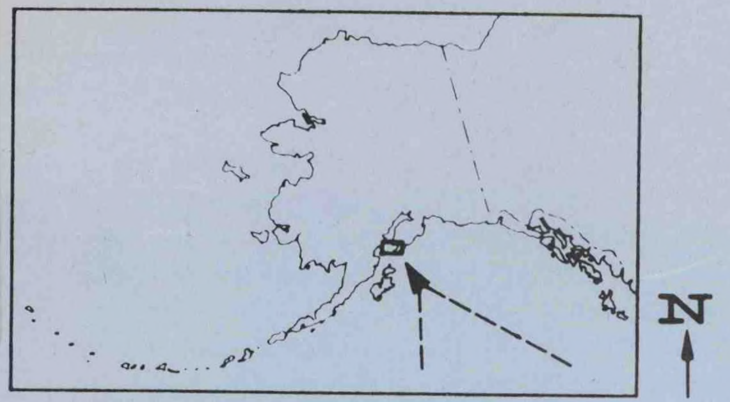
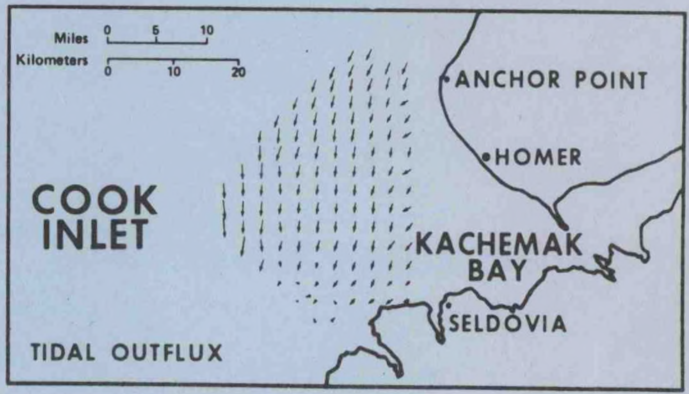
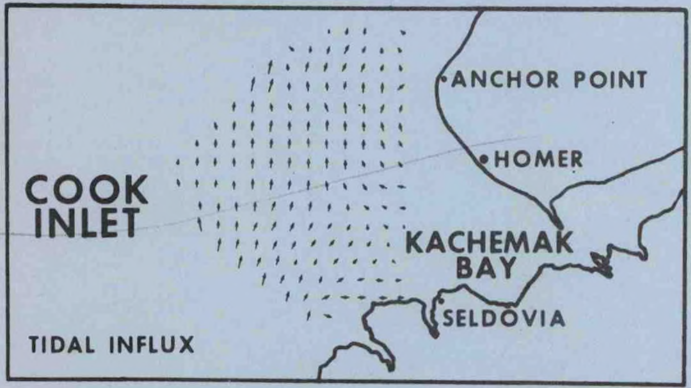






NOAA WORKSHOP ON OCEANIC REMOTE SENSING

VOLUME I
ACTION SUMMARY & REPORT
DECEMBER, 1979

COVER*

A unique radar system developed by the Wave Propagation Laboratory of NOAA's Environmental Research Laboratory produced these maps of water movements in Alaska's Cook Inlet at two different times on July 1, 1977. A pair of transportable, high-frequency antennas stationed on the coast are used to sense ocean surface currents out to 80 kilometers (50 miles) from shore. The information thus derived is used to generate computer-drawn maps of current movements over 2,000 square kilometers (750 square miles) every fifteen minutes. Because of the large volume of surface current data obtainable continuously in space and time (data unobtainable by any alternative technique), these radars offer unique opportunities for oceanic services.

*Courtesy of Dr. Donald E. Barrick, Wave Propagation Laboratory, Environmental Research Laboratory, Boulder, Colorado.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

WORKSHOP ON

OCEANIC REMOTE SENSING

ESTES PARK, COLORADO

AUGUST 19-24, 1979

VOLUME I

ACTION SUMMARY AND REPORT

DECEMBER, 1979

CO-CHAIR

JOHN W. SHERMAN, III   ROBERT L. EDWARDS   JOHN R. APEL

JOHN W. SHERMAN, III
WORKSHOP COORDINATOR
WORKSHOP REPORT EDITOR

NANCY J. HOOPER
WORKSHOP SUPPORT
METRICS, INC.

PREFACE

The fair breeze blew, the white foam flew
The furrow followed free.
We were the first that ever burst
Into that silent sea.

(Samuel Taylor Coleridge,
The Rime of an Ancient Mariner.)

The sea, under the extremes of winds, waves, or ice cover, is a difficult environment in which to conduct scientific experiments and oceanic operations. Seldom ever are conditions ideal for the measurements being sought. Although the sea appears to be silent when viewed from the perspective of a great distance, features being measured can change faster than the ability to make the measurements. Poets and romanticists use the distance from the fireplace to the sea. Ever increasing numbers of oceanographers and earth scientists use the distance from satellites and aircraft to the sea.

Volume I

REPORT OF THE NOAA WORKSHOP ON OCEANIC REMOTE SENSING

TABLE OF CONTENTS

Volume II

WORKSHOP SUPPORT DOCUMENTATION

TABLE OF CONTENTS

ACTION SUMMARY

THE NOAA WORKSHOP ON OCEANIC REMOTE SENSING WAS CONDUCTED AT ESTES PARK, COLORADO, DURING THE WEEK OF AUGUST 19-24, 1979. THE OBJECTIVES OF THIS WORKSHOP WERE TO:

- REVIEW THE PRESENT STATE OF OCEANIC REMOTE SENSING FROM SURFACE, AIRCRAFT, AND SATELLITE PROGRAMS;
- REVIEW AND ESTABLISH NEEDS AND PRIORITIES FOR REMOTE SENSING REQUIREMENTS WITHIN NOAA, AND AS THE NATIONAL REPRESENTATIVE FOR THE CIVILIAN OCEANIC COMMUNITY, THE GENERAL CIVILIAN REQUIREMENTS;
- REVIEW MAJOR NOAA OCEANIC PROGRAMS ANTICIPATED FOR THE 1980-85 PERIOD AND RECOMMEND APPLICATIONS OF REMOTE SENSING TECHNIQUES TO THESE PROGRAMS; AND
- IDENTIFY SPECIFIC PROBLEMS AND ISSUES, BOTH TECHNICAL AND ADMINISTRATIVE, TO BE ADDRESSED BEFORE IMPLEMENTING POSSIBLE APPLICATIONS.

OCEANIC REMOTE SENSING, AS DEFINED BY THIS WORKSHOP, IS RESTRICTED TO THE USE OF ELECTROMAGNETIC ENERGY TO OBSERVE OR MEASURE PROPERTIES OF THE OCEAN WHILE REMOTELY LOCATED FROM THAT PORTION OF THE OCEAN BEING OBSERVED. OTHER IMPORTANT TECHNIQUES, SUCH AS ACOUSTIC REMOTE SENSING OR SURFACE-TO-SATELLITE TELEMETRY SYSTEMS, WERE NOT INCLUDED IN THE WORKSHOP TECHNICAL AND PROGRAMMATIC REVIEWS.

WITH THE LAUNCH OF TIROS-1 IN 1960 AND SUBSEQUENT EARLY TIROS AND NIMBUS SERIES SATELLITES, SPACECRAFT REMOTE SENSING MADE ITS INITIAL IMPACT ON THE ACQUISITION OF METEOROLOGICAL DATA. NOW, AFTER NEARLY TWO DECADES, THE CONTINUED DEVELOPMENT OF THIS TECHNOLOGY HAS INFLUENCED THE TRAINING OF AN ENTIRE GENERATION OF METEOROLOGISTS, AND THE METHODS AND TECHNIQUES OF REMOTE SENSING ARE IMPACTING THE TOTAL OPERATIONAL PRACTICES IN METEOROLOGY.

BY WAY OF CONTRAST, THE FIELD OF OCEANOLOGY WAS NOT SIGNIFICANTLY TOUCHED BY THE NEW TECHNOLOGY UNTIL THE LAUNCHES OF NOAA-2 IN 1972, GEOS-3 IN 1975, AND SEASAT AND NIMBUS-7 IN 1978. THE VERY HIGH RESOLUTION INFRARED SCANNER ON NOAA-2 AND SUBSEQUENT OPERATIONAL SATELLITES MADE IT POSSIBLE TO MONITOR, IN DETAIL, POSITIONS OF MAJOR WATER MASS BOUNDARIES ON A NEAR CONTINUOUS BASIS. UNFORTUNATELY, SEASAT FAILED EARLY IN ITS MISSION LIFE AND GEOS-3 HAS SUCCUMBED TO TIME, SO THAT ONLY BIO-OPTICAL AND PASSIVE MICROWAVE DATA FROM NIMBUS-7 AND THERMAL DATA FROM THE NOAA SERIES ARE NOW AVAILABLE FOR CONTINUED OCEANIC EXPERIMENTATION. HOWEVER, THE RESULTS FROM THESE FOUR SYSTEMS HAVE SUCCESSFULLY DEMONSTRATED THE POTENTIAL OF OCEANIC REMOTE SENSING TO PROVIDE THE BASIS FOR A REVOLUTION IN THE TRADITIONAL SCIENCE OF DYNAMIC OCEANOLOGY, SIMILAR TO THAT EXPERIENCED IN METEOROLOGY IN THE LATE 1960'S AND 1970'S.

