SEASAT-A

REMOTE SENSING ENTERS THE MARINE ENVIRONMENT

S.W. McCandless, Jr.
Manager, (SEASAT Programs)
Office of Applications
NASA Headquarters
Washington, D. C.

ABSTRACT

In recent years the potential for remote sensing of physical phenomena has been advanced by research and by developments in the fields of meteorology and earth observations; with the exception of cloud cover photographs and infrared derived temperature determinations, little use has been made of such techniques for oceanological purposes. On the other hand, recognizing the dynamic nature of oceanological phenomena and the difficulty and expense of obtaining in situ measurements (particularly the needed globally consistent, geographically and temporally dense, data) a need exists to consider the potential for application of such tehniques to ocean-oriented phenomena. Now, the Seasat-A space program has been initiated as a "proof-of-concept" mission to evaluate the effectiveness of remotely sensing oceanological and meteorological phenomena from a satelliteborne platform in space, through utilization of remote sensors developed on previous space and aircraft programs. The users initiated Seasat-A nd continue to serve as the architects of the program. Requirements for a system, derived from the expressed needs of potential users of such data, are discussed, together with the current capabilities and limitations of spaceborne sensors to obtain such data. The goals of the Seasat-A spacecraft and its associated data system are described, as well as the approach planned to verify the measurements being taken and to confirm the benefits and effectiveness of the system in meeting the needs of the ocean-using community.

THE PAST

"In 1872 HMS Challenger left Portsmouth on a voyage that was to take her around the world, eight times across the Equator, into the Antarctic ice over 68,000 nautical miles at sea. She was a three-masted corvette with auxiliary steam, and, as well as a crew of 243 she carried a team of scientists led by Professor Wyville Thomson.

The voyage of the Challenger was a pioneer expedition of immense importance. It was 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. The ambitious aim of the voyage was to chart the depths, movement and content of the seas, to scour the oceans for marine life, for clues to climatic phenomena, and for minerals." (Ref. 1)

One hundred and five years later Seasat-A will be launched into earth orbit from Vandenberg Air Force Base, California. In less than five hours Seasat-A will have travelled a distance equivalent to that travelled by the Challenger and have embarked on a voyage of perhaps even greater importance.

The voyage of Challenger was initiated by the ocean-using community, both government and commercial, and the ocean scientists. The Seasat Program, which is under the sponsorship of the Office of Applications, Special Programs Division, National Aeronautics and Space Administration, in collaboration with the Jet Propulsion Laboratory of the California Institute of Technology, has its origins with these same users, and thus, blends the requirements of government and commercial sea users with those of the scientific community.

TODAY'S NEEDS

From a symposium in Williamstown, Mass., in 1969[2], the goals and objectives for observation, measurement, and interpretation of physical ocean phenomena have evolved, aided by continuing interaction between Ocean Users and System Designers. In 1972 NASA's Oceans Applications Programs objectives were published; they included specific recommendations from a group of governmental, institutional, and private ocean users working with the program. Since then, regular meetings of a Users Working Group have assisted NASA during all program phases beginning with the refinement of program requirements during the program definition phase, to take advantage of advancements in the field of remote sensing, and to resolve any apparent conflicts between requirements and capabilities, and to develop their own supporting programs. Currently, a formally organized Oceanology Advisory Subcommittee under the auspices of NASA's Applications Advisory Committee, derived from the Users Working Group, conducts regular quarterly meetings to continue these interactions. These continuing interactions have been essential in converting user requirements into a total system with the sole goal of providing continuous useful data to the Ocean using community in a timely manner.

The list of active users is large. From the federal government it includes the following:

- o Department of Commerce (National Oceanic and Atmospheric Administration, Maritime Administration, National Marine Fisheries)
- o Department of Defense (Defense Mapping Agency, Army Corps of Engineers, Navy Weather Service Command, Office of Naval Research, Naval Surface Weapons Center, Naval Research Laboratory, Naval Oceanographic Office)
- o Department of Interior (Geological Survey)
- o Department of Transportation (Coast Guard)
- o Energy Research and Development Administration
- o National Science Foundation
- o National Academy of Sciences
- o National Academy of Engineering

Institutional users who are active participants follows:

- o Smithsonian Astrophysical Observatory; Environmental Center for Atmospheric Research
- o Woods Hole Oceanographic Institution
- o Scripps Institute of Oceanography
- o City University of New York
- o Battelle Memorial Institute

From the private sector, the user community includes representatives of the:

- o shipping industry
- o oil industry
- o fishing industry
- o and coastal industries

The private sector will most likely be the future prime economic and social beneficiary.

The ocean community, like many others - and probably more than most - suffers from a lack of data. Most current observations, obtained from shipboard personnel, suffer a degree of inconsistency in quality as well as in temporal correlation. Other more consistent observations, (the NOAA buoys are an example) are from a limited number of locations and leave vast areas of the globe with little or no coverage. On the other hand, satellite-derived cloud cover and infrared temperature data, while providing synoptic coverage (valuable in its own right), in general lacks correlation with wind and wave information and cannot penetrate cloud cover to measure ocean surface conditions. Thus, the effectivity of a monitoring and now-casting system for the oceans is very limited. For example, forecast of wave heights depends upon time and space forecasts of surface winds, themselves subject to considerable uncertainty. Similarly, locations of ocean currents are only approximately known and the ability of shipping and fishing interests to exploit ocean currents and upwellings is lacking. Long-range weather forecasting for both continental and ocean areas is dependent upon a space- and time-dense initialization of wind, temperature, and pressure data. It is estimated(3) that observations of ocean conditions in about the same frequency and spatial density as available now for the continents will be required for improved weather forecasting.

The measurement needs as expressed by the wide range of users are summarized in Table 1.(4) Essential ingredients in any future operational ocean dynamics monitoring system are the attainment of global, all-weather, coverage; near-realtime data processing, evaluation, and distribution of data; and user feedback of operational utility to ensure continued system responsiveness to needs. Current systems such as Seasat-A are not capable of meeting these requirements. For comparison purposes, Seasat-A capabilities are shown in Table 2. A more complete description of the Seasat-A system is included later in this paper.

In Table 3, the principal groups of users of data are correlated with estimated needs for data. An almost unanimous need for data on wind fields and wave height and direction is apparent.

