	2	1	2	1	2	-
Water vapor	-	1	1	-	-	-
Wave refraction	1	-	-	-	1	-
Wave spectrum	2	-	-	-	1	2

1 - Primary; 2 - Secondary; 3 - Tertiary usefulness; C - Calibration Support

TABLE 7. CURRENT CONSENSUS OF REAL SENSOR CAPABILITIES

Sensor	Measurement	Results to Date
Altimeter	The objective of the Seasat altimeter calibration activity was to determine the accuracy and precision of the height measurement, the bias in the height measurement, the bias in the data time tag and the accuracy of the altimeter in measuring the significant wave heights and surface wind speeds.	• Timing bias: ±2 ms. • Weighted mean height bias: b = +16 to 18 cm ± 10-cm uncertainty. • Noise (precision) in the altimeter height measurement was on the order of 3 to 4 cm for the 4 m $H_{1/3}$ and 8 to 10 cm for higher sea states. • Two-thirds of all surface truth comparisons differ by less than 0.50 m in $H_{1/3}$. • The algorithm for converting the altimeter $\sigma°$ to wind speed at a height 10 m above sea level is in general agreement with the data buoy results to within 2 m/s. • The mean value of the altimeter-derived $\sigma°$ is 1.55 dB higher than that derived from the wind field. • Errors of 5 percent in significant wave height occur when sea states departs from a Gaussian distribution
Scatterometer	The objective of the Seasat calibration activity was to compare meteorologically determined winds (in situ measurements) with winds inferred from the scatterometer.	• Sensor winds biased high by 1.9 m/s with a standard deviation of 1.8 m/s about this bias. • The mean wind direction differences are less than 10 deg with standard deviations of approximately 20 deg. Correct assessment of wind direction accuracy can be made after an alias removal scheme is perfected. • Current projections indicate that the sensor will measure winds well within the 3 to 25 m/s ± 2 m/s or 10 percent and 20 deg direction specification. • As a result of work to date, experimentors expect to remove measurement biases.
Scanning Multichannel Microwave Radiometer	The objective of the Seasat and Nimbus-7 calibration activity was to convert microwave brightness temperature to accurate wind speed, sea surface temperature, atmospheric, water vapor, and water quantities.	• With further algorithm refinements, ± 2 m/s wind speed can be met for nonprecipitating conditions. Current bias is 1.54 m/s. Root-mean square difference is 3.30. Standard deviation about the mean is 2.93 m/s. • Sea surface temperature mean bias is -3°C to -4°C; standard deviation is 1.3°C to 1.8°C. With bias removal, measurement accuracy is expected to currently yield ∿ 1.5°C. This accuracy is degraded seriously by rain. • Integrated water vapor measurements are quite consistent with radiosonde observations to within 0.3 g/cm^2 rms. • Continued uncertainty in measurement and location accuracy due to lack of antenna pattern correction algorithm.
Synthetic Aperture Radar	Assessment of the ocean wave detection capabilities. Assessment of surface conditions.	• Repeatability of ±15 percent in wave lengths and ±25 deg (with ambiquity) in direction. • Some defocusing and degradation of azimuth travelling waves reduces detectability. • 1 to 2 m for $H_{1/3}$ is near the lower limit for wave direction detection. • High-quality, ocean, coastal, and polar region surface images in all weather conditions.
Coastal Zone Color Scanner	Assessment of chlorophyll concentration levels and Gelbstroffe pigment analysis.	• Lower five-band gain standard deviation less than 1 percent over 10 months of operation. • 16 ranges of concentration of chlorophyll possible based on Gulf of Mexico Experiment. • Final results await further processing.
Existing Visible and Infrared Sensors (AVHRR)	Operational images and sea surface temperatures.	• 80-m to 1-km images • 0.3°C temperature accuracy

the latest contributions and results from the Seasat and Nimbus programs are being analyzed and final statements acceptable to project scientists are not available, preliminary results support the measurement values shown.

The table illustrates the contributions made by microwave, infrared, and visible sensors to ocean, coastal, and polar region observations.

1. Spectral Generalizations

In the visible regime, the passive spacecraft sensor collects reflected solar energy. The sun angle can thus be important to the obtainable energy levels or to the ground shadowing for identification of detail. Surface features are normally sought in approximately two visible channels, although additional infrared channels provide similar utility. Colorimetric measurement of composition can be done with less resolution, but requires many more channels to permit separation of effects. Sensors with a spectrographic sweep or with more than 10 separable channels provide a difficult task in producing enough input energy to allow the spectral differentiation. A trend towards space-operated colorimetric instruments with 10 channels exists.

The infrared regime is similarly limited by the energy required for fine spectral resolution. Instruments on the order of 20 channels are typical, presently, in order to separate out a sufficient number of temperature and humidity layers and to determine cloud heights and extent. Accurate surface temperatures based on thermal emissions in the infrared spectrum must include channels with the best windows through the atmosphere, plus channels with good water column determination, plus channels which separate out effects due to surface roughness, foam, or vegetation canopies, etc. Instruments with five or six channels and with reasonably high resolution exist and are being planned with larger apertures and higher resolutions. The numerous absorption line possibilities in the infrared spectrum also provide a mechanism for determining composition.

Active infrared or visible lasing type sensors have not been discussed here. Although feasible under some conditions in space they are not presently practical in terms of weight and power. Initial attempts to put laser sources in space will probably emphasize ranging and differential absorption pairs for atmospheric trace constituent identification and atmospheric wind determination. Such an instrument is being planned for a Shuttle research mission in the mid-1980s and for the DMSS program in the late 1980s.

Active and passive microwave instruments are relatively new to applications spacecraft, but have special capabilities that make them specially appropriate for ocean, coastal, and polar region phenomena. Table 8 illustrates this special affinity. Microwave sensors form the core of the NOSS program and are important augmentations to the DMSS program.

Passive imaging microwave sensors are developing along two major thrusts; Horizontal Surface Temperatures and Atmospheric Column Measurements. Surface measurements evolve from sensors with about six channels to separate out effects, while achieving as fine a surface resolution as possible. Resolution is controlled by antenna aperture and wave length selection. Due both to packaging on the spacecraft and to implementing the scanning necessary to achieve reasonable swath widths, four meter dimensions are currently being planned. Vertical temperature and humidity measurements are similar to the infrared counterparts, but as few as five channels are used.

Active microwave instruments can interact with atmospheric and surface conditions in special ways to make measurements of surface roughness, undulations, or composition. At the apex of these measurements are all-weather, day/night images with fine resolution.

2. Areal Generalizations

Sensor instantaneous field of view or footprint resolving capability between 25 m and hundreds of kilometers are current. These provide vertical and horizontal temperature distributions, plus wind, pressure, moisture,

TABLE 8. APPLICATIONS AND MICROWAVE INSTRUMENTS

Needs	Parameters to be Measured	Analytical Scheme	Applicable Microwave Instrumentation	Status of Knowledge
Operational Forecasts	Wave length Wave period Wave direction Wave height Wind speed Wind direction Current speed Current direction Current gradient Current extent Sea temperature Cloud cover	Direct wave spectra Significant wave period Wave statistics Significant wave length Wind field charts Wind/wave interaction Ocean current charts Wave current interaction Surface topography Surface temperature distribution	Synthetic aperture radar Real aperture radar Nanosecond radar Radar altimeter Scatterometer Microwave radiometer Radar altimeter Microwave radiometer Microwave radiometer	Seasat Navy 1975 NRL Geos-3, Seasat Skylab, Seasat Nimbus-7, Seasat Geos-3, Seasat Nimbus-7, Seasat DMSP, NOAA, Seasat, Nimbus-7 ITOS, Tiros, DMSP
Navigation Hazards	Iceberg location Iceberg density Iceberg size Iceberg motion Current speed Current direction	Iceberg track charts Iceberg statistics Ship crossings	Synthetic aperture radar Real aperture radar	USCG Operational
Economical Navigation	Wave extremes Target detection	Wave climate analysis Wave climate information ship design Ship count traffic Structure identification	Synthetic aperture radar Radar altimeter Real aperture radar Synthetic aperture radar	Seasat Geos-3, Seasat Aircraft experiments Seasat
Ocean Engineering Hazards	Wave height Wave length Wave direction Wave period Current Ice extent Ice type Ice dynamics Wind speed Wind direction	Significant wave height Wave refraction 2-D wave spectra Wave force calculation Shelf transportation models Pack, shear, zone First, multi-year ice Wind field in hurricane	Radar altimeter Synthetic aperture radar Synthetic aperture radar Microwave radiometer Radar altimeter Microwave radiometer Synthetic aperture radar Real aperture radar Scatterometer	Seasat Marineland 1975 Seasat, aircraft experiments Seasat Seasat, Nimbus-7 Skylab, Seasat
Coastal Protection Land Use	Wave height Wave length Wave direction Current velocity Current location Current extent Rain location Rain rate	Wave breaking analysis Shoaling/energy dissipator Refraction, differential reflection, runup & overtopping forces on structures Along-shore transport Waste discharges thermal Oil pollution Precipitation prediction Hurricane modeling	Radar altimeter Synthetic aperture radar Microwave radiometer Synthetic aperture radar Microwave radiometer	Seasat, Geos-3 Seasat Seasat, Nimbus-7, Tiros, DMSP
Military	Sea surf topography Wave data Wind data Sea surf temperature	Marine geoid determination Logistics Sea state forecasts	Radar altimeter Scatterometer	Geos-3 Seasat