FOR THE FIRST TIME, OCEANOGRAPHERS AT MAJOR ACADEMIC AND RESEARCH INSTITUTIONS ACROSS THE UNITED STATES, INDEED ACROSS THE WORLD, ARE ACTIVELY INVOLVED IN DEVELOPING AND APPLYING REMOTE SENSING METHODS FOR OCEANOLOGY IN THE MEASUREMENT OF WIND, WAVES, TEMPERATURE, SEA ICE, CURRENTS AND CIRCULATION, CHLOROPHYLL, WATER MASS DETECTION, AND OPTICAL PROPERTIES.

THIS INTEREST BY OCEANOGRAPHERS AND OTHER EARTH SCIENTISTS IS DRIVEN PRINCIPALLY BY THE DATA NEEDS AND PRIORITIES ASSOCIATED WITH THE CLIMATE PROGRAM, THE DECADE OF OCEANIC USE AND MANAGEMENT, OCEANIC POLLUTION, ENVIRONMENTAL PROTECTION, PRESERVATION OF LIFE AND PROPERTY, MANAGEMENT AND CONSERVATION OF RESOURCES, ENVIRONMENTAL MODIFICATION, OCEANIC SERVICES, AND LEGISLATION SUCH AS THE NOAA ORGANIC ACT.

TOWARD SATISFYING THE OCEANIC NEEDS AND PRIORITIES, THIS WORKSHOP CONCLUDES THAT:

- REMOTE MEASUREMENT OF PHYSICAL AND BIOLOGICAL PARAMETERS OF THE SEA HAS ADVANCED ENORMOUSLY IN THE LAST FOUR YEARS. THERE ARE NOW CLEAR AND IMPORTANT APPLICATIONS OF OCEANIC REMOTE SENSING TO NOAA'S MISSION;
- MAJOR NOAA PROGRAMS THAT CAN BENEFIT TO A SIGNIFICANT DEGREE INCLUDE: FISHERIES, BOTH PHYSICAL AND BIOLOGICAL MEASUREMENTS IN SUPPORT OF MANAGEMENT; MARINE POLLUTION; OCEANIC SERVICES; CLIMATE VARIABILITY; SEVERE STORMS; GEODESY; AND SUPPORTING RESEARCH ACTIVITIES;
- CAPABILITIES FOR OCEANIC MEASUREMENT FROM AEROSPACE REMOTE SENSING INCLUDE: VISIBLE, INFRARED, AND MICROWAVE IMAGING RADIOMETERS; RADAR ALTIMETERS, SCATTEROMETERS, AND IMAGERS; LASERS AND LIDARS; AND CAMERAS. THE PLATFORMS INCLUDE SURFACE, AIRCRAFT, AND SATELLITE SYSTEMS;
- INSTITUTIONAL STRUCTURES MUST BE ERECTED TO REALIZE THE MAXIMUM BENEFITS AVAILABLE VIA REMOTELY SENSED INFORMATION;
- DEDICATED AIRCRAFT SUPPORT IS ESSENTIAL TO CARRY OUT THE REMOTE SENSING ACTIVITIES FOR FISHERIES, POLLUTION, AND OCEANIC/ATMOSPHERIC AND OCEANIC/LAND INTERFACES. NOAA UNITS KNOWN TO HAVE UNFULFILLED AIRCRAFT REQUIREMENTS INCLUDE NMFS, NOS, ERL, NWS, OMPA, OOE, SEA GRANT, AND NESS;
- RESEARCH ON THE FEASIBILITY OF OIL SPILL REMOTE SENSING WILL BE EFFECTIVE ONLY AS A CONTINUING RESEARCH PROGRAM RATHER THAN AS AD HOC RESPONSES TO CATASTROPHIES;
- AN OCEANIC REMOTE SENSING EDUCATIONAL AND TRAINING PROGRAM IS NEEDED BY NOAA AS A MEANS OF TRAINING MARINE SCIENTISTS FROM BOTH WITHIN AND WITHOUT THE AGENCY;
- LACK OF CENTRAL, DEDICATED FACILITIES FOR NONROUTINE PROCESSING OF REMOTELY SENSED OCEANIC DATA IS IMPEDING THE DEVELOPMENT OF INFORMATION FOR A DIVERSE GROUP OF SCIENTISTS AND USERS; AND
- OCEANIC REMOTE SENSING WORKSHOP/REVIEWS SHOULD BE PLANNED AND BUDGETED TO OCCUR EVERY THREE YEARS.

THE WORKSHOP RECOMMENDS THAT:

- NOAA CONDUCT A SIMILAR WORKSHOP DEALING WITH ACOUSTIC OCEANOLOGY IN THE VERY NEAR FUTURE;
- THE GEOS-3, SEASAT, AND NIMBUS-7 DATA RESEARCH AND ANALYSES EFFORTS BE COMPLETED USING MATURE GEOPHYSICAL ALGORITHMS;
- DURING FY-81 AND BEYOND, CONTINUITY BE ESTABLISHED BETWEEN SEASAT AND NIMBUS-7 WITH THE NATIONAL OCEANIC SATELLITE SYSTEM (NOSS) DEVELOPMENT, REQUIRING ABOUT $1.5 TO $2.0 MILLION PER YEAR;
- A COASTAL ZONE COLOR SCANNER (CZCS)-TYPE SENSOR BE FLOWN ON NOAA-H/I IRRESPECTIVE OF THE FATE OF NOSS;
- NOAA STRONGLY SUPPORT THE NASA GRAVSAT AND ICE PROGRAMS;
- OCEAN CIRCULATION BE GIVEN A HIGH PRIORITY AS A REQUIREMENT FOR FUTURE OCEANIC SATELLITES;
- SUFFICIENT DEVELOPMENTAL FUNDING BE PROVIDED FOR AN INITIAL COMMERCIAL VERSION OF THE HIGH FREQUENCY RADAR FOR COASTAL SURFACE CURRENT MEASUREMENT;
- NOAA CONDUCT A STUDY TO DETERMINE THE BEST MEANS OF PROVIDING AIRCRAFT SUPPORT DEDICATED TO OCEANIC RESEARCH AND PROGRAMS;
- NESS PREPARE AN INVENTORY OF AIRCRAFT-BASED OCEANIC SENSORS;
- A FOCUSED, CONTINUING REMOTE SENSING ACTIVITY BE ESTABLISHED TO SUPPORT OIL SPILL DETECTION AND MEASUREMENT;
- INTERACTIVE OCEANIC DATA PROCESSING CAPABILITIES BE MADE AVAILABLE TO NOAA INVESTIGATORS; AND
- AN OCEANIC REMOTE SENSING PROJECT OFFICE BE CREATED TO REPORT TO THE ASSOCIATE ADMINISTRATOR OR TO AN ASSISTANT ADMINISTRATOR (AT THE OPTION OF THE ADMINISTRATOR).

THE ULTIMATE SUCCESS OF OCEANIC REMOTE SENSING WITHIN NOAA DOES NOT REST NECESSARILY WITH THE TRANSFER OF A REMOTE SENSING RESEARCH SUCCESS TO AN OPERATIONAL SUCCESS. THE REAL MEASURE MAY BE WHEN USERS DO NOT DISCRIMINATE BETWEEN WAVE DATA FROM A WAVE STAFF OR AN ALTIMETER, OR CHLOROPHYLL INFORMATION FROM A FLUOROMETER OR A CZCS SENSOR. THE LONG-TERM GOAL OF NOAA OCEANIC REMOTE SENSING IS TO PROVIDE ADDITIONAL TOOLS IN THE OCEANOLOGIST'S REPERTOIRE OF INSTRUMENTS--TOOLS TAILORED TO THE DYNAMICS OF THE OCEAN.

THE COMMENTS, DIALOGUE, TECHNICAL DEBATES, SCIENTIFIC ENTHUSIASM, AND AFTER-HOURS COMMITMENT TO SPECIAL PROBLEMS MADE THIS WORKSHOP A SUCCESS UNTO ITSELF AS A FORUM AND COMMUNICATION MECHANISM FOR NOAA. IT IS HOPED BY ALL WORKSHOP PARTICIPANTS THAT NOT ONLY WILL THE ALACRITY AND DEDICATION EXHIBITED DURING THE WORKSHOP BE CARRIED FORWARD IN THIS REPORT, BUT ALSO THE CONCLUSIONS AND RECOMMENDATIONS WILL BE REVIEWED AND ACTED UPON.

I. INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) Workshop on Oceanic Remote Sensing met the week of August 19-24, 1979, at Estes Park, Colorado. Forty NOAA scientists and managers participated in this Workshop with two additional participants from the U.S. Geological Survey (USGS) and one participant from the National Aeronautics and Space Administration (NASA). These participants are cited in Volume II, "Workshop Support Documentation," Section I.