IV-B-81

Table 1

MEASUREMENT NEEDS

MEASUREMENT			RANGE	PRECISION/ ACCURACY	RESOLUTION	SPATIAL GRID	TEMPORAL GRID
TOPOGRAPHY	GEOID		5 cm TO 200 m	< ±10 cm	< 10 km		WEEKLY TO MONTHLY
	CURRENTS, SURGES, ETC.		10 cm TO 10 m 5 TO 500 cm/sec	< ±10 cm +5 cm/SEC	10 TO 1000 m	< 10 km	TWICE A DAY TO WEEKLY
SURFACE WINDS	AMPLITUDE	OPEN OCEAN	3 TO 50 m/s	+1 TO 2 m/s OR ±10%	10 TO 50 km	50 TO 100 km	2 TO 8/DAY
		CLOSED SEA			5 TO 25 km	25 km	
		COASTAL			1 TO 5 km	5 km	HOURLY
	DIRECTION		0 TO 360 DEG	±10 TO 20 DEG			
GRAVITY WAVES	HEIGHT		0.5 TO 20 m	+0.5 m OR +10 TO 25%	< 20 km	< 50 km	2 TO 8/DAY
	LENGTH		6 TO 1000 m	+10 TO 25%	3 TO 50 m		2 TO 4/DAY
	DIRECTION			+10 TO 30 DEG			
SURFACE TEMPERATURE	OPEN OCEAN		-2 TO 35°C	0.1 TO 2° RELATIVE 0.5 TO 2° ABSOLUTE	25 TO 100 km	100 km	DAILY TO WEEKLY WITH SPECTRUM OF TIMES OF DAY AND TIMES OF YR
	CLOSED SEA				5 TO 25 km	25 km	
	COASTAL				0.1 TO 5 km	5 km	
SEA ICE	EXTENT AND AGE			1 TO 5 km	1 TO 5 km	1 TO 5 km	WEEKLY
	LEADS		> 50 m	25 m	25 m	25 m	2 TO 4/DAY
	ICEBERGS		> 10 m	1 TO 50 m	1 TO 50 m		
OCEAN FEATURES	OPEN OCEAN			50 TO 500 m			TWICE DAILY TO DAILY
	COASTAL			10 TO 100 m			
SALINITY			0 TO 30 ppt	±0.1 TO 1 ppt	1 TO 10 km	100 km	WEEKLY
SURFACE PRESSURE			930 TO 1030 mb	±2 TO 4 mb	1 TO 10 km	1 TO 10 km	HOURLY

TABLE 2

GEOPHYSICAL OCEANOGRAPHIC MEASUREMENT CAPABILITIES FOR SEASAT-A

MEASUREMENT			RANGE	PRECISION/ACCURACY	RESOLUTION, km	SPACIAL GRID, km	TEMPORAL GRID
TOPOGRAPHY	GEOID	ALTIMETER	5 cm - 200 m	<± 20 cm	1 6 - 12	~10	LESS THAN 6 MONTHS
	CURRENTS, SURGES, ETC		10 cm - 10 m				
SURFACE WINDS	AMPLITUDE	MICROWAVE RADIOMETER	7 - 50 m/s	±2 m/s OR ±10%	50	50	36 h TO 95% COVERAGE
		SCATTER-OMETER	3 - 25 m/s	± 2 m/s OR 10%	50	100	36 h TO 95% COVERAGE
	DIRECTION		0 - 360°	± 20°			
GRAVITY WAVES	HEIGHT	ALTIMETER	0.5 - 25 m	±0.5 TO 1.0 m OR ±10%	1.6 - 12	NADIR ONLY	1/14d NEAR CONTINENTAL U.S
	LENGTH	IMAGING RADAR	50 - 1000 m	±10%	50 m		
	DIRECTION		0 - 360°	±15°			
SURFACE TEMPERATURE	RELATIVE	V&IR RADIOMETER	-2 - 35°C CLEAR WEATHER	1.5°	~5	~5	36 h
	ABSOLUTE			2°			
	RELATIVE	MICROWAVE RADIOMETER	-2 - 35°C ALL WEATHER	1°	100	100	36 h
	ABSOLUTE			1 5°			
SEA ICE	EXTENT	V&IR RADIOMETER		~5 km	~5	~5	36 h
		MICROWAVE RADIOMETER		10-15 km	10-15	10-15	36 h
		IMAGING RADAR		±25 m	25 m		1/14d NEAR CONTINENTAL U.S
	LEADS		> 50 m	±25 m	25 m		
	ICEBERGS		> 25 m	±25 m	25 m		
OCEAN FEATURES	SHORES, CLOUDS, ISLANDS	V&IR RADIOMETER		~5 km	~5	~5	36 h
	SHOALS, CURRENTS	IMAGING RADAR		±25 m	25 m	25 m	1/14d NEAR CONTINENTAL U S
ATMOSPHERIC CORRECTIONS	WATER VAPOR & LIQUID	MICROWAVE RADIOMETER		±25 m	50	50	36 h

TABLE 3

OCEAN DATA APPLICATIONS

BENEFICIARIES \ PHENOMENA	WINDS	WAVES	TEMPS	CURRENTS	SEA ICE (LEADS/ BERGS)	PRESSURE	SALINITY	UP-WELLINGS	POLLUTION	GEOID
1. TRANSPORTATION/ROUTING										
MARINE TRANSPORTATION	X	X		X	X					
NAVAL SHIPS	X	X		X	X	X				
2 OCEAN EXPLOITATION/USE										
FISHERIES	X	X	X	X			X	X	X	
OFFSHORE RIGS	X	X					X			
OCEAN MINING	X	X		X		X	X	X	X	
3 GENERAL SERVICES										
WEATHER FORECASTING	X	X	X			X				
COAST GUARD SERVICES	X	X	X	X	X				X	
LAW ENFORCEMENT	X	X	X	X					X	
GEOLOGICAL SURVEYS										X
ENVIRONMENTAL PREDICTION	X	X	X	X				X	X	
4 RESEARCH AND SCIENCE	X	X	X	X	X	X	X	X		X

THE FUTURE

As more complete and more accurate synoptic data of ocean surface conditions become available, additional uses for data can be anticipated. In general, these requirements can be expected to develop in the direction of improved information transfer and assimilation,more precise data, and complete global coverage on a daily scale. Also, it can be anticipated that information requirements will develop relative to conditions both above and below the surface of the sea - particularly the air sea interface and the atmosphere above the sea; and the dynamic upper levels of the ocean important to physical oceanography and biology.

Specific requirements can be foreseen as a result of increased marine activity in the Arctic Zone - particularly tied to the development of oil resources on the Alaskan North Slope and transportation of the products to the conterminous 48 states. The Arctic ice cover recedes from shore for only a very limited period of the year, and its subsequent approach and recedance are currently unpredictable for more than short time spans. Thus, the hazards of sea transportation to the North Slope could be greatly lessened by an understanding of development of ice leads and the forces influencing the dynamics of the Arctic ice cover. The difficulties experienced during summer 1975 at Point Barrow clearly point up the need for improvements in forecasting such phenomena.