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR rain, and pollutants information necessary to monitor atmospheric changes on a global and regional scale. Resolutions of 1 to 10 km provide local weather peculiarities, plus ocean and ice dynamics. They also provide information on ocean compositions, fish, vegetation and crops, etc. As resolutions move toward 100 m, classification applications begin. Resolutions in the 10 to 100 m range provide major mapping functions. These are primarily useful for structure- and object-locating applications. Requirements for finer resolutions have generally not been generated due to the overwhelming implementation costs given present technologies.

Common survey swath or field-of-view dimensions are in the neighborhood of 1500 km. The high accuracies quoted for temperatures, winds, etc., are normally only true within ± 30 degree incidence angle from the vertical. In the satellite altitude region of 600 to 1200 km, this is equivalent to about 1500 km in swath. Fifteen hundred km is also about half the orbit-to-orbit spacing for satellites in this altitude range.

Imaging swaths are smaller due to power and data rate system limitations. Typical physical dimensions for the microwave instruments are shown in Table 9. A range of typical data rates from one NOSS study, using all channels and the range of resolution cell sizes, is also provided for reference.

3. Temporal Generalizations

Associated with each measurement is a time frame that is controlled by the mechanization of change. The atmosphere changes rapidly; land changes relatively slowly; and the oceans and ice are somewhat intermediate. This effect is shown in Table 10.

Geosynchronous satellites are needed to monitor local weather and storm conditions which change hourly. Geosynchronous satellites can follow this change. Non-sun-synchronous polar satellites are needed to provide information on diurnal effects in polar regions and to provide diurnal sampling for measurements from active microwave instruments, which are not

TABLE 9. NEXT EVOLUTION INSTRUMENT INTERFACE REQUIREMENTS

	LAMMR	CZCS	Altimeter	Scatterometer
Weight	320 kg, max	40 kg	180 kg	224 kg
Power	285 W, max	50 W, average 85 W, peak	120 W, heater 17 W, typical operation	165 W, average 400 W, peak
Envelope	140 m^3	--	--	--
Volume		60 x 60 x 80 cm	2 units: 35 x 51 x 25 cm 2 units: 1 m dia. x 80 cm	1 unit: 30 x 40 x 110 cm 6 antennas, ea: 3 m x 10 cm x 15 cm
Command	30 discrete 6.8 level	40 relay coils	8 relay coils	35 non-latching relay driven
Dissipation	350 W	50 W, average	177 W	165 W, average
Momentum	1 to ft-lb/sec	5 kg/cm 2/5	None	None

	System Output	% Duty Cycle	Data Rate (kbps)
Low data rate	Scatterometer	100	4
	LAMMR	100	4
	Altimeter	100	8
	Experimental	100	4
	Engineering data	100	4
	Location header data	100	3
	Total low rate		32 kbps
High data rate	AVHRR } CLR	100	350
	CZCW }	25	950
	LAMMR	100	80
	Location/header data	100	120
	Total high rate		1.5 Mbps

TABLE 10. TEMPORAL NEEDS

Temporal Repeat		Hourly	2 to 4 Times/Day	Daily	Weekly	Monthly	Quarterly	Yearly
Orbit Required		Geostationary	Polar	Sun Synchronous	Mixed			
Observations	Air	Local weather and storms	Regional and global weather, pollutants	← Climatology →				
	Sea		Waves, tides, surges, ship locations	Temperature, currents, nutrients, upwellings, sediment, pollution, fish	Shoal and shoreline dynamics, salinity		Geoidal variations	
	Ice		Leads, icebergs	Snowline, ice extent, ice thickness				

readily implementable from geosynchronous orbit. Wind, temperature, waves, pollutant concentrations, tides, surges, and water absorption by soil all have diurnal effects, which must be understood if forecasting is to be effective. Ships and icebergs change position rapidly, and ice leads open and close rapidly enough that several samples a day are needed to chart their status. The visible and near-infrared channels require sun-synchronous orbits in order to provide the constant sun angle that optimizes feature resolution. These measurements benefit from operating in a sun-synchronous orbit. Wide-swath visible instruments need daily coverage at the desired sun angle; narrow swath visible instruments are normally used for mapping on a weekly-to-monthly coverage basis.

4. Mission Combination

Physics or orbital dynamics do not allow all temporal needs to be met in any one satellite orbit. Geostationary and sun-synchronous orbits miss the poles. The 87 deg inclination has the best global fill in pattern, but even it only progresses through the diurnal cycle two to three times per year (less than seasonal). Compromise and synergism between several differing orbits thus become an important dimension of a cohesive program.

This leads to the delineation of the sensors desirable in each orbit type shown in Table 11. The sun-synchronous orbit must carry the visible and near-infrared sensors and the other instruments needed to provide a synergistic weather picture in terms of winds, temperatures, pressures, moisture, and rain. It also performs colorimetry and high-resolution visible and infrared mapping. The geostationary orbit (not shown in Table 11) is used to monitor weather on a more hourly basis and uses large optical systems to get appropriate resolutions in the visible and infrared regimes.

Non-sun-synchronous satellites emphasize microwave implementations in that the sensors utilized are not dependent on solar reflectance, and a large fraction of the measurements being made have strong diurnal variations. The microwave instruments are also difficult, at best, to implement

TABLE 11. ORBIT CHARACTERISTICS AND SENSOR LINEUP

	Sun-Synchronous Orbit (99 deg inclination)	Polar Orbit (84 to 87 deg inclination)	Low-Inclination Orbit (50 to 60 deg inclination)
Key Physical Characteristics	Constant sun angle for visible sensors Separation of diurnal and seasonal effects	Full polar coverage for narrow swath sensors Parallel radar paths for best fill-in patterns Good north/south current crossings Slow diurnal variation tracking	Rapid diurnal variation Good east/west current crossings
Desirable Sensor Types	AVHRR-II CZCS Radar scatterometer Weather and marine boundary layer sensors	AVHRR-III CZCS SAR Radar altimeter Radar scatterometer SMRR Laser altimeter Ocean surface LIDAR	Radar altimeter Simple microwave radiometer Laser altimeter

from geostationary satellites. An infrared sensor similar to that flown in the sun-synchronous orbit is suggested for relative calibration use in non-sun-synchronous orbits. The coastal zone color scanner is also shown in the polar orbit, even though it will not be functional during part of each year over U.S. coastal waters. It will be used to accumulate data on diurnal variations in chlorophyll and other water mass determinations for proper interpretation and extrapolation of the more optimized sensors in the sun-synchronous orbit.

G. NASA PROGRAMS AND CONTRIBUTIONS

NASA has made many important contributions to improving sensor and system technologies, expanding the base of scientific information, and assuming leadership in applying space techniques toward improving social and economic conditions.

There are numerous examples of NASA's contributions in these areas. Visible and infrared multispectral imaging sensors with high resolutions have been pioneered by NASA on the ERTS and Landsat programs. Active and passive microwave sensors with special value for hydrologic, oceanic, and polar monitoring have also been pioneered by NASA. Of special note are efforts such as the development of short-pulse radar techniques in support of the Geos and Seasat programs. NASA has developed special reflective array compression techniques so that narrow pulse widths could be generated to permit fine-scale ocean geodetic, current, and tidal evaluations. Table 12 provides a list of some of the major technology developments and host programs that fostered advancements in ocean, coastal, and polar region science and applications.