This Workshop was the third in a series of workshops/conferences held since NOAA's formation. In October, 1971, a conference jointly sponsored by NOAA, NASA, and the Navy, entitled "Sea Surface Topography from Space," was held at Key Biscayne, Florida.[1] In October, 1976, at the direction of the Associate Administrator for Environmental Monitoring and Prediction and the Associate Administrator for Marine Resources, an Ocean Color Workshop was held at the Atlantic Oceanographic and Meteorological Laboratory (AOML).[2] The sea surface topography meeting was instrumental in preparing the oceanic community for the Geodynamics Experimental Oceanographic Satellite (GEOS-3), and the Ocean Color Workshop focused attention on the capabilities of the Nimbus-7 Coastal Zone Color Scanner (CZCS). Participants in these workshops/conferences have found them to be an essential element for successful mid-to-long-term, goal-oriented planning within NOAA. The recent Workshop <u>concludes</u> that:

- Oceanic remote sensing workshops should be planned and budgeted to occur every three years.

This Workshop was conducted with the approval of the Assistant Administrators for Oceanic and Atmospheric Services, Fisheries, and Research and Development (see Volume II, Section VII). The National Environmental Satellite Service (NESS) Spacecraft Oceanography (SPOC) Group, the Pacific Marine Environmental Laboratory (PMEL), and the Northeast Fisheries Center (NEFC) served as joint hosts for the Workshop, with NESS serving as the overall Workshop facilitator. In addition to preparing a workshop report for the NOAA Assistant Administrators, the objectives of the Workshop were to:

- Review the present state of oceanic remote sensing from surface, aircraft, and satellite programs;

- Review and establish needs and priorities for remote sensing requirements within NOAA, and as the national representative for the civilian oceanic community, the general civilian requirements;

- Review major NOAA oceanic programs anticipated for the 1980-85 period and recommend applications of remote sensing techniques to these programs; and

- Identify specific problems and issues, both technical and administrative, to be addressed before implementing possible applications.

<u>Oceanic remote sensing, as defined by this Workshop, is restricted to the use of electromagnetic energy to observe or measure properties of the ocean while remotely located from that portion of the ocean being observed.</u> As such, neither acoustic nor *in situ* techniques used with satellite telemetry were included within the Workshop review process. However, the Workshop recognizes the importance of acoustic and *in situ* - telemetry techniques as vital and necessary technology to NOAA's oceanic mission and:

- <u>Recommends</u> that NOAA conduct a similar Workshop dealing with acoustic oceanology in the very near future with the Environmental Research Lab (ERL), the National Marine Fisheries Service (NMFS), and the National Ocean Survey (NOS) as the principal sponsors; and

- Endorses the steps being taken to improve and reduce the cost of *in situ* - telemetry techniques wherein platform location can also be derived.

Based on the comment, dialogue, technical debate, scientific enthusiasm, and after-hours commitment to special problems, this Workshop, as a forum and communication mechanism for NOAA scientists and managers, was a major success unto itself. It is hoped by the Workshop participants that the alacrity and dedication that existed during the Workshop are carried forward in the Workshop documentation.

The documentation is contained in two volumes. Volume I contains the Action Summary and Report. Volume II presents the Support Documentation for the technology, program, policy, and administrative matters which were reviewed and discussed.

---

[1]NOAA Technical Report ERL 228-AOML 7-2, "Sea Surface Topography from Space," John R. Apel, Editor, Boulder, Colorado; May, 1972.

[2]Summary Report "Ocean Color Workshop," Donald A. Wickham, Editor, NMFS Office of Program Planning, Budget and Evaluation, November 11, 1976.

II. TECHNOLOGY STATUS

Oceanic remote sensing systems have made major advances during the last four years, ranging from surface based radar measurement and mapping of coastal currents (Volume II, Section III-14) to the detection of oceanic currents and eddies, not only by the more conventional satellite infrared techniques but also by satellite altimetry methods (Volume II, Section III-20) and by ocean color measurements (Volume II, Sections III-3 and III-6). This summary discussion focuses on two aspects of oceanic remote sensing: the first, illustrating the need for continued research, and the second, a successful research effort for which there is currently an operational need.

The first example is the Seasat Synthetic Aperture Radar (SAR) whose basic characteristics were such as to optimize the imaging of ocean waves of wavelengths greater than 50m and the imaging of sea ice. However, the SAR has far exceeded its prelaunch expectations in imaging internal waves, current and eddy boundaries, surface wind and stress related features, apparent effluent and tidal effects, apparent oil spills, and other forms of air-sea interactions.

Figure 1 is a single SAR image of about a 100-km square area collected on September 28, 1978, just off the North Carolina coast. By comparison to *in situ* and Seasat-A Scatterometer System (SASS) data, it is known that the windspeed in the dark portion of the image corresponds to winds less than 2 m/sec. Recent analyses show a direct correlation between image "brightness" and surface winds. Such studies are important to the wind measurements proposed for the National Oceanic Satellite System (NOSS) which addresses a requirement of 25-km resolution for its wind measurement. Additionally, there are eddy structures in Figure 1 for which no acceptable physical descriptions exist to explain the presence of apparent windrows (the absence of capillary crispations in the oil slicks that may be associated with Langmuir circulation) or possible internal waves in the upper central portion of the image or apparent oil films in the central upper right portion.

Continued research on the SAR and its companion space sensors such as the altimeter, the SASS, the Scanning Multichannel Microwave Radiometer (SMMR), and the CZCS are essential to understanding both ocean dynamics and the interaction of these sensors with the ocean. Therefore, the Workshop recommends that:

- The GEOS-3, Seasat, and Nimbus-7 data research and analyses efforts be continued until global data sets have been analyzed using mature algorithms for geophysical data, including winds, waves, temperature, color, selected sea-air interaction areas, currents, sea ice, ice sheets, internal waves, and geodesy.

Furthermore, the continuation of the research, while important to understanding ocean phenomena, is critical in itself to the supporting research program needed for NOSS and its related programs. The Workshop recommends that:

- During the FY 81 time period and beyond, Seasat and Nimbus-7 funding be continued and become the base funding for NOSS research activities. The level of funding needed, excluding aircraft and ship time, is estimated to be $1.5 to $2 million.

The second example illustrating the technology status is the capability of ocean color to define ocean water masses, locate current boundaries, and define eddy systems. This capability, an example of which is shown in Figure 2, has been demonstrated by the Nimbus-7 CZCS and requires no further quantitative development to support these specific qualitative data needs. The Workshop concludes that:

- The detection of water masses is directly possible with existing CZCS capabilities and that the utility of such a product can be used operationally by NOAA at this time.

The Workshop recommends that:

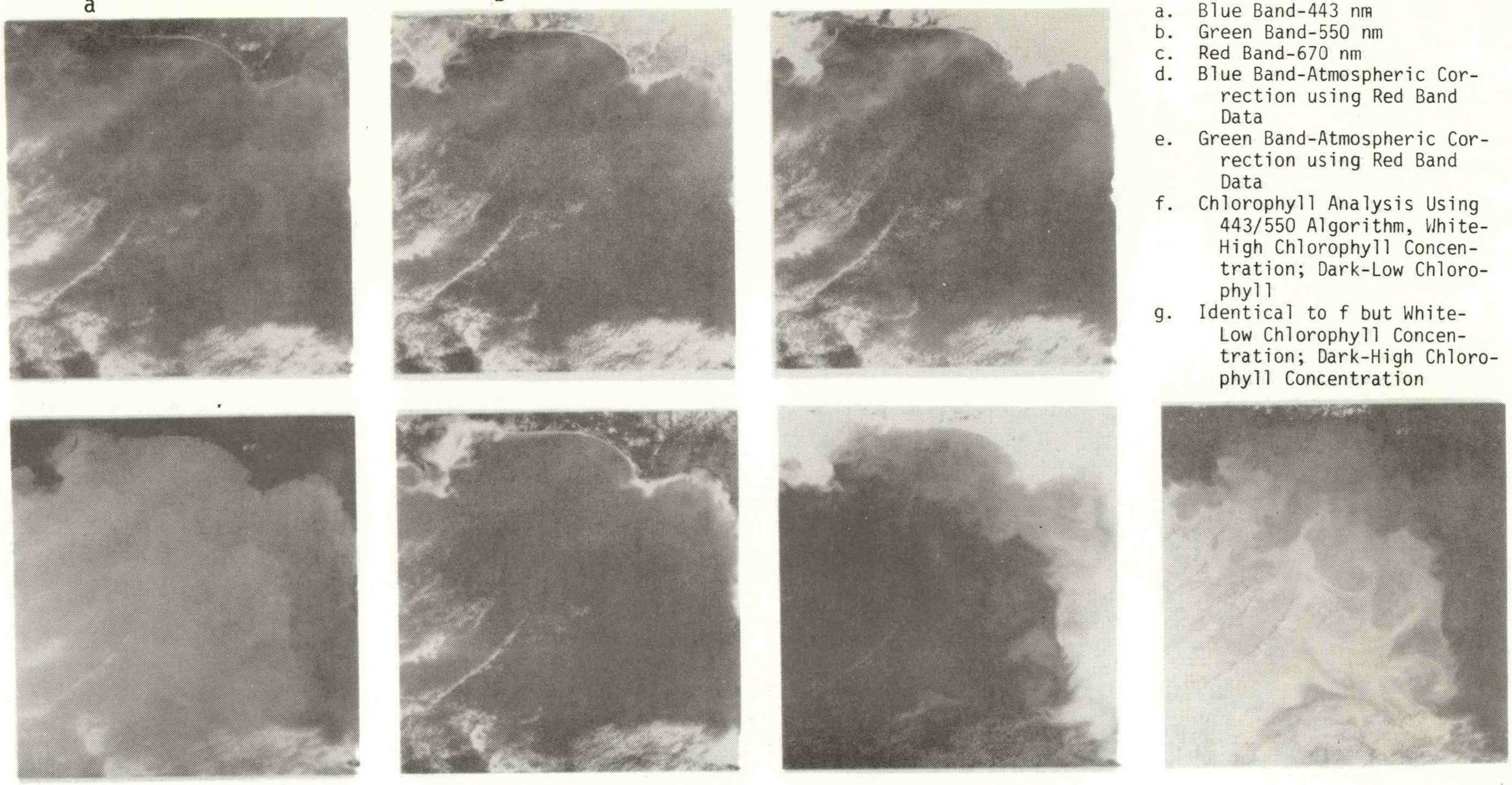
- A CZCS-type instrument be considered as a candidate instrument on NOAA H/I independent of its consideration as a NOSS payload instrument, even if NOAA must provide partial or total funding for its inclusion on the NOAA-family of sun-synchronous operational satellites.