Another example is the U.S. adoption of a 200-mile coastal fishing limit, which will increase monitoring, surveillance, and enforcement missions of the U.S. Coast Guard by an order of magnitude. At the same time many other countries (Mexico and Australia for example) are adopting similar limits with even less preparedness. As a result, the needs for a data system - to collect, assess, and alert - can be expected to proliferate.

Not least in importance is the strong potential for improvements in weather forecasting - both for ocean surfaces and adjacent continental masses (like our own Pacific Northwest) - that may ultimately result from increased knowledge of ocean surface conditions, heat transport, and ocean currents. Once we have the capability to collect such data and merge it with other sources of weather data to produce forecasts, the firmer the needs will become evident to achieve true long range predictions and better understanding of climatic processes.

EMERGENCE OF SEASAT

A means for synoptically monitoring wave heights and directional spectra, surface winds, temperature, ice, icebergs, storm surges, and other influences (or hazards) of the oceans is needed. Although remote sensing of such phenomena has not been widely accepted by the oceanic community, it appears that remote sensing may be the only approach that will yield consistent, spatially dense data. With the advancement in use of satelliteborne sensors by the Skylab, LandSat and MetSat programs, remote sensing of oceanic phenomena appears feasible. Certainly global coverage of internally consistent data is a basic attribute of satellite sensing. Thus, in response to user expressed interest and needs, a proof-of-concept satellite mission called Seasat-A intended to evaluate the feasibility of remote sensing techniques for oceanic phenomena, was initiated. The only issue to be resolved was the availability of instruments that could sense physical phenomena which, in turn, can be correlated with oceanic phenomena of interest.(5)

An array of suitable spaceborne sensors had been developed during earlier space programs, i.e., GEOS, Skylab and NIMBUS(6). As specific requirements were solicited within the using community, candidate instruments from this array were evaluated jointly by the users and NASA for application to the ocean dynamics mission - Seasat-A. A set of three active radars and two passive radiometers has been ultimately selected. The characteristics of these sensors are summarized in Fig. 1. The sensors include a pulse-compressed radar altimeter, a microwave radar scatterometer, a synthetic aperture imaging radar, a scanning multifrequency microwave radiometer, and a visible/infrared scanning radiometer.

The Seasat radar altimeter serves two functions[8]: it monitors average wave height to within 0.5 to 1 meter along its narrow (2 to 12 km) swath by measuring the broadening of its returned echo caused by increased surface wave actions; it measures to a precision of 10 cm the relative shape of the ocean geoid due to gravity variations and ocean tides, surges, and currents. As surface winds increase, so does surface roughness or chop. The radar scatterometer measures the signal of its returned echoes. Signal strength increases with the increase in wind-driven waves, which can be converted directly into wind speed and direction. **The scatterometer measures wind speeds from 3 to 25 m/sec within 2 m/sec and direction within** 20 deg over two 500-km swaths on either side of the spacecraft ground track. The five-frequency microwave radiometer serves four functions: (1) it measures surface temperature by measuring the microwave brightness of the surface to within 1 deg C; (2) it measures foam brightness, which can in turn be converted into a measurement of high (up to 50 m/sec) wind speed; (3) it maps ice coverage; and (4) it provides atmospheric correction data to the active radars by measuring liquid and gaseous water content in the upper atmosphere. The surface

SENSOR	COMPRESSED PULSE ALTIMETER	MICROWAVE SCATTEROMETER	SYNTHETIC APERTURE IMAGING RADAR	MICROWAVE RADIOMETER	VISIBLE AND INFRARED RADIOMETER
SENSING OBJECTIVE	GLOBAL OCEAN TOPOGRAPHY GLOBAL WAVE HEIGHT	GLOBAL WIND SPEED AND DIRECTION	WAVELENGTH SPECTRA LOCAL HIGH-RESOLUTION IMAGES	GLOBAL ALL-WEATHER TEMPERATURE GLOBAL WIND AMPLITUDE GLOBAL ATMOSPHERIC PATH CORRECTIONS	GLOBAL CLEAR-WEATHER TEMPERATURE GLOBAL FEATURE IDENTIFICATION CLOUD COVERAGE
FREQ/ WAVE LENGTH	13.9 GHz	14.6 GHz		6 6, 10 69, 18, 22 235, 37 GHz 1 275 GHz	0 52 TO 0 73 µm 10 5 TO 12 5 µm
ANTENNA/ OPTICS	1 m PARABOLA	5 TO 2.7 m STICK ARRAYS	11 X 2 2 m PHASED ARRAY	0 8-M OFFSET PARABOLA	12 7 cm OPTICS
POWER	125 W AVE	165 W AVE	200 TO 250 W AVE	50 W	10 W
DATA RATE	8 kb/s	2 kb/s	15 TO 24 Mb/s	4 kb/s	12 kb/s
HERITAGE	SKYLAB/ GEOS-C	SKYLAB	APOLLO 17	NIMBUS G	ITOS

swath of the microwave radiometer is 920 km. The visible and infrared radiometer will provide clear weather surface temperature data, cloud coverage patterns, and corroborative images of ocean and coastal features with a resolution of 5 km over a swath of 1500 km. These four sensors, known as the global sensors, will monitor the oceans and adjacent coastal waters globally. Their data will be recorded on magentic tape recorders on board Seasat. The data will be played back while the satellite is over one of the ground stations supporting Seasat.

The fifth sensor, the synthetic aperture radar, will provide all-weather imagery of ocean waves, ice fields, icebergs, ice leads, and coastal conditions and dynamic processes to a resolution of 25 m over a 100-km swath. Because of the very high data bandwidth of the radar imagery, this sensor, with its own separate data system, will be operated only in realtime while within line-of-sight of specific tracking stations equipped to receive and record its data. Seasat's sensor coverage is depicted in Fig. 2. Virtual global coverage is achieved every 36 hours.

SEASAT-A MISSION

The Seasat-A program objectives stem from a balanced program providing proof-of-concept, which is research based as well as providing basic oceanographic and meteorological data that are operation and application oriented. Its combination of active radar and passive microwave and infrared instruments gives it the capability of observing the ocean on a day/night, nearly all-weather basis. Thus, quantitative measurements of the ocean surface can be obtained not only in clear weather, but also in regions covered by persistent cloud cover or during severe storms.