In addition to sensor device and systems technology developments, certain major thrusts in data extraction and information processing and enhancement have been pioneered by NASA. Notable contributions have been the image processing and enhancement efforts using Landsat's multispectral information and the first-time processing of geodetic data sets from Skylab and GEOS satellites. This processing required precise orbit determination,

TABLE 12. MAJOR TECHNOLOGY DEVELOPMENTS BY NASA IN OCEAN, COASTAL, AND POLAR APPLICATION

Development	Activity Area	Application
Microwave radiometers	Aircraft developments followed by Skylab, Nimbus, and Seasat exposure	Ocean surface temperature, ice mapping and morphology, and atmospheric temperature and moisture corrections
Short-pulse radar altimeter	Aircraft developments followed by Skylab, Geos, and Seasat use	Ocean geoid, ice volume mapping, coastal and major current structure evaluation, and wave spectral measurements using scanning techniques
Radar scatterometer	Single and dual frequency aircraft tests, Skylab, and Seasat application	Wind vector field, ice surface roughness, and rain-rate possibilities
Synthetic aperture radar	Aircraft developments followed by Seasat exposure	Surface wave spectra, current detection, wind effect patterns, pollutant detection, marine transport, and offshore development observations
LIDAR-laser spectrometry	Aircraft tests	Bathymetry, surface layer constituent identification, pollutant detection and classification, and subsurface temperature profiles
Visible and infrared multispectral images	High-altitude aircraft evaluations, ERTS, Landsat, Nimbus, and Tiros programs	Ocean surface temperature and other conditions, ice mapping, pollutant detection, and coastal zone detailed color sensing
Data extraction and enhancement techniques in support of the above	Landsat optical and digital image processors; Seasat-SAR optical and digital processing; and geodetic data processing	Support for various scientific and applications experiments

arc smoothing, and modeling techniques as well as noise evaluation algorithm developments and special curve-fitting analyses. The special techniques, equipment, and software required to process space-collected synthetic aperture radar data were also established during the Seasat program. This program placed emphasis on ocean, coastal, and polar region monitoring using a combination of active and passive sensors and data analysis technologies originated and developed by NASA's Office of Space and Terrestrial Applications.

In the area of scientific contributions, NASA has been preeminent in ocean geodetic research, wave and wind/wave analysis on a global synoptic scale, current dynamics evaluations, and polar region morphological and seasonal dynamics research. Most of the major contributions made in these areas that require the snynoptic, geometric, or stable perspective of a space-based platform have been pioneered by NASA.

Overall, NASA's scientific achievements have provided a foundation for researchers and public sector applications and have led to advancements in our understanding of basic ocean, coastal, and polar region processes. Table 13 summarizes some of the notable scientific endeavors in the subject areas that have been supported by NASA-produced information and interest.

The many NASA scientific discoveries and contributions in the past decades have led the way for public sector and industrial use and interest in information about ocean, coastal, and polar environments. Of particular note are contributions in areas that improve our quality of life. Landsat data have been used to advantage in agricultural, geological, mining, water quality, and other land and hydrological areas of endeavor. Nimbus, Geos, and Seasat data have been and are being applied to ocean, coastal, and polar applications. Applications experience in these latter areas postdates the earlier land-use efforts. In fact, many of the ocean, coastal, and polar region areas shown in Table 14 are just now being evaluated. Early results have spurred the interest and enthusiasm of large government agencies.

TABLE 13. SCIENTIFIC CONTRIBUTIONS BY NASA IN OCEAN, COASTAL, AND POLAR AREAS

Advancement	Program Support	Contribution
Geodetic Baseline	Geos, Lageos, Seasat	Sensor satellite development, orbit determination and data processing support, and state-of-the-art improvements
Synoptic understanding of the dynamics of Arctic and sub-Arctic seasonal changes and the morphology of Arctic regions	Nimbus Seasat	Sensor satellite development, data analysis, and science experiment support
Physical oceanography provided a synoptic view of surface dynamics, topography, wave spectra, wind/wave interactions, surface temperature, wind vector field, and detailed radar images of ocean, coastal, and Arctic areas	Seasat	Sensor and satellite development, data analysis, and science experiment support
Coastal colorimetric mapping and water quality evaluation	Nimbus	Sensor and satellite development, data analysis, and science experiment support

TABLE 14. APPLICATIONS/DEMONSTRATION EXPERIMENTS USING NASA INFORMATION

Area	Program	Experiments
In-land and coastal hydrography	Landsat multispectral imagery, U-2 infrared photography, Nimbus data	Evaluation of estuarine and embayment movement and constituents and river and river bight pollution and entrapment effects
Offshore resource development and operations support	Seasat and Nimbus microwave imagery and surface dynamics measurements	Several experiments in geographically diverse areas
Marine transportation	Seasat and Nimbus information used in forecast models	Cargo and tanker intercontinental transport
Arctic resource extraction and transport	Seasat and Nimbus information	Oil and gas exploration and product and resupply transport
Great Lakes shipping	Aircraft radar data	Near-real-time images and analysis of surface conditions, leads, etc.

For example, the Department of Defense is including microwave technologies in the form of a passive surface imager and a wind field scatterometer on their DMSS Block VI Meteorological Satellite program upgrade scheduled for the 1984-1985 time frame, and the Department of Commerce (through NOAA) and the U.S. Navy are sponsoring a new initiative, with NASA's Office of Space and Terrestrial Applications, for a limited operational demonstration ocean monitoring system--the National Oceanic Satellite System (NOSS). Both of these actions stem from NASA's pioneering efforts on the Seasat and Nimbus programs.

Because of the success of programs such as these, there is a need to continue both R&D and major programs support in ocean, coastal, and polar regions. The value of the information produced by current and future programs will be solidly tied to how this information gets from producer to users. There is a definite trend of increased remote sensing activity in the subject areas. Figure 3 illustrates this fact by showing the past and present buildup of major NASA programs and programs in which NASA has participated that have a full or partial application in the subject areas. The magnitude of investment by NASA and other federal agencies in remote sensing, systems support, and data analyses for ocean, coastal, and polar use increased primarily as a result of NASA's lead in sensor and information processing development, which convinced many scientific and applications users that remote sensing could play an important role in these areas. As a result of this increased interest, a wide range of current activities are under way. These activities are tied to supporting budgets such as controlling NASA Center Research and Technology Operating Plans (RTOP) and the Applications Notice (AN) selections, which result from requesting help in specific areas from other government and private sector people. Tables 15a, 15b, and 15c summarize the current RTOP and AN activities planned for each of the three subject areas and also outline the applications initiatives and Applications Systems Verification Tests (ASVT) planned by NASA.

TABLE 15a. RTOP AND AN ACTIVITIES PLANNED FOR OCEAN AREAS

	Ocean Circulation and Topography (Marsh GSFC; Loomis, JPL)	Advanced Ocean Sensor System Development (Kim GFSC, Swift LaRC McGoogan, WFC)	Research Applications of Ocean Data to Large Scale Forecasting Models (Halem GSFC)	Ocean Research Mission Definition Study (Loomis, JPL)	Microscale Ocean Surface Dynamics (Huang, WFC)	Topographic Mapping Using Satellite Altimeter Data (Marsh GSFC)	Ocean Tidal Parameter Recovery From GEOS 3/Seasat Altimeter (Pelsaw, Treger, GSFC)	Use of Altimeter and Conventional Data Tropical Pacific Currents (Bernstein, SIO)	Aircraft Measurements of Ocean Salinity and Temperature (Swift, LaRC)	Ocean Fine Structure (Phillips, JHU)	Models Relating Satellite Data to Sea Surface Stress and Winds (Brown U Wash)	Study and Test Models Relating Satellite Data to Air Sea Surface (Katsaros U Wash)	Monitoring Mesoscale Ocean Currents Using Altimeter Data (Lambert SAI)	3 D Structure of Mesoscale Ocean Features (Wechman Naval Postgraduate School)	Ocean Front Identification and Application to Tuna Management (Williams, U, Miami)	Pacific Ocean Mining Experiment (Deepsea Ventures Inc., Kennecott Ocean Minerals Co)	Bering Sea Experiment (Ocean Service Inc)	Optimum Ship Routing (Ocean Routes, Inc)
	146 40 97	146 40 13	146 40 14	146 40 XX	146 40 05	AN 481/76	AN 482/77	AN 258/42	AN 409/65	AN 57/11	AN 582/99	AN 634/104	AN 98/23	AN 402/62	AN 692/112	ASVT 6	ASVT 7	ASVT 16
Capillary wave formation/dissipation			X						X	X	X	X				X	X	X
Gravity wave formation/propagation	X				X	X			X	X	X	X				X	X	X
Gravity wave attenuation dissipation	X				X	X			X	X	X	X				X	X	X
Internal wave formation propagation attenuation																		
Freak wave formation													X	X		X	X	X
Geostrophic current pattern	X				X	X		X					X	X		X	X	X
Current eddy formation attenuation dissipation	X				X	X		X										
Ocean surface layer transport																X		
Upwelling pattern																		
Astronomical tide motion	X				X	X	X											
Storm tide motion	X				X	X	X											
Ocean geoid	X				X	X												
Surface roughness attenuation (oil fish ships)																		
Surface feature identification (ships rigs)																		
Latitudinal ocean thermal transport			X													X		
Ocean thermal mixing in depth			X													X		
Ocean/atmosphere thermal exchange			X															
Ocean/atmosphere water exchange			X															
Ocean, vegetation growth cycles									X							X		
Ocean phytoplankton zooplankton growth cycles									X							X		