In support of NOAA's needs for data in the coastal region, two additional areas of remote sensing technology are highly endorsed by the Workshop. First, the Workshop concludes that:

- Surface-based High Frequency (HF) radars have demonstrated with advanced, prototype radars the near-real-time measurement and mapping of surface currents (i.e., the upper 2 meters of current) to an accuracy approaching that of conventional *in situ* systems.

This radar technology is immediately applicable to near-shore (out to 100 km) circulation measurements required for tidal studies, river and estuary current fluctuations, surface transport of contaminant (including oil spills), tracking of fish larvae during specific seasons, etc. Initial studies by ERL

Figure 1. Complex radar backscatter patterns in a nearly calm region of the ocean located just outside the mouth of the Chesapeake Bay, captured by the Seasat imaging radar, 28 September 1978. The dark regions generally correspond to low surface winds (less than 2m/s), but the patterns also indicate a wide variety of surface interactions having little relationship to the wind. Eddies in the lower left quadrant may be the confluence of the Labrador Current with the slope water of the Gulf Stream. Dark streaks at the upper edge of the image show increased surface tension possibly from pollutants. A low energy swell system with 200 m wave length and significant wave height less than 1 m is travelling through the area from the east-south-east. At least four ship wakes are visible, with lengths of several kilometers. This image was obtained with the JPL digital correlator, and has an inherent resolution of 25 m. Horizontal dimension is equal to 100 km.



a. Blue Band-443 nm
b. Green Band-550 nm
c. Red Band-670 nm
d. Blue Band-Atmospheric Correction using Red Band Data
e. Green Band-Atmospheric Correction using Red Band Data
f. Chlorophyll Analysis Using 443/550 Algorithm, White-High Chlorophyll Concentration; Dark-Low Chlorophyll
g. Identical to f but White-Low Chlorophyll Concentration; Dark-High Chlorophyll Concentration

Figure 2. Nimbus-7 Coastal Zone Color Scanner (CZCS) Imagery and Derived Products From Orbit 130 in the Northeastern Portion of the Gulf of Mexico (November 2, 1978).

indicate the need for about 40 such HF radar systems. Developmental funding for a commercial model by private industry is required. The Workshop recommends that:

- Sufficient developmental funding be provided for an initial commercial version of the HF radar and a sufficient "first" buy to make it an attractive commercial venture.

The second requirement for data in the coastal region became a theme at the Workshop. The need to collect data over relatively large areas (≈100's of km) with time scales which are not satisfied by satellite temporal and/or spatial resolution was a basic concern of both the scientists and program managers. The Workshop concludes that:

- An aircraft capability for oceanic measurements is necessary to serve NOAA's needs for sensor development, scientific studies, and program operational data requirements, and can well be justified by its diverse audience of users.

The Workshop notes that NASA has in times past been instrumental in aircraft sensor development, but with the advent of the Space Transportation System (Shuttle), no additional oceanic aircraft sensors have become available during the last five years. Hence, there is a technology void in an area where aircraft support is dictated by temporal and/or spatial requirements. The Workshop recommends that:

- The NOAA Assistant Administrators for Fisheries, R&D, and OAS authorize a joint study to determine the best approach to provide aircraft support for NOAA's research and operational marine needs; and

- NESS provide an inventory of aircraft-based oceanic sensors, with an assessment of their capability, presently available within NOAA, NASA, and other federal agencies, and include the appropriate aircraft imposed requirements for proper use of each sensor.

The Workshop concludes that:

- Oceanic remote sensing systems, based on surface, aircraft, or satellite platforms, have demonstrated those capabilities specified in Table 1.

Additionally, while surface currents have not specifically been derived from satellite altimetry measurements (to date), there is every expectation that satellite altimetry techniques will provide a major breakthrough in measuring global circulation. Dynamic sea surface topography has been derived recently from Seasat altimeter data for western boundary currents.

Table 1. Oceanic Remote Sensing Systems with Demonstrated Capability

Marine or Oceanic Parameter	Sensor/Technique
Ocean Color	Spectrometers, CZCS, Landsat, Cameras
Chlorophyll	
Attenuation Coefficient	
Water Mass Detection	
Sea Surface Temperature	IR Radiometers (NOAA and Nimbus Satellites)
Subsurface Profiles	
Temperature	Lidar (Range-gated Laser)
Salinity	Lidar
Plankton Distribution	Lidar
Velocity	Lidar
Particle Distribution	Lidar
Waves	
Significant Wave Height	Altimeter, Laser, HF Radar
Wave Patterns	Imaging Radar, Cameras
Wave Spectra	Imaging Radar, Cameras, HF Radar
Boundary Layer Winds	Scatterometer, Microwave Radiometer, Inertial Navigation Systems
Surface Currents, Eddies	HF and Imaging Radars, CZCS Mapping, Camera Mapping
Integrated Water Vapor	Microwave Radiometer
Ice	
Sea Ice	Imaging Radar, Microwave Radiometers, Cameras
Ice Sheet Height Change	Altimeter
Oil Spills (Sheen Stage)	Imaging Radar, Microwave Radiometers, Cameras
Marine Fish and Animal Surveys	Cameras
Photogrammetric Mapping	Cameras
Geodesy	Altimeter, Satellite Ephemeris

III. SCIENTIFIC NEEDS

The previous section presented a summary of oceanic remote sensing technology. This section defines the NOAA and oceanic community research needs for remote sensing as distinct from operational requirements. More quantitative research requirements are considered in Volume II, Section V.

A major point of discussion throughout the Workshop was the relationship between conventionally measured and remotely sensed parameters. Also of concern were the constraints placed on the orbital inclination of a satellite by the type of geophysical data to be collected. Table 2 provides a summary of the three basic orbital configurations that will meet the research needs of NOAA.

Table 2. Relationship Between Orbit and Geophysical Parameter

Parameter	Prime Sensor	Orbital Requirement	Comment
Wind Waves (H 1/3) Temperature	Scatterometer Altimeter IR radiometer	None	Wind, waves, and temperature measurements can use any orbit with $\pm 70^{o}$ latitude coverage.
Sea Ice	Radiometer	Coverage to $\pm 75^{o}$ lat.	The sea ice coverage to meet NOAA's explicit requirements is to $\pm 75^{o}$ latitude. However, the non-NOAA ice community requires coverage to the poles.
Ice Sheets	Altimeter	87^{o} or 93^{o}	
Ocean Color			
Chlorophyll	CZCS-type	Sun-synchronous	For typical satellite altitudes, the orbital inclination is 93^{o}.
Attenuation Coef.	CZCS-type		
Currents (Surface)			
Ocean Current	Altimeter	108^{o}	Seasat orbit optimum
Ocean Tides	Altimeter	108^{o}	Seasat orbit optimum
Boundary Cond. & Mapping	CZCS-type IR Imager	Sun-synchronous	Current velocity derived from repeat coverage

Winds, waves, and temperature have no special orbital requirements other than the provision of a sufficiently high latitude to provide global ($\pm 70^{o}$ latitude) coverage. Conflicts arise between ice, color, and surface current measurements. Hence, the Workshop recognizes that:

- The requirements for measurement of these three orbitally conflicting parameters cannot be met by any one choice of orbit, and that ocean color determination is primarily a NOAA responsibility and need.

The Workshop therefore recommends in the strongest possible terms that:

- In order to optimally fulfill the ocean color requirements, the CZCS-type of instrument be placed on a near-polar, sun-synchronous satellite such as NOAA-H/I, irrespective of the fate of NOSS.[1]

If the CZCS-type instrument is a part of the NOAA-H/I payload, then the altimetry approach to ocean current measurement is in conflict with the ice mission requirement of the non-NOAA ice research community but not with the ice requirements of NOAA. For this reason, the Workshop concludes that the choice between the ice orbit and the ocean current orbit is for the ocean current orbit. However, the Workshop recommends that:

---

[1]See similar recommendation in Section II, p. 2.