The specific Seasat-A objectives[7] are:

a. To Demonstrate the Capability For

- o Global monitoring of wave height and directional spectra, surface winds, ocean temperature, and current patterns
- o Measuring precise sea-surface topography
- o Detecting currents, tides, storm and surges.
- o Charting ice fields and navigable leads through ice
- o Mapping the global ocean geoid

b. To Provide For User Applications Such Data As

- o Predictions of wave height, directional spectra and wind fields for ship routing, ship design, storm-damage avoidance, coastal disaster warning, coastal protection and development, and deep water port development

- o Maps of current patterns and temperatures for ship routing, fishing, pollution dispersion, and iceberg hazard avoidance

- o Charts of icefields and leads for navigation and weather prediction

- o Charts of the ocean geoid fine structure

c. To Determine The Key Features Desired in Future Operational Systems For

- o Global sampling

- o Near-realtime data processing and dissemination

- o User feedback for operational programming

d. To Demonstrate the Economic And Social Benefits of User Agency Products

The Seasat spacecraft bus, the Agena, first flown on military space missions in 1959 and subsequently on over 300 missions, has been configured to support the oceanographic mission requirements. The overall configuration of Seasat-A is shown in Fig. 3. The Seasat spacecraft comprises a standard satellite bus and a customized sensor module that supports and accommodates Seasat sensors and their antennas.

The single Seasat-A satellite is to be launched in the second quarter of Calendar Year 1978 from the Western Test Range into a near-polar (108-degree) circular orbit. The satellite will cruise at an altitude of 790 km, circling the earth every 101 minutes. Sensors with 1000 km cross-track coverage will provide global repeat coverage every 36 hours, using both day and night passes to complete the fill-in. This orbit will precess through a pattern that will begin to repeat ground tracks after about 4-1/2 months. During this time a first measurement precise determination of the ocean geoid with a 18 km a grid density will have been completed. Seasat's ground track for one day is shown in Fig. 4; its coverage extends over virtually all the unfrozen oceans, including the Alaskan North Slope to the Antartica, under all lighting conditions.

FIGURE 2

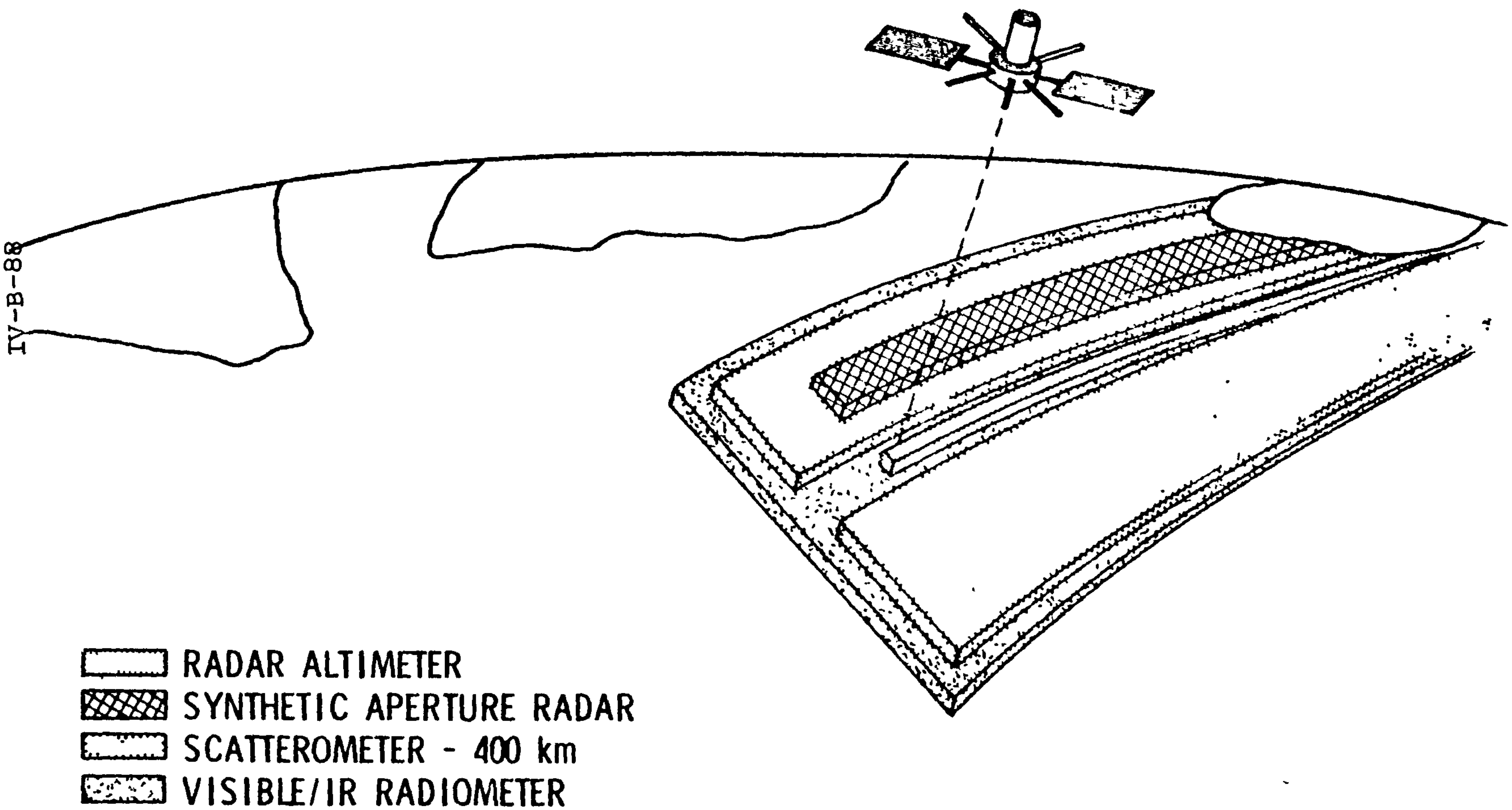
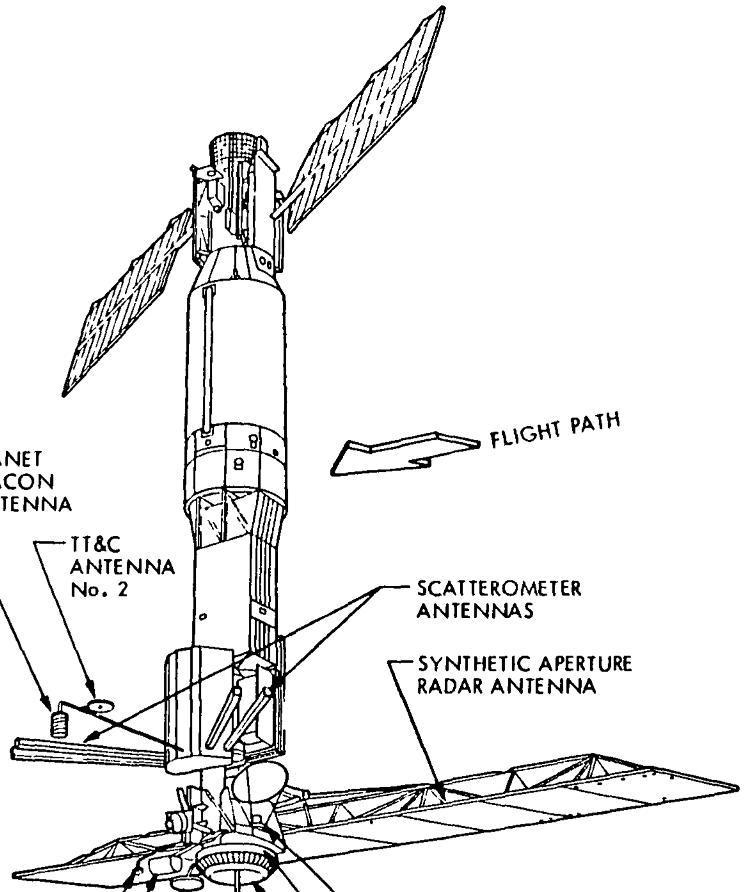