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TABLE 15b. RTOP AND AN ACTIVITIES PLANNED FOR COASTAL AREAS

	Surface Layer Dynamics (Mueller, GSFC)	Investigation of Catastrophic Phytoplankton Events (GSFC)	Advanced Ocean Sensor System Development (Kim, GSFC)	Ocean Dynamics Mesoscale Experiments Analysis (Shemdin JPL)	Ocean Research Definitions Study (Loomis JPL)	Microscale Ocean Surface Dynamics (Jones LaRC)	Environmental Monitoring of Bioprocesses (LaRC)	Application of Laser Technology to Subsurface Monitoring (WFC)	3 D Structure Mesoscale Ocean Features (Wickham Naval Postgraduate School)	Ocean Front Identification and Application to Tuna Utilization Management (William U Miami)	Dynamics of Spring/Autumn Bloom Gulf of Maine Georges Bank (Yentsch)	Beaufort Sea Experiment (Gulf Oil Canada, Ltd; Esso Resources Ltd, Dome Petroleum)	Labrador Sea Experiment (Esso Resource Canada, Ltd; Total Eastern Exploration Ltd)	Gulf of Mexico Experiment (American Gas Assoc)	U S East Coast Experiment (Conoco)	Worldwide Offshore Drilling and Production Operations (Getty Oil Co)	Bering Sea Experiment (Ocean Services, Inc)	North Sea Experiment (Conoco Union Oil Co)	Marine Environmental Forecasting in the North Sea (Ocean Routes, Inc)	Ocean Thermal Energy Conversion (Ocean Data Systems, Inc)	Improved Weather Forecasting (Atmospheric Environmental Service of Canada)	200 Mile Coastal Zone Monitoring (USCG, NOAA)
	146 40 93	146 40 XX	146 40 13	146 40 04	146 40 XX	146 40 05	146 40 XX	146 40 XX	AN 402/62	AN 692/112	AN 10/01	ASVT-1	ASVT 2	ASVT 3	ASVT 4	ASVT 6	ASVT 7	ASVT 8	ASVT 9	ASVT 10	ASVT 22	ASVT
Capillary wave formation/dissipation				X		X																
Gravity wave formation/propagation				X								X	X	X	X	X	X	X	X	X	X	
Gravity wave attenuation/dissipation				X								X	X	X	X	X	X	X	X	X	X	
Internal wave formation/propagation/attenuation																	X					
Petroleum pollutant transport/dispersion																						
Chemical pollutant transport/dispersion																						
Tsunami attenuation				X		X						X	X	X	X	X	X	X	X	X	X	
Wind-derived circulation pattern												X	X	X	X	X	X	X	X	X	X	
Tidal-derived circulation pattern				X								X	X	X	X	X	X	X	X	X	X	
Coastal eddies				X																		
Surface layer transport	X			X																		
Coastal upwelling pattern	X		X																			
Coastal tidal attenuation	X		X																			
Coast ocean thermal fronts/patterns																				X		
Powerplant thermal plumes	X		X				X	X		X												
Ocean-freshwater thermal mixing	X							X														
Coastal-ocean thermal mixing in depth			X					X														
Ocean-atmospheric thermal exchange			X					X											X			
Bottom movement around offshore structures																						
Bottom movement relative to ship navigation												X	X	X	X	X			X		X	
Beach erosion/redeposit																						
Wave/shore interactions																						
Sediment transport/deposit																						
Biological growth patterns																						
Chlorophyll			X									X	X	X	X	X			X		X	
Plankton	X		X				X	X		X	X	X	X	X	X	X			X		X	
Fish	X						X	X														
Shellfish	X						X	X														
Biological disease blooming								X	X													
Point source pollutant transport/dispersal	X	X	X				X	X			X	X	X	X	X	X			X		X	
Pesticide/chemical pollutant	X																					
Runoff patterns/dispersal	X		X																			
Sewage transport dispersion	X																					
Radioactivity effects																						

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TABLE 15c. RTOP AND AN ACTIVITIES PLANNED FOR POLAR AREAS

	Mesoscale Ice Dynamics Processes (Zwally, GSFC) 146 40 02	Cryosphere Mission Studies (Wilks, GSFC) 146 40 XX	Cryosphere Research (Elachi JPL) 146 40 08	Microscale Ice Dynamics (Gedney, LeRC) 146 40 06	Ice Sheet Elevation from Satellite (Zwally, GSFC) AN 487/82	Algorithm Development SAR Polar Ice Motion Measurement (Elachi, JPL) AN 272/43	Ice Dynamics by Remote Sensing (Chu, Mai Ling USGS) AN 651/106	Use of Seasat and Other Satellite Data Sea Ice Features (Barnes ETR, Inc) AN 365/59	Ice Type/Surface Roughness Active Microwave Algorithm Development (Gedney, LeRC) AN 631/102	Numerical Modeling of Sea Ice Dynamics and Thickness (Hibler, CRREL) AN 656/108	Beaufort Sea Experiment (Canadian Gulf Oil, CAnmar Esso) ASVT 1	Labrador Sea Experiment (Canadian Esso, ESCAN Exploration) ASVT 2	Bering Sea Experiment (Ocean Service, Inc) ASVT ?
Ice edge motions	X		X	X		X	X	X		X	X	X	X
Ice deformation rotation, and ridging	X		X	X		X	X	X	X	X	X	X	X
Sea ice formation and breakup				X						X	X	X	X
Wind/sea ice interactions				X						X	X	X	X
Ocean current/sea ice interactions				X						X	X	X	X
Ocean tide/sea ice interactions				X						X	X	X	X
Ocean wave/sea ice interactions				X	X								
Ice lead formation/closing			X								X	X	X
Glacier formation/recession													
Iceberg formation/dispersion													
Ice/snow/atmospheric thermal exchange													
Ice/snow/ocean thermal exchange													
Polar biological growth patterns													
Point source pollutants transport/dispersion													
Arctic mammal ecology													
Arctic bird ecology													
Permafrost variability													

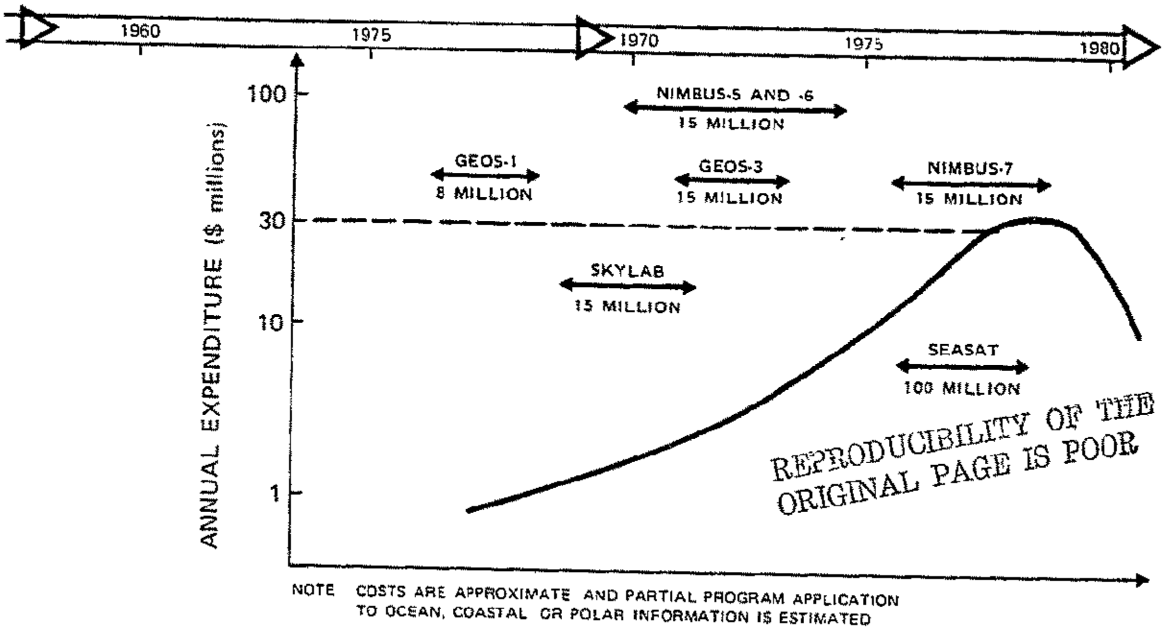

FIGURE 3. FUNDING FOR SATELLITE PROGRAMS PROVIDING ENVIRONMENTAL DATA

Although RTOP and AN activities may be adjuncts to or evolve from major program developments such as Nimbus or Seasat, they are not tied directly to these programs. There are, in addition, investigations sponsored on behalf of or as part of these major programs. Table 16 describes a set of scientific investigations covering the subject areas that are currently being jointly sponsored by NOAA and NASA. These investigations are being conducted by non-agency scientists using data produced by the Seasat program with SMMR sensor support from the Nimbus program.