- NOAA support the NASA research and development of an altimeter and a single-channel, nadir-looking microwave radiometer flown on a drag-free satellite in order to obtain precise sea surface topography; and

- NOAA support the NASA GRAVSAT-type mission to determine independently surface gravity and the geoid in order that surface currents be derivable from sea surface topography measurements.

These two recommendations not only conform to the views expressed by the International Symposium on the Interaction of Marine Geodesy and Ocean Dynamics in October, 1978, but are also consistent and supportive of the view made by the Committee on Earth Sciences of the Space Science Board to the NASA Associate Administrator for Space and Terrestrial Applications in March, 1978. The Workshop concludes that:

- Given a sun-synchronous orbit for ocean color and related measurements and given separate GRAVSAT and sea surface topography satellites, the NOSS orbit should be flown to address the ice mission of the polar community.

Other science-related concerns, issues, and ensuing recommendations are summarized in the following paragraphs in terms of multispectral data analysis, colorimetry, and oil detection.

Multispectral Data Analysis

Considering only multispectral data (i.e., data from the Nimbus-7 CZCS and the NASA U-2 Ocean Color Scanner (OCS)), the image processing capability within NOAA is not sufficient to meet NOAA's needs. Principal investigators and interested scientists frequently have no alternative other than to depend upon NASA to provide either the processed data or machine time. This dependence on NASA, especially in the research mode, has proven to be only marginally tolerable and has been in some instances disastrous. A simple solution exists with the acquisition of off-the-shelf, turn-key interactive image processing systems. The Workshop recommends that:

- Interactive capabilities be made available to NOAA investigators working with or anticipating such needs. Systems should be selected with the needs of potential operational users in mind to insure timely transfer of the technology. For example, the interactive system proposed and funded by NMFS over two years ago should be supported and expedited through the computer procurement cycle as a means to offset a portion of the data analysis problem in fishery programs.

Colorimetry

The initial CZCS results presented at this Workshop show that the stated measurement accuracy objectives of the NOSS colorimeter have been met or exceeded by the CZCS. There is agreement that phytoplankton pigments (chlorophyll) and turbidity (seston) or attenuation coefficients can be measured from space with accuracies meeting the operational and research requirements of the NMFS and other user organizations. However, to effect this, a fine tuning of the algorithm requiring a continuation of the ongoing NESS program of surface measurement of atmospheric and oceanic optical properties is considered to be necessary for NOSS support. The Workshop recommends that:

- Resources be made available, through NOSS or NOAA base programs, to continue this surface measurement program using CZCS data preparatory to NOSS implementation.

Oil Detection

A considerable number of interests with varied viewpoints on the feasibility of detecting surface oil were present at this Workshop. A single, best approach could not be agreed upon because technology is limited. However, it was unanimously agreed upon that oil spill detection and mapping is a major problem area that should be addressed within the NOAA research community. It was observed that the remote sensing research community presently is involved in oil spill detection only during a time of catastrophe, and not as a continuing NOAA research activity.

Two approaches to oil detection are believed to be reasonable: surface detection dependent on sheen effects, and subsurface measurements dependent on potential fluorescent effects. The Workshop recommends that:

- Airborne imaging radar be flown over oil spills of opportunity to study wind/capillary suppression effects and limitations as a means of mapping oil spills and their duration in the sheen stage;

- Microwave radiometer/interferometer techniques be resumed as a means of measuring oil spill thickness while in the sheen stage; and

- A modest effort to explore ultraviolet and laser fluorescences in surface and subsurface states be initiated as a laboratory/pier measurement program. Additionally, Fraunhofer Line Discriminating Systems should be examined, in cooperation with the USGS and NASA, as a tool for oil spill observations.

The Workshop <u>concludes</u> that:

- Oil spill research will be effective only as a continuing program. The catastrophe-response mode is insufficient to develop the technology needed for this effort.

The Workshop recognizes that the marine pollution assessment is much larger than that of oil spill detection. However, even less oceanic remote sensing research has been directed toward this more general assessment need than toward oil spill detection. The Workshop did not address this need.

IV. PROGRAMMATIC NEEDS: AN EXAMPLE OF MARINE BIOLOGY AND FISHERY RESEARCH APPLICATIONS

Introduction

Informational requirements of the National Marine Fisheries Service (NMFS) encompass most remotely sensed oceanic data needs of NOAA except those related to marine geodesy. As such, NMFS requirements were a major element of interest and priority within the Workshop and are used to exemplify most NOAA programmatic needs. Other programs are discussed in Volume II, Section IV.

Aerospace remote sensing techniques provide oceanic measurements temporally and spatially unavailable by any other means. Such measurements, when made on an operational basis, will be directed toward effective management of living marine resources. The greatest immediate success in this application will be in those instances where there is already understanding of relationships between the biology and the oceanic phenomena which can be sensed remotely. Remote sensing also may play a significant role in the resolution of subtle and scientifically complex problems in marine ecosystems such as the long-term impact of pollution, an ever increasing concern of the fishery community--commercial, research, and management activities.

The Workshop review of typical fishery research programs demonstrated four areas of need:

- Meso- and macroscale data on winds, waves, and oceanic and coastal fronts;
- Distributional data relatable to ocean color, primary production, turbidity, and pollutant flux;
- Coastal circulation and current variables; and
- Meso- and microscale turbulence.

The CZCS appears to date to offer the greatest potential for satisfying many of the research needs. While absolute values for parameters sensed were considered desirable, and in some instances essential, it was generally agreed that many of the fundamental problems being addressed required only precise relative data.

Because most remote sensors detect the near-surface of marine ecosystems, considerable work is still necessary to relate surface phenomena to the rest of the water column and benthos. Since many biological problems are essentially surface layer phenomena (e.g., those concerned with the survival of fish eggs and larvae and factors affecting their aggregation and dispersion), remote sensing should have immediate application to many fishery-related problems. Sampling of the planktonic component of marine ecosystems through traditional approaches cannot answer many questions about ecosystem dynamics because of the lack of simultaneity of measurement. This problem is exacerbated by the short generational time of most planktonic organisms, which for some is measured in days. The use of remotely sensed data can increase sampling effectiveness by an order of magnitude or more, both by more effective placement of research vessels and by significantly improved spatial and temporal coverage.

Direct measurements of pollutant fluxes in most shelf waters are difficult if not impossible to obtain. However, various indirect evidences of pollution, such as shifts in the species composition of plankton communities, have been identified. The ability to remotely detect indicators of pollution appears promising, especially those indicators which alter ocean color. Additionally, the ability to monitor the distribution and extent of turbid and colored waters will provide insights into the distribution of pollutants and their impacts, as well as the consequences of events yet to occur.

There are a number of applications of remote sensing to specific marine resources management problems that provide capabilities otherwise not at hand. The tracking of animals such as sea turtles, whales, and porpoises with satellite-linked transmitters has already been demonstrated, and ultimately, the satellites themselves may provide even more useful information on those environmental aspects that guide these animals on their migrations. Other practical applications include the use of satellites for the estimation of fishing effort and geographic distribution.

The Workshop participants recognized that neither all fishery nor other major NOAA programs could be reviewed in the course of the Workshop. However, a specific, in-depth review was undertaken of several fishery programs. An abbreviated synopsis is presented in the following subsection.

Specific Fishery Program Interface Activities

The major focus in marine ecosystem studies has been in boreal-temperate areas (e.g., North Sea, Norwegian Sea, Baltic, Northwest Atlantic) and studies of subtropical ecosystems have long been neglected. Subtropical and boreal-temperate marine ecosystems support diverse marine resource populations. Boreal-temperate systems are characterized by low species diversity at high levels of abundance whereas subtropical systems support many more species, but in fewer numbers. The reasons for these differences are not fully understood.

Scientists in the Northeast and Southeast Fisheries Centers are initiating joint studies on the comparative productivity of boreal-temperate and subtropical ecosystems. The initial focus of the study is on the linkages among primary production, secondary production, and the productivity of fish stocks. The area under study extends from the Gulf of Maine to the Gulf of Mexico and the Caribbean. The general approach will include studies on the mesoscale level (10- to 100-kilometer station placements) to monitor changes on a broad time and space scale. In addition, studies will be conducted on the "processes" of energy transfer within the ecosystems at the microscale levels (1- to 10-kilometer station placements) at a few selected sites within the study region.

Traditional sampling methods are inadequate to sample regions of this size synoptically. However, through the use of appropriate aircraft- or satellite-based remote sensors, it is possible to sample the entire region and begin to piece together relationships between primary production and ecosystem dynamics. NMFS proposes to extend the Large Area Marine Productivity-Pollution Experiments (LAMPEX), currently underway from Cape Hatteras to the Canadian border, to the Gulf of Mexico and Caribbean continental shelf areas.

The approach proposed is to capitalize on existing Marine Resources Monitoring, Assessment, and Prediction (MARMAP) and pollution studies (e.g., Ocean Pulse) in the shelf regions of the eastern United States augmented with CZCS-derived chlorophyll and optical information. Circulation features impacting shelf ecosystems will be monitored in part by high resolution thermal scanners on satellites and in part by aircraft sensors.