RADAR ALTIMETER
SYNTHETIC APERTURE RADAR
SCATTEROMETER - 400 km
VISIBLE/IR RADIOMETER

FIGURE 3

SEASAT-A MISSION



• MANAGEMENT

- OVERALL NASA OFFICE OF APPLICATIONS
- SATELLITE SYSTEM JPL
- SATELLITE BUS/SENSOR MODULE SYSTEM INTEGRATION LMSC
- SENSORS
  - SCANNING MULTIFREQUENCY MICROWAVE RADIOMETER JPL
  - RADAR SCATTEROMETER GENERAL ELECTRIC
  - SYNTHETIC APERTURE RADAR JPL
  - RADAR ALTIMETER APL
  - VISUAL INFRARED RADIOMETER NOAA

• MISSION OBJECTIVES

- MEASURE GLOBAL OCEAN DYNAMICS AND PHYSICAL CHARACTERISTICS
- DETERMINE KEY FEATURES OF AN OPERATIONAL SYSTEM
- IMPROVE BODY OF SCIENTIFIC OCEAN DATA/KNOWLEDGE
- DEMONSTRATE UTILITY OF DATA TO USER COMMUNITY

• MISSION ORBIT

- ALTITUDE (CIRC) 800 Km
- INCLINATION 108°
- WEIGHT ON ORBIT 1820 Kg

• LAUNCH DATA

- DATE MAY 1978
- SITE VAFB SLC 3W
- VEHICLE ATLAS F/AGENA

• COST DATA

- SPACECRAFT $66 5M
- LAUNCH SUPPORT $11 0M

NASA HQ ES77 2143 (1)
3 25-77

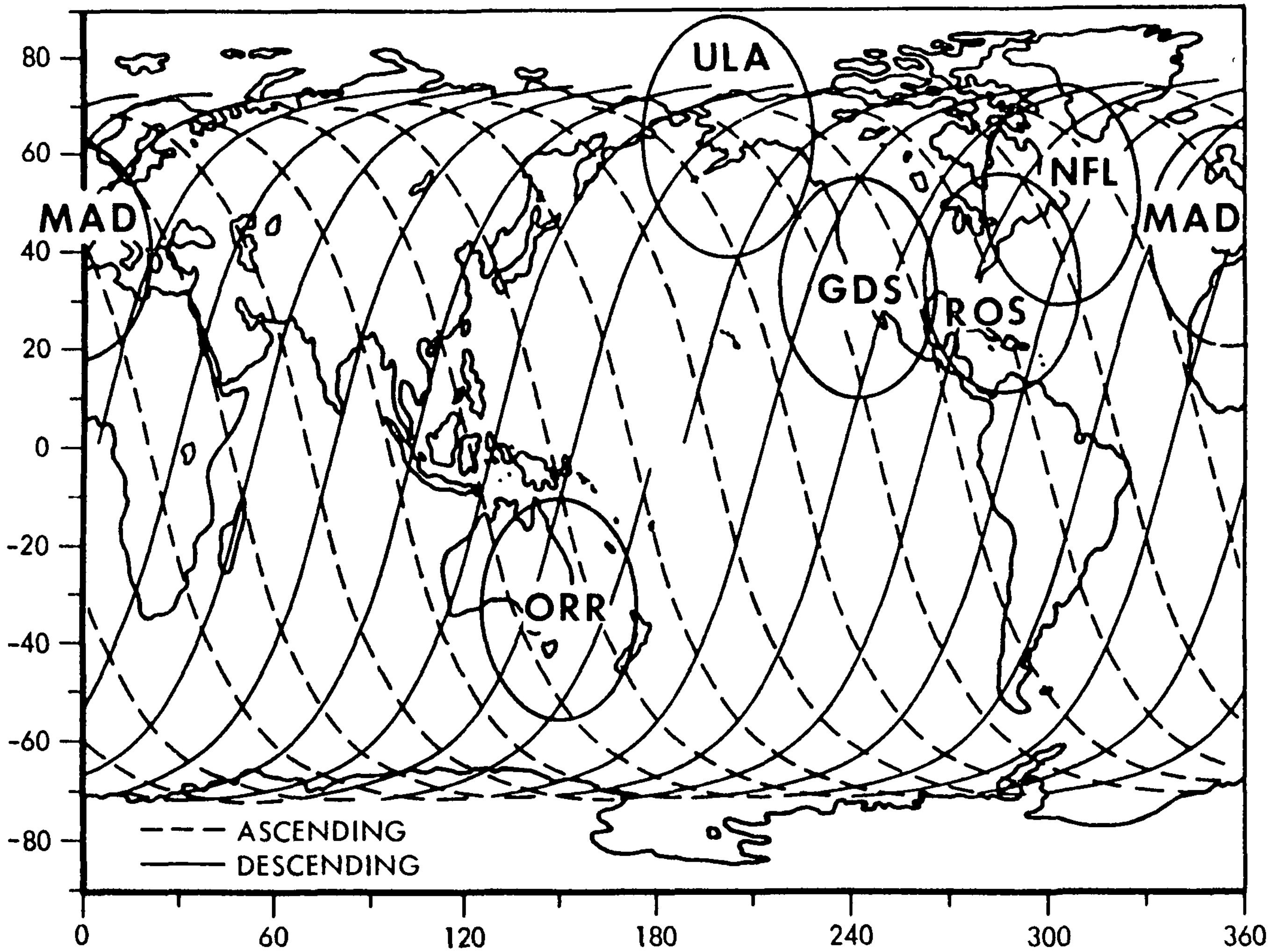


Fig. 4 SEASAT-A Trajectory and Ground Station Coverage

An ocean surface truth program has been initiated that will provide the user with insitu measurements of the sea-to-air interface that Seasat will monitor remotely from space. This program, already underway, will run through the proof-of-concept phase. It will provide the users with testdata from which algorithms for sensor data conversion can be formulated and with calibration and verification of the actual sensor performance from orbit. The ocean surface truth program is being operated concurrently with and will take full advantage of parallel ocean data tests being conducted by other government and academic agencies. The program will utilize data buoys, surface ships, and aircraft. NASA is currently designing several industrial Evaluation Experiments in cooperation with selected segments of the commercial ocean community. These experiments are intended to begin the transfer of ocean remote sensing technology to commercial users as well as to obtain experimental data to help validate previous economic benefit estimates. Further, these experiments will provide data to aid in the definition of those characteristics necessary for future Seasat systems which are of economic importance to commercial users.