In addition to the investigations described in Table 16, both Seasat and Nimbus projects have investigative teams, under the direct support of each project, that are tasked with evaluating data from each program. Data validation and algorithm developments are closely tied to these activities, which are listed in Tables 17a and 17b.

TABLE 16. SEASAT NOAA/NASA SCIENTIFIC EXPERIMENTS

Principal Investigator	Affiliation	Objective	ALT	SMMR	SCATT	SAR		VIR		Geographic Area
						CCTS	IMAGE	CCTS	IMAGE	
Wunsch	MIT	Geodesy, physical oceanography	X	X						N.W. Atlantic Ocean
Weinman	U. of WA	Precipitation rates		X					X	N.W. Atlantic Ocean
Estoque	U. of Miami	Sea surface wind and temperatures		X	X					Western Indian Ocean
Bernstein	Scripps	Ocean mesoscale eddy investigation		X						N.W. Pacific Ocean
Lipa	SRI	Swell amplitudes and wave heights	X							JASIN
Beal	JHU/APL	Ocean wave detection					X			Coastal U.S. (10 locations)
Schuchman	ERIM	Ocean current detection					X			N.E. Pacific Coast (4 locations)
Stewart	Scripps	Oceanic rainfall measurements		X						JASIN/N. Pacific
Jarrell	SAI	Surface stress, winds, and temperature verification		X	X					California Coast
Rapp	OSU	Geoid, sea-surface topography	X							Altimeter Calibration Zone
Talwani	Lamont	Geodetic studies	X							N W. Atlantic/N. Pacific
Roufosse	SAO	Geoidal height/bathymetry	X							Pacific Ocean
Schutz	U. of Texas	Precise ephemeris/topography	X							Global
Brammer	TASC	Altimeter resolution capability	X							Altimeter Calibration Zone
Brooks	EG&G	Ice sheet mapping	X							Greenland/Antarctica
Niebauer	U. of Alaska	Fisheries oceanography	X	X						Bering Sea
Martin	U. of WA	Bering Sea ice	X				X		X	Bering Sea
Katsaros	U. of WA	SST validation and application		X						JASIN
Peterson	Stanford U.	Open ocean wave measurements					X			JASIN
Brown	ASA, Inc.	Altimeter wind and ice measurements	X							
Bowling	U. of Alaska	SST and meteorological connections			X				X	Gulf of Alaska/Aleutians
Maresca	SRI Int'l	Ocean waves, winds, and pressure		X	X			X	X	E. Pacific and Gulf of Mexico
Estes	UCSB	Oil spills				X		X		Santa Barbara Channel
Matthews	U. of Alaska	Storm surge, tides, and SST	X				X		X	Cook Inlet, Alaska Arctic Coast
Hayes	ERT	Shallow water wave refraction	X			X		X		Baltimore Canyon/N. England Coast
Goldsmith	VIMS	Sea wave climate model	X					X		Cape Hatteras/Long Island
Suomi	U. of WI	Wind stress measurements		X	X					Atlantic/Pacific/Indian Oceans
Gentry	GE-MATSCO	Tropical cyclone research		X	X					Atlantic/E. Pacific Oceans
Blanchard	TAMU	Soil moisture				X		X		4 areas in U.S.
Brooks	EG&G	Altimeter overland tracking analysis	X							U.S.
Schuchman, Polcyn	ERIM	Ocean wavelength				X				Cape Hatteras

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TABLE 17a. SEASAT PROGRAM EXPERIMENTS

Sensor	Geophysical Observables	Experiments	Investigators
Altimeter	Instantaneous mean surface height Significant (or RMS) wave height Nadir wind speed Wave skewness (and possible dominant wave length)	Comparison of geophysical algorithms for wave height extraction	W. F. Townsend, L. S. Fedor, G. S. Hayne
		Wave height validation using surface observation data base	L. S Fedor, W. F. Townsend, G. S. Hayne
		Altimeter windspeed observation for Nadir 0°	G. S. Brown, L. S. Fedor
		Signal anomalies due to sea surface wave height and tracking system effects	J. Lorell, L. S. Fedor
		Wave height skewness and dominant wave lengths	E. J. Walsh, N. E. Hufing
		Height tracking error vs. sea state	G. S. Hayne, E. J. Walsh, J. S. Fedor
		Altimeter engineering assessment	W. F. Townsend
		Altimeter time bias	R. D. Tapley, B. Schutz, C. Shum, R. Eanes, J. Marsh, S. Smith
		Altimeter height bias	R. Kolenkewicz, C. Martin
		Altimeter correction algorithms	J. Lorell, M. Parke, C. Born S. Smith, C. Goad
VIRR	Sea surface temperature (clear air) Visual and IR images of features (clouds, ice, etc.)	Geophysical evaluation of VIRR data	E. P. McClain, R. A. Marks, G. Cunningham
		Use of VIRR data to estimate severe attenuation of microwave signals	E. P. McClain, G. G. Dome
Scatterometer (SCATT)	Surface wind speed Surface wind direction	Sensor description/0° measurement accuracy	E. M. Bracalente, D. H. Boggs, Y. E. Delnore, W. L. Jones
		Atmospheric attenuation for scatterometer	G. G. Dome, R. K. Moore, F. J. Wentz
		Wind vector algorithm and model function	F. J. Wentz, G. G. Dome, R. K. Moore, W. J. Pierson, I. M. Halberstam
		SCATT wind vector comparisons with surface spot observations and surface fields	J. H. Ernst, M. G. Wurtele, E. M. Bracalente, D. H. Boggs, R. A. Brown, G. G. Dome, W. L. Jones, J. L. Mitchell, S. Peterherych, W. J. Pierson, L. C. Schroeder, P. M. Woiceshyn
		Error analysis of wind spot observations for SCATT	W. J. Pierson

TABLE 17a. (Continued)

Sensor	Geophysical Observables	Experiments	Investigators
SMMR	Sea surface temperature Surface wind speed Integrated atmospheric water vapor over column to surface Integrated liquid water content over column to surface Raindrop sizes and distribution Ice field maps	Antenna pattern correction	
		a. Instrument analysis	E. Njoku
		b. Implementation of algorithm	E. J. Christensen, B. B. Wind
		Geophysical algorithms	
		a. Nonlinear estimation algorithm	F. Wentz
		b. Linear regression algorithm	T. Wilheit
		Sea surface temperatures	R. Betstein
		Wind speed	V. Cardone
		Atmospheric water	K. Katsaros, J. Alishouse
SAR	Dominant wave period Dominant wave direction Sea ice and freshwater ice Land and snow cover images Surface expression of currents, internal waves, shallow bathymetric features, and surface winds	Dominant ocean wavelength and direction measurements by SAR	F. I. Gonzalez, R. A. Shuchman, D. B. Ross, C. L. Rufenach, J. E. R. Gower, P. Deleonibus
		Comparison of SAR image intensity sector with ocean wave height directional spectra	W. E. Brown, R. A. Shuchman, F. I. Gonzalez, D. B. Ross
		Peak to background ratios of SAR image intensity as a measure of ocean wave detectability	M. E. Brown, R. A. Shuchman, F. I. Gonzalez, T. W. Thompson
		SAR ocean wave imaging mechanisms	C. L. Rufenach, R. A. Shuchman
		SAR ocean surface current detection capabilities and limitations	R. A. Shuchman, F. I. Gonzalez, J. F. R. Bower
		Ocean surface features detection by SAR	F. I. Gonzalez, R. A. Shuchman
		Analysis of continental shelf internal waves	J. R. Apel
Seasat Sensors Inter-Comparisons		0° intercomparisons at nadir between Seasat-SASS, Seasat-altimeter, and Geos-altimeter	E. M. Bracalente, W. L. Grantham, G. S. Brown, L. S. Fedor
		Windspeed comparisons between altimeter, SCATT, SMMR	C. T. Swift, E. M. Bracalente, L. S. Fedor, G. S. Brown, W. L. Grantham
		SCATT/Geos wind intercomparison	W. L. Grantham
		SCATT vs. SAR surface wind intercomparisons for orbit 1339	R. C. Beale, P. M. Woiceshyn, D. Lichy, W. L. Jones, D. E. Weissman, E. M. Bracalente, W. L. Grantham, T. W. Thompson
		Intercomparison of SMMR and VIRR sea surface temperatures, including SMMR water vapor corrections to VIRR measurements	E. P. McClain
		Significant wave height in the SAR swath inferred from altimeter data and the FNWC-SOWM (wave) model	L. S. Fedor, F. I. Gonzalez
		Comparison of SAR relative image intensity with SCATT winds for orbits 1126 and 1169	D. E. Weissman, F. I. Gonzalez