The program will be multidisciplinary in nature, involving scientists from SEFC, NEFC, ERL, NESS, and NOS, and remote sensing specialists from NASA and academic institutions. Biological and hydrographic sampling from NOAA vessels will be done primarily by NMFS in cooperation with NESS and ERL. Analysis of satellite data will be done by ERL and NESS in cooperation with NMFS. Certain basic research aspects of sensors, processing, and analysis of aircraft remotely sensed data will be done by NASA. Where appropriate and practicable, team approaches to data integration and analyses in all areas will be emphasized.

Fishery Relationships to Other NOAA Programs

As noted in the Introduction of this section, the informational requirements of NMFS are representative of all oceanic data needs of other NOAA activities, except the needs associated with marine geodesy. While NMFS does not require wind and wave data on a global scale, it does need these data on a rather large meso-scale. For safety at sea for commercial fishery vessels, these data are needed daily on a continuous basis, while for fishery management, the data are required daily during select periods of time. Thus, if the requirements for fishery data and information are satisfied, a significant portion of the data requirements for other NOAA programs is also satisfied.

An analysis of the Fiscal Year 1980 NOAA Program/Budget Structure reveals correlation between fishery data and information and other NOAA programs. Figure 3 presents the analysis summary of the data and informational correlation between representative fishery program needs and representative other NOAA programs. The analysis summary is somewhat subjective since not all informational needs are defined according to a universal standard. However, the Integrated Ocean Oriented Observing System (IOOOS) Study, discussed in the next section, has reviewed a large number of marine data needs that support this analysis. Furthermore, the correlations defined in Figure 3 make no assumptions about the source of data, be it derived acoustically, electromagnetically, or *in situ*, or whether it came from a ship, buoy, or aircraft data system.

For definition, direct correlation between two programs is the sharing of a common requirement for at least one type of environmental data or information. It does not imply that the shared requirement is identical nor that the two programs have all requirements in common. Partial correlation means that a data or informational requirement of one program is derivable from related data or information in a second program. An example of direct correlation is two programs which both require sea surface temperature. An example of partial correlation is one program requiring sea surface temperature while the second program requires oceanic frontal analysis, an analysis derivable from sea surface temperature.

● Direct Correlation
○ Partial Correlation

Ocean Fisheries and Living Marine Resources	Activity Level 1	Marine Ecosystems		International Projects		Mapping, Charting and Surveying Services					Basic Environmental Services			Environmental Satellite Service		Public Forecast and Warning Services				Environmental Data and Information Services				Weather Modification	Coastal Zone Management	
	Sub-Activity Level 2	Marine Ecosystems Investigations		Great Lakes Research	GARP	Geodetic Surveys and Services		Ocean and Coastal Mapping, Invest. and Services			Basic Observations			Development and Applications of Satellite Tech.	Environmental Warning Services Support	Hurricane Warning Services		Marine Prediction Services		Environmental Data and Information Services				Modification of Severe and Convective Storms	Estuarine Sanctuaries	Marine Sanctuaries
	Line Item Level 3	Effects of Marine Environmental Alterations	Ocean Dumping Research	Great Lakes Research	Global Atmospheric Research Programs	Marine and Satellite Applications	Estuarine and Lake Invest.	Structure and Motion of the Ocean Research	Coastal Mapping and Marine Boundary Surveys	Marine	Local Display of Satellite Data	Remote Sensing Research	Application of Satellite Data	Development of Satellite Sensors	Geostationary Spacecraft	Hurricane Warning Preparation	Hurricane Research	Marine Weather and Oceanic Forecasts	Marine Prediction Research	Climatic Data Services	Environmental Data	Oceanic Data Services	Environmental Documentation and Information Services	Hurricane Modification	Estuarine Sanctuaries	Marine Sanctuaries
Managing and using Fishery Resources	Marine Recreation Fisheries	●	●	●	●		●		●	●	○	●	●	●	●	●		●			●	●	●		●	○
	Fisheries Enforcement and Surveillance	○							●		●	●		●				○					○		●	●
	State - Federal Fisheries Management	●	●			○	●		●	●	●	○	○	●	○	○		●	○	●	●	●	●		●	●
	International Fisheries Management	●	●	●	●		●	●	●	●	●	●	●	●	●	●		●	○		●	●	●		○	○
Restoring and Increasing Fishery Resouces	Disaster Assistance									●	●	●	●	○	●	●		●			○	○	○			
	Aquaculture R & D	○	○				○		○	●					○	●		○			●	○	○		●	
Conserving Marine Resources	Endangered Species Conservation	●	●		○		●	○	●	●	●	●	●	●	○			●		●	●	●	●		●	●
	Marine Mammals Conservation	●	●		○		●	○	●	●	●	●	●	●	○			●		●	●	●	●		●	●
	Fisheries Habitat Investigations	●	●	●	●		●	●	●	●	●	●	○	●	●		●	●		●	●	●	●		●	●
Marine Resources Monitoring, Assessment and Prediction	Survey Technology Development	●	●		●					○	●	●	○	●							●	●	●			
	Fishery Oceanography	●	●	●	●		●	●	●	●	●	●	●	●	○		○	○	○	○	●	●	●		○	○
	Resource Surveys	●	●	●			●		●	●	●	●	○	●			○	○	○	○	●	●	●		○	○

Figure 3. Correlation of Representative Fisheries Data and Informational Needs With Representative Other NOAA Programs. The Analysis Conducted Using the NOAA Program/Budget Structure, Effective FY 1980.

V. REQUIREMENTS

NOAA marine requirements have been reviewed and documented on previous occasions. Instrumental in focusing these requirements during the developmental stages of Seasat was the Apel and Sherman report of 1973.[1] In establishing satellite marine environmental requirements for the 1980-85 period, Eskite and DeRycke[2] prepared a draft report in 1977 which strongly influenced the choice of parameters and priorities for the National Oceanic Satellite System (NOSS). Presently under review are the requirements for an Integrated Ocean Oriented Observing System (IOOOS)[3] that defines data needs for specific marine users. Operational requirements for satellite data acquisitions are in the NOSS report.[4]

Four specific elements of the requirements reviewed at this Workshop are summarized here: the geodetic requirements, the NOSS requirements, a brief description of the purpose of IOOOS, and a discussion of the need for an integrated aircraft remote sensing program. The Workshop participants provided review and revision to the Eskite and DeRycke draft which is contained in Volume II, Section V. Inputs on the IOOOS are being provided directly to that activity.

Geodetic Needs/GRAVSAT

The Eskite and DeRycke report defined the marine environmental requirements, exclusive of the marine geodetic needs. Therefore, this Workshop defined the geodetic marine requirements as shown in Table 3. Geodetic needs appear in two aspects: (a) direct determination of position and gravity; and (b) providing a reference datum (the geoid) for sea surface topography. Examples of (a) are the first five items in the table.

The column headed as "future accuracy" refers to what is desired in terms of accuracy over the next ten years rather than what is achievable. However, the Department of Defense (DoD) Global Positioning System, suitably refined, should be able to satisfy the first two items, and refined measuring techniques should yield the requirements for gravity. The numbers listed for ocean floor positioning and for deep ocean tides will be the hardest to achieve. The determination of the geoid to 10 centimeters will probably depend on the launch and success of a special low-altitude pair (GRAVSAT) envisioned for the mid-1980's.

GRAVSAT (gravitational satellite) is a satellite system being considered by NASA for launch around 1985 for the purpose of determining gravity perturbations ranging from 100 to 3000-km wavelength on a global scale. Thus, it would provide a geoid of sufficient extent and accuracy to serve as an authentic reference datum for sea surface topography obtained by satellite altimetry. Two possible configurations are envisaged: (a) two satellites in the same (polar) orbit at about 200-km altitude, separated by 300 km; or (b) one satellite at 200-km altitude and another at geosynchronous altitude. The data type is continuous range rate between the satellite pair. In mode (a) this can be measured to 10-6 m/sec, much more accurately than in mode (b). This factor makes (a) appear presently as the more feasible alternative. The lifetime of the experiment is 6 months to 1 year. Because of the low altitude, drag compensation devices at 200 km are necessary.

Potential applications for GRAVSAT are:

- Marine geophysics: isostatic compensation, correlation with bathymetry. Accuracy desired: 3 mgal down to 100-km resolution;
- Sea surface topography: eddies, boundary currents, seasonal variations, ocean circulation. Accuracy desired: 10-cm geoid height down to 100-km resolution;
- Satellite ephemerides: improved determination of earth and ocean tides and polar motion; and
- Geoid and deflection of vertical on land. Accuracy desired: 10 cm per 100-km, and 0.5 sec. of arc.

---

[1]Apel, John R. and Sherman, John W., III, "Monitoring the Seas from Space: NOAA's Requirements for Oceanographic Satellite Data," Report AOML-LORS 6.73.1, NOAA/DoC, Miami, Fl.; June, 1973.

[2]Eskite, W. H., Jr. and DeRycke, D., draft "Requirements for Marine-Related Data Which May Be Obtained By Satellite Remote Sensing in the Period 1980-85 and Beyond;" March 20, 1977.

[3]Draft, "User and Measurement Requirements for an Integrated Ocean Oriented Observing System," OAS/NOAA/DoC; July 25, 1979.