The National Oceanic and Atmospheric Administration (NOAA), in cooperation with NASA expects to fund a number of scientific investigations within the non-Federal Ocean Research Community during 1978 and 1979. Cooperating also with NOAA is the Office of Naval Research (ONR), the National Science Foundation (NSF), the U.S. Coast Guard and the U.S. Geological Survey. This Solicitation of Investigations will provide support to the ocean science community for research activities utilizing Seasat-A data. Concurrently, it is expected that these investigations will augment the process of validating the scientific contribution expectations developed for Seasat-A.

USERS AND SEASAT DATA

Specific data acquisition, processing, and distribution plans. systems are currently being established by user organizations and NASA. Consistent with initial program formulation in 1973, NASA will establish proof-of-concept engineering and geophysical validation of Seasat data and users will provide the resources required for processing, analysis, dissemination and application of data peculiar to their special interests. Figure 5 provides a generalized view of this division of responsibilities.[9]

The data products of the Seasat sensors must serve a variety of users in a variety of forms. Weather data are highly perishable; to be of practical value, operationally, they must be processed (e.g., formatted, merged, blended, and analyzed) and applied in near realtime. Data older than 8 hours are of little interest except for climate studies or model development. At the opposite end of the spectrum is the geodesist, whose data are nearly time invariant. The geodesist's approach to analysis is often to fit and refit data for a bootstrap approach, finally achieving a best fit model of the ocean geoid. Some of the users will have sizable ground data systems available to assist them in processing and analysis; others will have only in expensive terminals with limited processing capability. Some users care only for specific outputs such as wind and wave data for use in ship routing; others, such as university researchers, want as much of the data as available for application to development of advanced prediction models. Thus, Seasat's end-to-end data system, consisting of NASA and user facilities equipment and communication networks, must be flexible and dynamic enough to meet the demands of this broad spectrum of currently identified and future user applications.

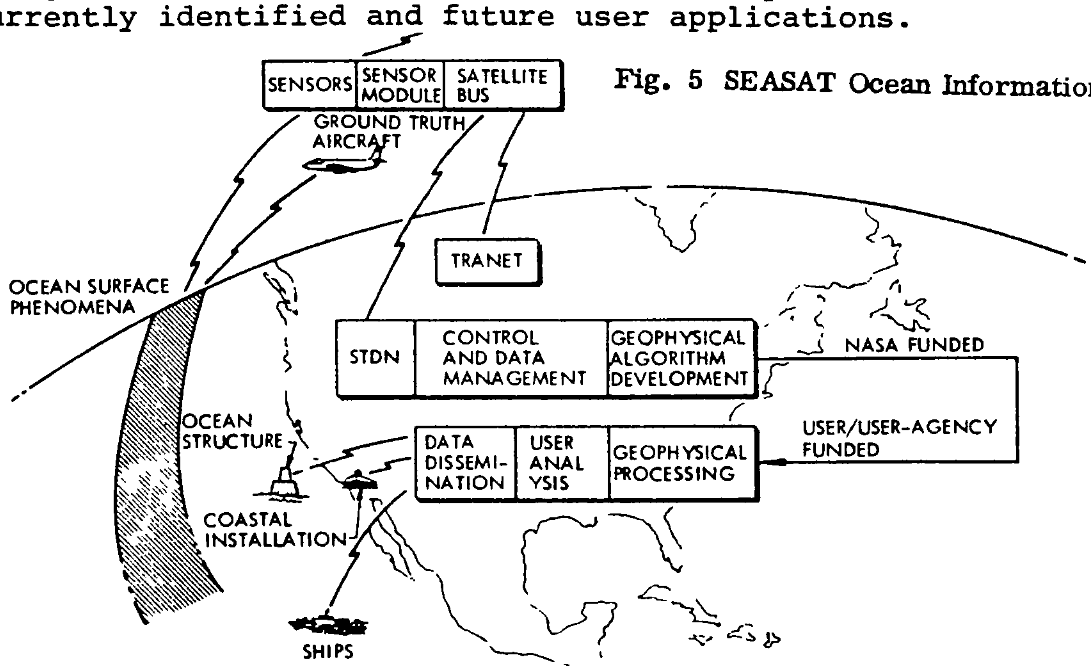


Fig. 5 SEASAT Ocean Information System

As indicated, this system comprises all elements from remote sensing of the ocean phenomena through collection and storage. Elements of this end-to-end system include location and sensor Calibration, onboard the satellite or on the ground, transmission to the earth for storage, conversion to geophysical meaning, merging of the various sensor data, blending with supporting external data, delivery to the ultimate users for data analysis, interpretation, and utilization; this process is shown in a simplified format in Fig. 6. Some elements of the present data system described below provide an example of data flow to one of the many Seasat users, the Navy Fleet Numerical Weather Central.

a. The Satellite Data Subsystem comprises those elements onboard the spacecraft for collection, storage, and transmission to earth of the sensor data and for command, control, and tracking of the satellite. To facilitate access to the data and to reduce costs to small users, the Satellite Data Subsystem is designed to a block telemetry format. This format separates data from each sensor into individual time-tagged data blocks. In future Seasat systems it is expected that these data blocks will also be ground located and combined with other pertinent onboard engineering data.

b. The Ground Tracking and Data Acquisition Subsystem tracks the satellite, transits stored commands for sequencing satellite events and receives sensor and status data from the satellite for retransmission to other using subsystems.

c. The Mission Operations and Control Subsystem receives the tracking and global sensor data from the tracking stations, monitors satellite and sensor health, reduces tracking data to provide satellite ephemeris, merges satellite attitude data with ephemerides to facilitate sensor footprints, and delivers data to the Seasat project and other users. This subsystem also generates timed commands for transmission to the satellite.

d. The Project Data Processing Subsystem has the primary objective of providing data processing support to the proof-of-concept mission for sensor system engineering and geophysical validation. In this regard it will support user-directed experiment teams to quantize system performance characteristics with emphasis on geophysical validation. In this way we hope to encourage and provide technology to users to promote direct independent distributed theme oriented data utility by users.