TABLE 17b. NIMBUS-7 PROGRAM EXPERIMENTS

Sensor	Geophysical Observables	Experiments	Investigators
SMMR	Sea surface temperature	Compare expendable bathythermographs with the SMMR	J. Mueller
	Near-surface wind algorithm	Compare SMMR-derived near-surface wind with model predictions	D. Ross
	Atmospheric frontal zone	Validation of atmospheric liquid water (L), atmospheric water vapor (W), and rain rate (R) retrieval algorithms	D. Staelin
	Sea ice parameter retrieval	Improved accuracy for sea ice and related parameter algorithms	W. Campbell
	Old sea ice, snow fields	Extensive analysis of instrumented snow fields in Scandinavia and snow courses in North America	P. Gloersen
	Soil index studies based on antecedent rainfall	Microwave brightness temperature with antecedent rainfall amounts	T. Schumugge
	Snow fall data	Snow depth, density, and temperature in Scandinavia, Canada, Northern U.S.A., Switzerland, and Austria	A. Chang
	Sea surface temperature and sea ice algorithms	Obtain radiances over selected sea ice and snow field test sites observations in the Northern Pacific Experiment (NORPAX) in the vicinity of Honolulu and Tahiti	P. Gloersen
	Initial SMMR ocean algorithm comparison with NOAA surface data	Determine error statistics for sea surface temperatures and near-surface wind speeds	T. Wilheit
	Snowpack properties	Follow the time variation of snow field test sites	A. Chang
	Observables or snow fields	Extend the multispectral analysis used on the NEMS/SCAMS data	
	Snow accumulation rates	Extend the analysis of GSMR-5 radiometric signatures of Greenland and Antarctica	H. J. Zwally
	SMMR data as orthogonal functions	Compress SMMR data in terms of geographic orthogonal functions	J. Mueller
	Cryosphere studies in Greenland	Correlate SMMR data with information from Greenland	P. Gudmandsen
	Antarctic ice studies	Generate a long-term data rank on oceans and shallow seas	P. Windson
	Snow field properties	Determine microwave signatures using prelaunch studies of Swiss and Austrian snow fields	K. Kunzi
CZCS	Gulf of Mexico Experiment	Cover various water mass types in the Gulf of Mexico utilizing the research vessel GYRE from Texas A&M University	C. S. Yentch, G. L. Clark, G. C. Ewing, C. J. Lorenzen, W. A. Hovis, M. L. Forman, L. R. Blaine, R. C. Smith, K. S. Baker, A. Morel
	Southern California, the Gulf of California	Utilizing a research vessel from the Scripps Institute of Oceanography, a surface validation expedition was carried out	
	Foreign Experiments	Validation investigations in European waters off South Africa by the Joint Research Center of the Commission of European Communities	

To add to an already growing list of information utilization paths, there are many industry or private sector uses of data from current programs. Table 18 provides a list of marine commerce applications associated with Seasat and Nimbus information. Even with the unexpected and early demise of Seasat, most of these activities continue and industry experiments, using a facility developed by the Navy and NASA at the Navy's Fleet Numerical Weather Central in Monterey, California, are operating with the limited data base that exists for Seasat, augmented by Nimbus SMMR data. The reason for showing each of these efforts in distinct and separate tables is to emphasize that they are supported by different budgets (administered in several parts of NASA's Office of Space and Terrestrial Applications) and involve numerous NASA centers and other government agencies. Program participants acquire and process the information they need in a variety of ways at many locations and publish and distribute their results independently in numerous journals, papers, and agency documents. The use of distributed resources, facilities, and personnel by diverse interests is a healthy sign of the widespread interest in programs dealing with ocean, coastal zone, and polar information. However, a library function dedicated to keeping track of production and aiding both insiders and those not directly engaged in the program to acquire pertinent information would be a significant improvement and is much needed. Each of the issues discussed in Section A are even more relevant when the current system is viewed objectively as one point on an expanding data base. A look at future efforts that range from investigative/proof-of-concept to limited operational programs confirms the need for better information systems. The future promises increases in information quantity, type and application. Figure 4 shows the new directions in remote sensing research and development and major new programs now in the concept and planning stage.

TABLE 18. ANALYSIS AND EVALUATION OF SEASAT DATA BY THE COMMERCIAL SECTOR

Commercial Sector	Organizations	Application	Area of Interest
Offshore oil and gas	Gulf Oil of Canada, Ltd. Canadian Marine Drilling, LTD ESSO Resources Canada, Ltd	Improve oil and gas exploration in the ice infested waters of the Beaufort Sea.	Beaufort Sea
	Total Eastcan Exploration, Ltd.	Monitor sea ice in the Labrador Sea.	Labrador Sea
	American Gas Association	Detect storm development in the Gulf of Mexico.	Gulf of Mexico
	Continental Oil Co.	Detect storms and hurricanes in the N.E. Atlantic.	North Sea, Baltimore Canyon
	Getty Oil Co.	Detect storms and hurricanes in the following locations: Offshore W. Africa, U.S. East Coast, N.W. Australia, Curacao, Argentina, Tunisia, Norway, and Spain.	
	Alaska Oil and Gas Assoc.	Evaluate the utility of SAR data in offshore petroleum operations in the ice-covered areas in the Bering Sea.	Bering Sea
Ocean Mining	Deepsea Ventures, Inc. Kennecott Exploration, Inc. Lockheed Ocean Laboratory	Access SAR data for ocean mining, design and exploration operations.	Tropical Pacific
Marine Fisheries	North Pacific Fishing Vessel Owners Assoc. (Alaska Crab Fishery)	Ice observations in the Bering Sea.	Bering Sea
	National Marine Fisheries Service/ NOAA (coordinating 20 to 30 tuna and albacore vessels	Study ocean conditions (wave and storm patterns) in the Pacific tuna and salmon fishing regions.	Tropical Pacific
	Marine Advisory Service (coordinating 10 to 15 salmon vessels)		U.S. West Coast
Marine Safety	International Ice Patrol (USCG)	Survey icebergs and sea ice in the N. Atlantic. Study drift properties of icebergs.	Baffin Bay, Labrador Sea, N. Atlantic
Marine Transportation	Ocean Routes Sun Shipbuilding and Drydock Co.	Operational forecasting for world's oceans.	Global