[4]"NOSS, National Oceanic Satellite System," Joint effort by National Aeronautics and Space Administration, Department of Commerce, and Department of Defense; March 23, 1979.

Table 3. Geodetic Marine Requirements

Type	Purpose	Present Accuracy	Future Accuracy	Future Mission	Frequency	Delay	Coverage	Grid Spacing	Horizontal Resolution
Positioning (Navigational)	Ship Location	100 m	1 m	1 m	—	Instantaneous	Global	—	—
Positioning (Surface)	Buoy, Pier, etc. Location	5 m	10 cm	10 cm	Yearly	—	Regional	—	—
Positioning (Ocean Floor)	Features Location	5-100 m horiz. 1-50 m vert.	10 cm 10 cm	10 cm 10 cm	Yearly	—	Regional	—	—
Gravity (Point)	Geophysical Exploration	1-5 mgl	.5 mgl	.5 mgl	—	—	Regional	—	—
Gravity (Mean Anomalies)	Geophysical, Geodetic	10 mgl	2 mgl	1 mgl	—	—	Global	50 km	50 km
Geoid	Sea Surface Reference	50 cm	5 cm	3 cm	—	—	Global	50 km	10 km
Deep Ocean Tides	Science	10 cm (model)	2-5 cm	1 cm	3/day	30 days	Global	100 km	10-100 km
Coastal Tides (Astronomical and Storm)	Mean Sea Level Determination	.5 cm	.1 cm	.1 cm	10/day	1 day	Regional	Local	1/2 - 10 km

The Workshop recommends that:

- The geodetic marine requirements specified in Table 3 become the NOAA requirements.

The altimeters on GEOS-3 and Seasat have provided the means of dramatically improving knowledge of the geoid over the oceans. This improvement applies in three respects: detail, coverage, and accuracy. Before GEOS-3, a broad picture of the geoid on a global basis was available from satellite tracking analysis and was good to about 5 meters. However, no details smaller than 1500 km in wavelength were available from this source. Only gravity data based on ship gravimeter surveys yielded finer structure in a few scattered areas, also good to about 5 meters. Even though less than half of all acquired altimeter data has been made available as of the end of 1979, undulations of the geoid, down to 100-km separations, are now known to an error of less than a meter for the entire ocean except for the polar regions.

The deviation of nontransient features of the ocean surface with respect to the geoid attains a maximum of about 1 to 2 meters. The task of depicting these features, which are due to currents, temperature fronts, and tides, presents a higher level of difficulty because accuracies at the 10-cm level are desired. Since the precision of the GEOS-3 altimeter was about 30 cm, only a start could be made toward a comprehensive mapping of this so-called sea surface topography. However, correlations with independent data from satellite infrared imagery and from shipboard instruments have verified the feasibility of the altimeter data to perform this task. Because the precision of the Seasat altimeter is at the 10-cm level, much more definitive results are expected from this source.

The exact delineation of the sea surface topography depends on how well the geoid, which serves as the reference datum, is known. Ideally, a data source other than altimetry is needed for determining the geoid to 10 cm in order to capitalize on the 10-cm precision of the altimeter. In addition, the radial position of the satellite should be known to a comparable level of accuracy. It is true that the satellite ephemeris error is long wavelength so that mesoscale sea surface features can be followed with an ephemeris no better than 1 meter. But measurements of the slope of sea level over an area the size of an ocean basin, for example, require an ephemeris accuracy to 10 cm.

These geodetic requirements impinge upon the NOSS program in two ways. First, a highly accurate geoid over the oceans must be supplied independently. The most feasible way of achieving this is by the proposed GRAVSAT satellite-pair at 200-km altitude, which should be able to sense the high-frequency variations in the earth's gravity field to the desired accuracy. Second, the altimeter-carrying satellite should be equipped with a drag-free device to minimize the effect of the atmosphere and radiation pressure, and it should be accurately and comprehensively tracked.

Recommendations and conclusions with regard to geodetic requirements have been previously given (Section III). However, the Workshop also recommends that:

- All the GEOS-3 and Seasat altimeter and ephemeris data be completely reduced and analyzed for its geodetic and sea surface topography content.

NOSS Requirements

The Workshop reviewed the NOSS summary operational requirements (see Volume II, Section V) and concludes the following:

- The temporal (frequency) requirement of 12 hours for wind and wave measurements is incongruous with the coverage of a single satellite system and, as such, should be modified to 24 to 36 hours since it specifies the NOSS output products;

- The global model grid size for wind, waves, and temperature should be the same and a grid of 100 km is appropriate;

- A major contribution of NOSS to severe weather and coastal dynamic conditions will be lost if provision is not made to provide wind and wave products on a local basis as is done with temperature (a local grid of 25 km is suggested as being compatible with NOSS characteristics with minor system impact);

- The spatial (horizontal) resolution for all parameters are appropriate except that for icebergs (10-m icebergs is the USCG requirement);

- The temporal (frequency) requirement for chlorophyll and turbidity should be the same (i.e., 2 days) as well as the delay (i.e., 8 to 12 hours);

- Turbidity is not a universally accepted term for which a standard exists for surface confirmation and, as such, a measure of the optical attenuation coefficient would be significantly better;

- The CZCS-type sensor may provide horizontal surface currents for coastal and regional applications with possibly significantly less data processing required than that required by the altimeter; and

- A major consideration in specifying the horizontal surface current measurement was in support of the National Climate Program (NCP), when indeed the absolute accuracy presently specified by NCP is for 2 cm/sec (see Volume II, Section V), exceeding existing capability.

Integrated Ocean Oriented Observing System (IOOOS)

The purpose of the "Requirements Study for an Integrated Ocean Oriented Observing System" is to provide a cohesive set of requirements which will facilitate the comparison between various potential observation systems and insure the definition of an optimum observing system. The study bases its requirements on user needs by identifying six major marine information users, discussing their activities that require marine information, and identifying the parameters the users need to make decisions. The discussion has been translated into a set of tables within the IOOOS, which specify the form in which the information could be used and the value of the information. Additional tables within IOOOS have been prepared which specify the engineering requirements.

The industries included in IOOOS are: offshore oil and gas, marine transportation, commercial marine fisheries, marine recreation, marine construction, and coastal communities. The format of the requirements developed by these six industries are in general compatible with, but not tailored to, remote sensing. The greatest discrepancy in requirements between IOOOS and the NOSS output products is in spatial and temporal resolution. While the vast majority of IOOOS spatial requirements are for 1-km resolution, no sensor suite has been factored into IOOOS for providing this data using *in situ* or other data collection sources. While it is recognized that not all of the defined user needs can be met by remote sensing inputs, NOSS and other satellite systems will become a major data source within an IOOOS. Many user requirements will have to be met by other, perhaps more conventional, data collection techniques. Much remains to be done to determine what role each observing system will play in the future. This responsibility remains as an unfinished task of the IOOOS and of the management organization recommended by the Workshop (Section VI).

Aircraft Support Development

While satellites are efficient in gathering global data sets in a very effective manner, the Workshop recognizes that aircraft capability is also needed because of:

- Spatial resolution needs;

- Unique atmospheric data collection;

- Temporal resolution needs;

- Choice of time for data collection;

- Complementary data for extending *in situ* data; and

- Calibration of satellite remote sensors.

Furthermore, aircraft development is needed for the oceanic remote sensing areas identified in Table 4. The conclusion and recommendations to support these aircraft needs were cited in Section II. As noted, the requirement for aircraft to support both research and operational modes of oceanic remote sensing remained a constant theme at the Workshop.

Table 4. Needed Aircraft Development Activities

Salinity

- 10 m spatial resolution
- 1.6 GHz Radiometer plus SST
- Open ocean 0.2 p/1000
- Estuaries 1.0 p/1000

Coastal Wave Fields

- 2 km 10^{o}
- From satellite - SAR only
- From land - CODAR
- From aircraft - SAR, laser, photography

Subsurface Profiles

- Temperature
- Salinity
- Constituents (pollution)
- Velocity
- Plankton diversity
- Fish

Coastal Mapping, Bathymetry, and Bottom Classification

Marine Animal Studies

Coastal and Estuarine Currents

- 0.1 knot

Surface Pollution

- Detection
- Mapping

Monitoring of Recreational Fishing

VI. MANAGEMENT CONSIDERATIONS

Organizational Structure

The Workshop review of the existing management structure for oceanic remote sensing concludes that:

- While significant research and development is progressing within the current organizational structure, the effectiveness, efficiency, and responsiveness could be improved by a re-organization and focusing of responsibilities within NOAA.

The Workshop recommends that:

- An Oceanic Remote Sensing Project Office be created to report to the Associate Administrator or to an Assistant Administrator (at the option of the Administrator).

The objective, scope, policy direction, and description of the Project Office and its relationship to other NOAA components are described below.

Objectives: Organize, coordinate, and manage NOAA's research, development, demonstration, and technology transfer of oceanic remote sensing capabilities to meet NOAA's operational and research missions related to:

- Oceanic and oceanic/atmospheric/land interface condition monitoring and prediction;

- Management of living and nonliving marine resources;

- Monitoring and predicting the effects of marine pollution; and

- Oceanic contributions to understanding and observing global climate conditions.