e. One of these direct, independent, theme-peculiar User Data Systems is exemplified by the Navy Fleet Numerical Weather Center at Monterey, California. Global sensor

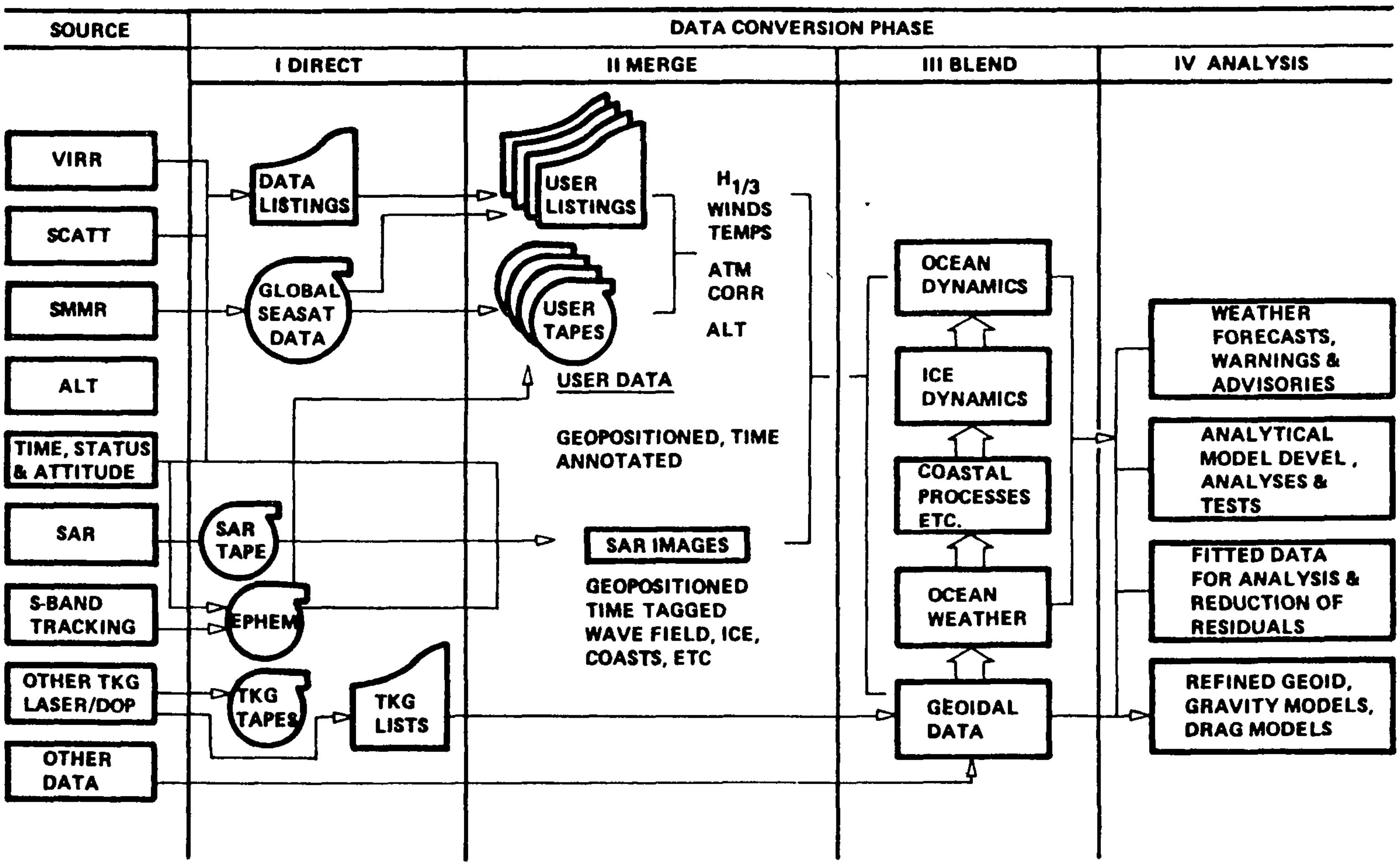


Fig. 6 Data Flow

and status data as received at Fairbanks are retransmitted in near realtime to Monterey, where they are processed and redistributed to the operational ocean-using community, civilian and military, as weather maps and advisories, with less than 8 hours turnaround time.

f. The Synthetic Aperture Radar (SAR) Data Processing Subsystem supports the unique requirements of the imaging radar experiment. Wideband SAR data is recorded digitally at specially equipped stations. The tapes are delivered to the SAR data-processing system, where selected data are processed to image tapes which are in turn processed into images by the Earth Resources Observation System (EROS) Data Center and provided, along with ephemeris, attitude, and status data, to the SAR experiment team and to all other users on a cost reimbursable basis.

POTENTIAL BENEFITS

Studies have been conducted for NASA by ECON, Inc., of Princeton, N. J.[10] to make preliminary estimates of the potential economic benefits. Arctic operations, marine transportation, and offshore oil and natural gas exploration and operations show great potential. Ocean fishing operations also appear as a potentially large beneficiary, although this is strongly dependent upon the oceans' ability to replenish the source of supply. The study assumed a multi satellite operational system beginning in 1985.

From the outset no attempt was made to estimate the effects of improved ocean data upon land operations, even though there cannot fail to be improvements in weather forecasting; instead, the study was directed to consider only ocean-based beneficiaries and is highly conservative. Table 4 shows these applications deemed of sufficient potential to be included in the study. Case studies were performed to examine operating parameters, constraints, and structure of each selected maritime operation. Incremental parameter changes resulting from application of improved knowledge of weather or ocean conditions were evaluated in terms of resultant economic benefits. Considerable care was exercised in the conduct of each case study to permit generalization to the operation as a whole - both in scale, time, and geographical location. The most likely benefits resulting from Seasat were estimated by initially establishing that portion which was likely to be directly attributable to use of Seasat data. In some cases, due to uncertainty in rate of development of an industry or sector, it became necessary to establish upper and lower and most likely bounds on likely ranges of benefits. An example of case study results is shown in Table 5 for the North American Arctic Transit Case. Additional information on the methodology of the economic benefit studies is available in Ref. 10.

Summarized in Table 6 is the most likely range of benefits for the cases studied. Ocean mining benefits were omitted because insufficient data was available from which to derive adequate estimates of benefit. The largest single beneficiary is the marine transportation industry followed closely by off-shore oil and natural gas exploration and Arctic operations.