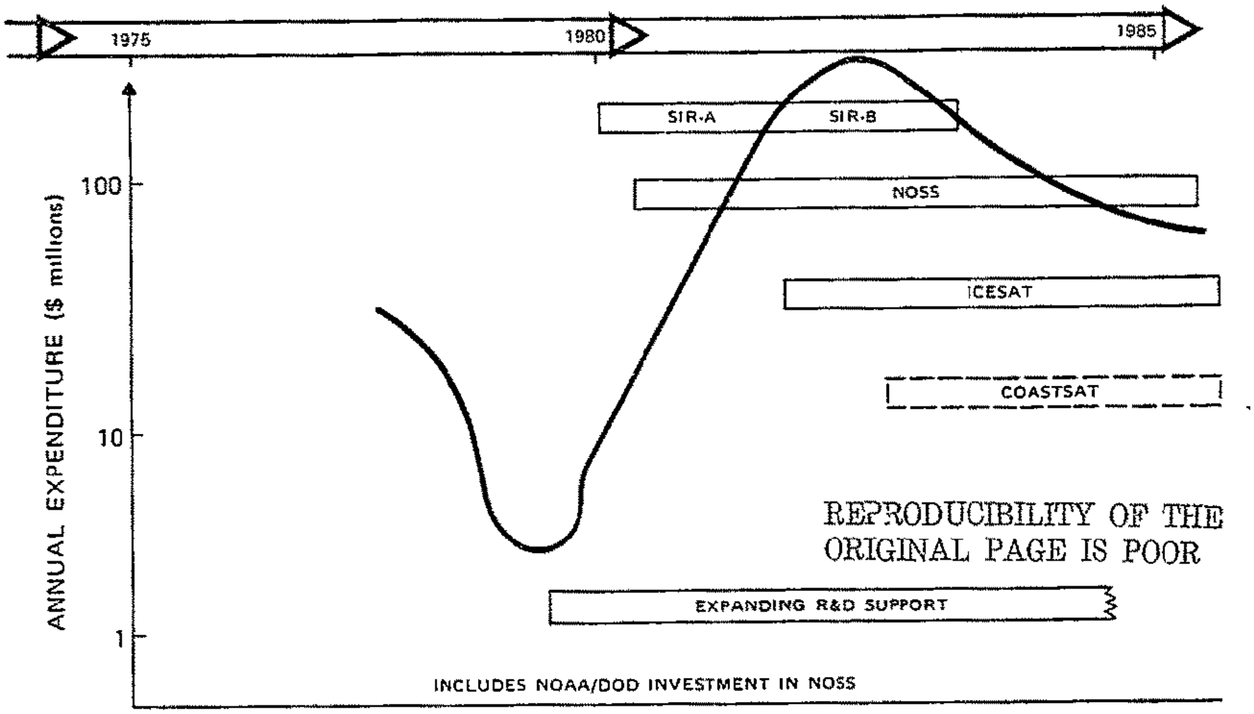

FIGURE 4. FUNDING ESTIMATES FOR PROGRAMS WITH OCEAN, COASTAL, OR POLAR APPLICATION

It is important to note that through RTOPs, ANs, AOs (announcements of opportunities), ASVTs, and project evaluations, NASA supports a large user community. This community is made up of scientific, agency, and industry users with diverse needs, all of which need to be considered in the evaluation of an Applications Data System. Many of the industry and agency users have to make considerable investments in order to gear the NASA data to their particular needs, and the quantity and quality of these investments requires careful consideration in the evolution of the Applications Data System.

Most of the preceding discussion concentrates on what NASA has done, is doing now, and is planning to do in the future as a producer of information valuable to the ocean, coastal, and polar region users. Other agencies and private sector organizations are also beginning to accelerate their use of space and space technologies in the subject regions. Establishment of an applications data system within NASA that includes these and other information categories becomes more important as time passes and also more difficult due to an accumulation of larger volumes of pertinent data.

H. INFORMATION FLOW--PRODUCER TO USER

Data or information emanating from programs that reside in the scientific or proof-of-concept state of evolution follow paths to users that are very different from programs that have progressed to dedicated, institutionalized long-term facilities. In case of the former, the data flow can follow unexpected osmotic paths from producer to user, as shown in Figure 5. In fact, there are many data paths that occur as fourth or fifth tier spinoffs of the ones shown. Many of the scientific or investigative results emanating from such a program are either obscured or are literally inaccessible to a larger audience interested in program results; hence, the need for a centralized reference library and acquisition path.

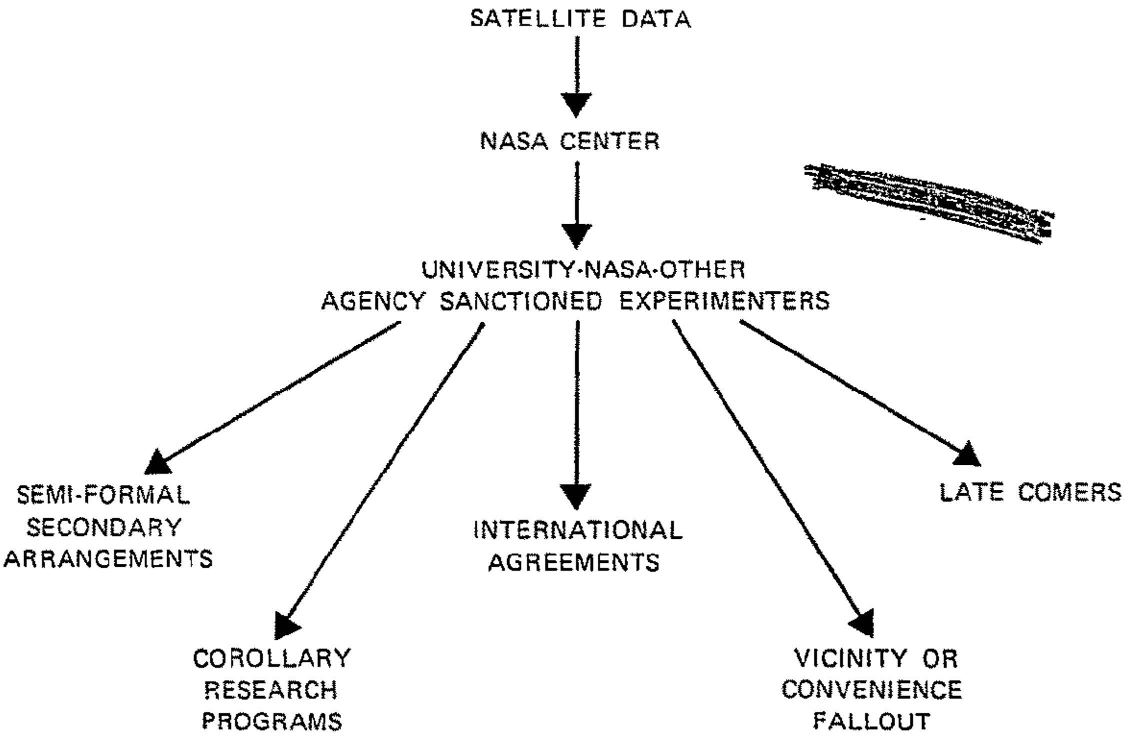

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FIGURE 5. SCIENCE OR PROOF-OF-CONCEPT PROGRAMS

At the other end of the spectrum, all major programs such as the limited operational NOSS program are currently in the planning and concept development stage. Figure 6 depicts the kind of ground segment and information processing and distribution system being considered. As discussed previously, these programs provide a few large users of information with continuous, high-volume, routine sets of information using a channelled, institutionalized system developed specifically to serve this need. These kind of systems are necessary for operational programs, particularly those with real-time or near-real-time data requirements. With the exception of these high-volume dedicated facility efforts, other users of information could be served by a system with the attributes shown in Figure 7.

What is needed is a common point to review and acquire the available information. An established method of format control to meet defense requirements is necessary, if such a system is to be made workable, and assured continuity of operation is essential to the success of such an information system.