Scope: The proposed Project Office includes oceanic remote sensing capabilities from all appropriate platforms (satellites, aircraft, ships, buoys, and submersibles) and from shore-based facilities, using all suitable instrumentation.

Policy Direction: An inter-Main Line Component (MLC)/Major Program Element (MPE) Policy and Management Group (PMG) (composed of one senior management official from each MLC or MPE) will be created to establish and specify the policies and priorities of the Office, and to review and approve major commitments of project resources to NOAA-wide programs.

Description: An inter-MLC/MPE "Oceanic Remote Sensing Project Office" will be created to:

- Assist in the planning and coordination of research, development, and demonstration efforts in response to requirements and priorities specified by the Policy and Management Group (PMG);

- Coordinate and, when appropriate, participate in remote sensing-related programs conducted within the MLC's and MPE's in response to mutually agreeable programs and funding arrangements;

- Serve as staff to the PMG in working with NOAA's MLC's and MPE's to clarify user and data requirements and to indicate present and potential remote sensing capacity to meet these needs;

- Act as the principal coordinators with other federal agencies (NASA, DoD, EPA, NSF, and others) on oceanic remote sensing issues;

- Manage and conduct a contracts and grants program as appropriate to the missions and functions of the Office using funds assigned for those purposes;

- Manage new, major remote sensing instruments (e.g., radars) or supporting facilities (e.g., aircraft) procured for multi-MPE use in research and operations; and

- Promote technology transfer from research to operationally interested/involved NOAA elements and other organizations.

Resources: Initially, the Office will be staffed and funded with resources obligated by the MPE's. It is envisioned that the Office ultimately will not exceed 20 people when fully functioning. An (unspecified) MLC will assume lead responsibility and provide a permanent core staff. Other MLC's and MPE's will detail individuals to a central facility (site to be selected).

Limitations, Responsibilities, and Collateral Functions: It is not intended that the Office assume the management prerogatives of the MPE's in the conduct of their program. In that sense, the Office serves as a coordinator of the oceanic remote sensing programs in NMFS, ERL, NWS, NOS, the Climate Office, the Ocean Marine Pollution program, etc. This does not preclude the Office from developing and managing multidisciplinary, multi-MPE programs that are approved by the PMG (using funds contributed by the MPE's, reimbursables, or new appropriations obtained for this purpose), or from obtaining and managing major, new resources dedicated to multi-use oceanic remote sensing facilities. In exercising this resource management function, the day-to-day operation of these facilities may be delegated to a qualified MPE as approved by the PMG (e.g., aircraft might be operated by NOS or ERL under the funding and direction of the Office).

Each involved NOAA organization will detail personnel and pledge other resources to the Office (in some proportion to its interest in and benefits from oceanic remote sensing). It will seek to protect these resource commitments to the Office through the budget cycle. For these new program initiatives in oceanic remote sensing (approved by the PMG) which must, because of the NOAA program/budget structure, appear as a single line item under the cognizance of a particular MLC, special consideration must be provided in the budget/Zero Base Budgeting process. The cognizant MLC must recognize that the NOAA-wide priority, as approved by the PMG, of an initiative may be higher than that of the specific application to the "host MLC."

Because of its inter-MLC/MPE staff of remote sensing experts and its contacts with other agencies and the academic community, the Office will be a very valuable resource. It should be used as a consultant to new and expanding programs (e.g., the ocean pollution or climate program) for the contributions that oceanic remote sensing can make. It may be used as a "contractor" to develop and manage defined remote sensing programs to meet these needs. Such "contractor efforts" would, of course, be fully funded by the requesting program manager, and the acceptance of such a "contract" would have to be approved by the PMG to assure that there is no interference with the basic function of the Office.

Education and Training

Because oceanic remote sensing techniques are in their infancy as operational tools for marine measurements, a means of technology transfer needs consideration within NOAA. The Workshop concludes that:

- Training is applicable to both intra- and inter-NOAA programs and involves oceanic scientists detailed to work in a remote sensing environment, such as that found in NESS or ERL, as well as the remote sensing scientists detailed to work in field programs.

For intra-NOAA activities, the Workshop suggests that the appropriate NOAA management encourage and endorse the exchange of scientists within programs that can utilize or potentially utilize oceanic remote sensing technology. For inter-NOAA activities, the Workshop recommends that:

- The Office of University Affairs, through perhaps the Intergovernmental Personnel Act, be requested to review, analyze, and recommend the best method(s) for exchange of scientists to and from the academic community to facilitate oceanic remote sensing education.

VII. CLOSING OBSERVATIONS

Basic research in remote sensing has produced the techniques that permit global monitoring of those critical ocean parameters required to initialize forecast models and improve predictive products. The expertise has also contributed to an improved understanding of many physical processes such as the flux of heat and momentum between the ocean and the atmosphere. The need now exists to properly place the present technology within the context of a general observational system. The frequency and accuracy of satellite measurements of wind, waves, temperatures, and currents must be considered in terms of similar measurements from buoys, ships, aircraft, and even shore-based techniques.

One of the principal impediments to the system concept is the competition for funds within programs. Decisions are often made on the basis of what one says can be done rather than what one can prove can be done. In the case of remote sensing, optimistic claims are often necessary since the research work is incomplete due to subcritical programs. Resolution of the problem undoubtedly consists of pursuing an integrative approach, i.e., the user should be using and developing remote sensing tools as well as *in situ* tools.

An essential element in having remote sensing become a common data collection tool is to have the appropriate instrumentation and data processing available. Furthermore, continuity must exist in the overall NOAA oceanic remote sensing program, be it a research or operational activity, if users are to depend on remote sensing as a tool. This is not to say that NOAA must do it all, but NOAA must be willing to take the lead in long-term planning, principally with NASA and DoD.

Perhaps the ultimate success of oceanic remote sensing rests not with the research program becoming an operational activity, but with users who do not discriminate between a wave staff or altimeter, a fluorometer or CZCS, an anemometer or scatterometer, a thermocouple or IR scanner, etc., except to note differences in scales. Hence, the long-term measure for success of the proposed Oceanic Remote Sensing Project Office is to terminate its function by becoming an inherent part of NOAA's ongoing oceanic programs.

VIII. LIST OF ACRONYMS

AFOS	Automation of Field Operations and Services
AIDJEX	Arctic Ice Dynamics Joint Experiment
AOML	Atlantic Oceanographic and Meteorological Labs
AVHRR	Advanced Very High Resolution Radiometer
BLM	Bureau of Land Management
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CEPEX	Controlled Ecosystem Experiments
CODAR	Coastal Ocean Dynamics Applications Radar
COOPS	Coastal and Offshore Ocean Prediction System
CZCS	Coastal Zone Color Scanner
DOMES	Deep Ocean Mining Environmental Study
EDIS	Environmental Data and Information Service
ERL	Environmental Research Labs
FIRST	Fisheries Imaging Radar Surveillance Test
FLD	Fraunhofer Line Discriminator
FMCA	Fisheries Management Conservation Act
FMZ	Fisheries Management Zone
FNWC	Fleet Numerical Weather Central
GEOS	Geodynamics Experimental Ocean Satellite
GFDL	General Fluid Dynamics Laboratory
GOASEX	Gulf of Alaska Seasat Experiment
GOES	Geostationary Operational Environmental Satellite
GOSSTCOMP	Global Sea Surface Temperature Computation
GRAVSAT	Gravitational Satellite
HAZMAT	Hazardous Materials Response Project
HF	High Frequency
ICES	Intergovernmental Council for Exploration of the Seas
JPL	Jet Propulsion Laboratory
LAMMR	Large Antennae Multichannel Microwave Radiometer
LAMPEX	Large Area Marine Productivity/Pollution Experiment
MARMAP	Marine Resources Monitoring, Assessment, and Prediction
MESA	Marine Ecosystems Analysis Program
MLC	Main Line Component
MPE	Major Program Element
NASA	National Aeronautics and Space Administration
NEFC	Northeast Fisheries Center
NESS	National Environmental Satellite Service
NMC	National Meteorological Center
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Survey
NOSS	National Oceanic Satellite System
NWS	National Weather Service
OCS	Ocean Color Scanner
OCSEAP	Outer Continental Shelf Environmental Assessment Program
OMPA	Office of Marine Pollution Assessment
OP	Ocean Pulse
OSC	Ocean Services Centers
OSDG	Ocean Services Development Group
OSP	Ocean Services Program
OSU	Ocean Service Units
OTA	Office of Technology Assessment
PMEL	Pacific Marine Environmental Lab
PROFS	Prototype Regional Observing and Forecasting Service
RAF	Remote Airborne Fluorosensor
SAIL	Sea-Air Interaction Laboratory
SAR	Synthetic Aperture Radar
SASS	Seasat-A Scatterometer System
SDSD	Satellite Data Services Division
SEAS	Shipboard Environmental Data Acquisition Systems
SFSS	Satellite Field Service Station
SIO	Scripps Institution of Oceanography
SLAR	Side Looking Airborne Radar
SMMR	Scanning Multichannel Microwave Radiometer
SPOC	Spacecraft Oceanography
SST	Sea Surface Temperature
SWFC	Southwest Fisheries Center
WPL	Wave Propagation Laboratory