Table 4

SOURCE OF ECONOMIC BENEFITS

INDUSTRY OR SECTOR	MOST SIGNIFICANT CONTRIBUTOR
o OFF SHORE OIL AND NATURAL GAS	o IMPROVED WEATHER AND OCEAN CONDITION FORECASTS (PLATFORM INSTALLATION, PIPELAYING, AND TRENCHING)
o ARCTIC OPERATIONS	o RESOURCE TRANSPORTATION (IMPROVED ICE COVERAGE INFORMATION AND IMPROVED OCEAN CONDITION FORECASTS)
o OCEAN FISHING	o FORECASTING OF FISH POPULATION AND MIGRATION (OCEAN CURRENTS AND TEMPERATURES)
o MARINE TRANSPORTATION	o REDUCTION IN TRANSIT TIME, REDUCTION IN DAMAGE OR CASUALTY LOSSES AND REDUCTION OF INSURANCE RATES (IMPROVED WEATHER AND OCEAN CONDITION FORECASTS)

Table 5

NORTH AMERICAN ARCTIC TRANSIT CASE STUDY RESULTS

CASE STUDY RESULTS

- o WESTERN ARCTIC 1992-2000
  - TRANSPORT 1.5 - 6.3 BILLION BARRELS OF OIL
  - NUMBER OF VOYAGES - 7900
  - QUANTITY OF OIL PER TANKER - 1.6 MILLION BARRELS
  - ANNUAL BENEFIT - $26 MILLION TO $494 MILLION*
- o EASTERN ARCTIC 1990-2000
  - TRANSPORT OIL, LNG, HYDROCARBONS
  - PRODUCTION CONSISTENT WITH ALBERTA COMMISSION FINDINGS
  - NUMBER OF VOYAGES - ABOUT 13,000
  - AVERAGE ANNUAL BENEFIT - $152 MILLION*
  - BEAUFORT SEA BENEFIT - $70 MILLION ANNUALLY BECAUSE OF ECOLOGY*

*ANNUAL BENEFIT FROM ALL SOURCES OF IMPROVED WEATHER AND OCEAN CONDITION FORECASTS AND ICE RECONNAISSANCE

Table 6

SUMMARY OF MOST LIKELY RANGE OF BENEFITS EXCLUSIVE TO SEASAT

- PLANNING HORIZON TO YEAR 2000
- 10 PERCENT DISCOUNT RATE

INDUSTRY OR SECTOR	INTEGRATED BENEFIT ($1975 MILLIONS)
o OFFSHORE OIL AND NATURAL GAS	214 to 344
o OCEAN MINING	NOT ESTIMATED
o COASTAL ZONES	3 TO 81
o ARCTIC OPERATIONS	96 to 288
o MARINE TRANSPORTATION	583
o OCEAN FISHING	42 TO 380
o PORTS AND HARBORS	0.5
o UNCLASSIFIED MILITARY APPLICATIONS	28
TOTAL	966 TO 1704

CONCLUSIONS

Global, synoptic oceanic data, available relatively soon after collection, are needed to satisfy both current and future anticipated needs of the ocean using community. The Seasat-A spacecraft, using a carefully selected set of remote sensors, beginning with launch in the second quarter 1978, will perform a proof-of-concept mission to evaluate the potential for space-based sensor systems to collect oceanic data of significant value to users - particularly data on ocean weather and surface conditions. A sincere attempt has been made on this program to encourage both ultimate and intermediate users of oceanic data to become involved with definition of requirements. selection of sensors, and evaluation of future potential benefits. Plans are being made within NASA and NOAA Headquarters, in conjunction with OMB and members of Congressional staffs, to follow Seasat-A with additional developmental space flights leading perhaps to a future operational system.

The individual user might easily conclude that his ability to affect the outcome of a project, such as Seasat-A is slight. The very remoteness, impersonality, and technological complexity of space programs almost mandate such a conclusion. However, such is not the case with the Seasat project. For example, if improved data on predicted ocean weather and oceanic surface conditions are needed, make your wishes known. From your individual needs, future requirements will be developed. Your personal observations are needed on types of data desired, data distribution and access methods and time span, display techniques desired, and formats of data. Also, it will be necessary, in the course of the Seasat-A operation to correlate the remote observations with in-situ measurements. Shipboard observations of wind, sea state, and water temperature and underflights of Seasat-A will be necessary to provide calibration and/or correlation with Seasat-A'derived information - particularly from remote locations, during severe extremes of oceanic conditions.

A test program for economic verification is being planned. Many industry users have already come forward with requests to support these tests . A coordinated , NOAA, NASA, NSF, NAVY, DOI, and Coast Guard solicitation for scientific investigations is being developed.

Because of the diversity of possibilities in terms of potential participation in Seasat, a single contact is provided who can help you make the interfaces peculiar to your specific interests and needs. Inquiries should be directed to:

Dr. Alden A. Loomis
Co-Chairman of the Ocean Dynamics Advisory Subcommittee
Jet Propulsion Laboratory (183-501)
4800 Oak Grove Drive
Pasadena, CA 91103
Telephone 213-354-6629

Seasat was conceived by the users and implemented to meet their needs. The potential user community is expanding daily. Only through continued interaction will we have the vision to continue the promise of Seasat.

REFERENCES:

1. "The Voyage of the Challenger" Eric Linklater, Doubleday, Inc., 1974

2. The Terrestrial Environment: Solid Earth and Ocean Physics Application of Space and Astronomic Techniques, Report of a Study at Williamstown, Mass., to NASA, sponsored by NASA ERC, MIT Measurement Systems Laboratory, Cambridge, Mass., August 1969

3. John R. Apel, "SEASAT: A Spacecraft Views the Marine Environment with Microwave Sensors," statement presented before the Subcommittee on Space Science and Applications Committee on Science and Astronautics House of Representatives, 1974

4. Nagler, R. G., and McCandless, S. W., Jr., "Operational Oceanographic Satellites - Potentials for Oceanography, Climatology, Coastal Processes, and Ice," September 1975

5. Gray, Robert M., McCandless, S. W. Remote Sensing of Oceanological Phenomena through use of SEASAT-A.

6. Rose, Jr. R., and McCandless, S. Walter, "System Definition of SEASAT-A, An Ocean Observation Satellite," paper at AIAA 13th Aerospace Sciences Meeting, Pasadena, Calif., January 20 - 22, 1975

7. McCandless, S. W. Jr., "SEASAT-A - A Product of User Interest," December 1975

8. McCandless, S. W. Jr., and Eaton, W. T., "SEASAT-A - Accepting the Challenge of Challenger," April, 1976

9. Hooke, Adrian, "SEASAT-A End-to-End Data System," December, 1975

10. SEASAT Economic Assessment, Vol. I, Summary and Conclusions, Final Report of a Study to NASA, sponsored by Office of Applications, Contract No. NASW 2558, 31 August, 1975.