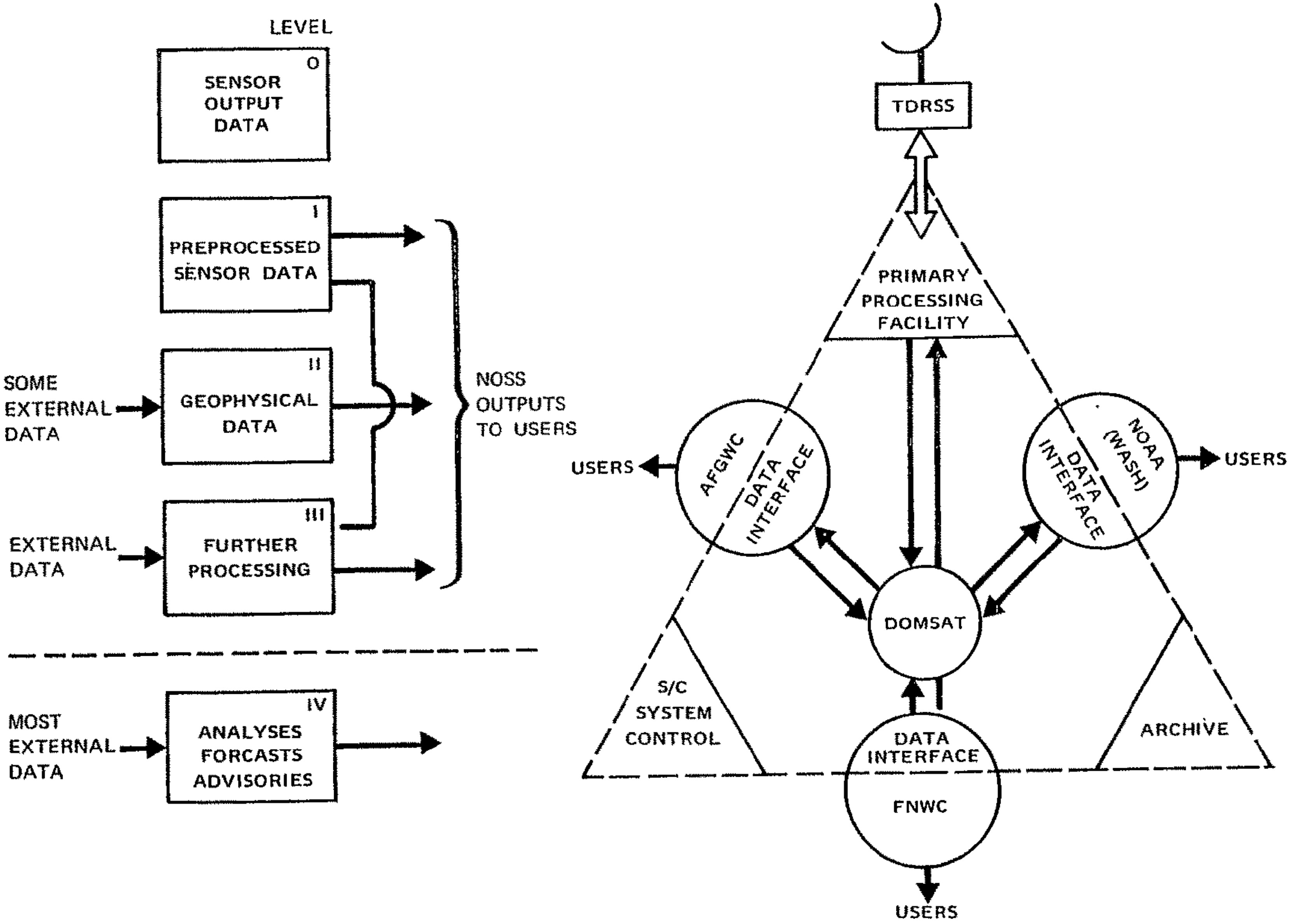

FIGURE 6. OPERATIONAL-TYPE PROGRAMS

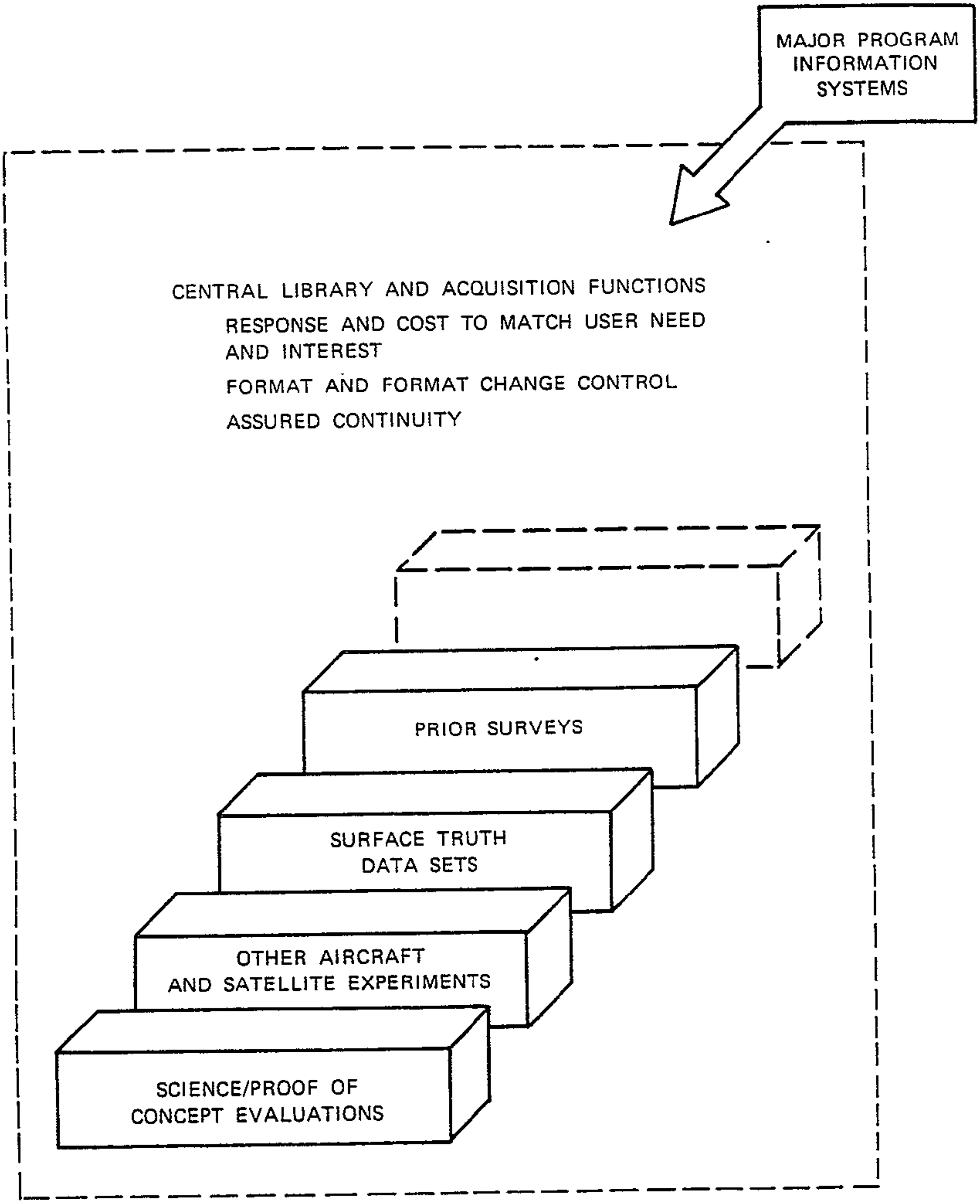

FIGURE 7. WHAT IS NEEDED

SELECTED REFERENCES

1. D. R. Montgomery and S. W. McCandless, SEASAT-A, A User Oriented Ocean Monitoring Satellite Program, National Aeronautics and Space Administration, 1974.

2. R. G. Nagler, "Surveying the Earth's Environment from Space: Spectral, Aerial, Temporal Coverage Trends," AIAA/AMS/AGU/IEEE/MTS/SEG Satellite Applications to Marine Technology, AIAA 77-1585, November 1977.

3. R. G. Nagler, S. W. McCandless, and R. Durstenfeld. "Marine Decision Aids from Space," AIAA/AMS/AGU/IEEE/MTS/SEG Satellite Applications to Marine Technology, AIAA 77-1611, November 1977.

4. P. J. Rygh, SEASAT-B Options Phase Final Report, Volume III, Technical Description, JPL Report 2000-24, June 1977.

5. R. G. Nagler, Advanced Ocean Mission Development, JPL presentation to Ad Hoc Oceans Advisory Group, April 1978.

6. National Aeronautics and Space Administration, Review Information: National Oceanic Satellite System, April 1978.

7. D. R. Montgomery and P. Wolff, SEASAT-A and the Commercial Ocean Community, NASA 77-1591, April 1978.

8. R. G. Nagler and S. W. McCandless, Operational Oceanographic Satellites Potentials for Oceanography, Climatology, Coastal Processes, and Ice, NASA Report, September 1975.

9. S. W. McCandless and V. J. Cardone, SEASAT-A Oceanographic Data System and Users, IAF Paper, June 1977.

10. W. A. Hovis, Jr., Ocean Color Measurement From High Altitude, NASA, April 1977.

11. Bradford Johnson and S. W. McCandless, Status of SEASAT-A User Investments, NASA Congressional Testimony, 1977.

12. R. Durstenfeld, "Advanced Marine Information Delivery System Development," presentation to Ad Hoc Oceans Advisory Group, April 1978.

13. V. Noble, Revision II of NOSS SG Interim Report, Naval Research Laboratory, July 1978.

14. A. A. Loomis, National Oceanic Satellite System Definition Phase Final Report, Volume II, Requirements and Rationale, JPL Report 624-12, June 1978.

15. Lockheed Missiles and Space Company, NOSS Study Status Report, August 1978.

16. R. G. Nagler and E. J. Sherry, Global Services Satellite Circa 1995, Vol. II, Environmental and Resource Management Services, JPL Report, September 1978.

17. Jet Propulsion Laboratory, National Oceanic Satellite System Cost Review, JPL Report 720-20, July 1978.

18. Jet Propulsion Laboratory, Follow On SEASAT User Needs Report, JPL Report 624-1, October 1976.

19. John R. Apel, Ocean Science From Space, EOS Volume 57, No. 9, September 1976.