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NASA Oceanic Processes Program

Annual Report - Fiscal Year 1981

Environmental Observation Division
NASA Office of Space Science and Applications
Washington, D.C.

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PREFACE

This, the Second Annual Report for NASA's Oceanic Processes Program, provides an overview of our recent accomplishments, present activities, and future plans. Although the Report was prepared for FY 1981 (October 1, 1980 to September 30, 1981), the period covered by the Introduction extends into February 1982. Sections following the Introduction provide summaries of current flight projects and definition studies, brief descriptions of individual research tasks, and a bibliography of refereed journal articles appearing within the past two years. We hope you find the report useful, and we would appreciate hearing from you in the event you have any questions or comments.

We would like to express our appreciation to all those individuals who have contributed material, and we would like to thank Dr. Joseph W. Siry of the Goddard Space Flight Center, who was responsible for editing the material and producing the final report.

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SECTION I--INTRODUCTION

As most of you know, NASA has a new Administrator and Deputy Administrator, Mr. James M. Beggs, a former vice president with General Dynamics, and Dr. Hans Mark, a former Secretary of the Air Force, respectively. Within the past few months there has been a reorganization within NASA Headquarters with the Office of Space Science (OSS) and the Office of Space and Terrestrial Applications (OSTA) having been combined into a new Office of Space Science and Applications (OSSA). The new Associate Administrator for OSSA is Dr. Burton I. Edelson, a former vice president with Comsat. Dr. Anthony J. Calio, the former Associate Administrator for OSTA, has become the Deputy Administrator for the National Oceanic and Atmospheric Administration. The Oceanic Processes Program has been unaffected by this reorganization. With the exception of the addition of the Space Plasma Physics and the Solar-Terrestrial Theory Programs, the Environmental Observation Division (EOD)--of which the Oceanic Processes Program is a part--has also been unaffected. Dr. Shelby G. Tilford, the former Atmospheric Processes Branch Chief, has been appointed Director of the EOD, replacing Dr. Lawrence R. Greenwood who has joined Ball Aerospace.

Currently, the personnel within the Oceanic Processes Program include Dr. Kendall L. Carder, Dr. Lawrence F. McGoldrick, Mr. William F. Townsend, and Dr. W. Stanley Wilson. The present program responsibility for Dr. Carder includes optics, sea ice, and primary productivity; that for Dr. McGoldrick includes the general area of physical oceanography; that for Mr. Townsend includes all activities related to the definition and development of spaceflight systems; and that for Dr. Wilson includes overall guidance and direction. With Dr. Robert Chase's return to the Woods Hole Oceanographic Institution last summer (after having worked with us two years) and with Dr. Carder's planned return to the University of South Florida at the end of this coming summer (also completing two years), we are actively looking for oceanographers to help with the management of the program. Should you know anyone who might be interested, please have them contact us.

Funds available to the Oceanic Processes Program in FY 1981 amounted to approximately $14 million (M); this supported all of the project and study activities noted in Section II (with the exception of the separately funded Nimbus-7 and Tiros-N projects), as well as the 83 specific tasks described in Section III. The distribution of the $14M according to institutions was roughly as follows:

Jet Propulsion Laboratory	$5.3M
Goddard Space Flight Center/ Wallops Flight Center	3.0
Other NASA Centers (Langley, Lewis, etc.)	2.8
Academic Institutions	2.3
Miscellaneous (other government & commercial)	0.6

On a project basis, the Seasat Data Utilization Project (SDUP) received about $2.5M and TOPEX studies were funded at $1.6M in FY 1981. (These projects are discussed below.)

Funds available in FY 1982 will increase to about $17M. Of this amount, we are planning $4M for TOPEX studies, $1M for other flight-related studies, and a significant increase for the academic institutions; no funds are needed for SDUP because of its completion.

Our overall program goal remains the same, namely, to evaluate the utility of spaceborne techniques for observing the oceans and to apply these techniques to advance our understanding of their fundamental behavior. We would like to note that, although our goal is directed toward fundamental scientific aspects of the oceans, many of the specific research questions being addressed by our program--when answered--will provide an improved capability for the utilization of spaceborne techniques for operational purposes. Thus, as our program progresses, we are taking steps to ensure that the operational oceanographic community is aware of and has access to our research results.

In the area of interagency coordination, and one which also helps effect a close coupling between the research and operational communities, aspects of the Oceanic

Processes Program have been discussed during this past year before the National Advisory Committee on Oceans and Atmosphere (NACOA), the Office of Technology Assessment (OTA), the Federal Coordinating Council for Science, Engineering and Technology's Committee on Atmosphere and Oceans (CAO), and various boards and committees of the National Academy of Sciences (NAS). Of special interest are the following associated publications: NACOA's "Ocean Services for the Nation--National Ocean Goals and Objectives for the 1980's" (January 1981), OTA's "Technology and Oceanography--An Assessment of Federal Technologies for Oceanographic Research and Monitoring" (June 1981), NAS/Ocean Science Board's "Satellite Oceanography--Selected Issues for Special Emphasis" (under review by NAS), and NAS/Space Science Board/Committee on Earth Science's "A Strategy for Earth Science from Space in the 1980's--Part I: Solid Earth and Oceans" (in press). During the present year, NAS/SSB/CES will be producing Part II of "A Strategy for Earth Science from Space" in which the cryosphere will be addressed, and the CAO's Subcommittee on Marine Research will be working on a report addressing overall oceanic satellite research needs and opportunities for interagency cooperation.

In the area of international coordination, we have been working with both the Joint Scientific Committee (JSC) and the Committee for Climate Change and the Oceans (CCCO), the work being focused on the determination of the role of the ocean in climate as part of the World Climate Research Program. Organizationally, JSC falls under the WMO and the International Council of Scientific Unions (ICSU), while CCCO falls under the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the Scientific Committee on Oceanic Research (SCOR) of ICSU. We participated in a JSC/CCCO meeting in Oxford, England (January 1981) on the international coordination of plans for future ocean satellite observing systems, and at that meeting a study concerning the feasibility of a World Ocean Circulation Experiment (WOCE) was initiated. Results from this feasibility study are due to be published within the year. Our potential contribution to WOCE would involve the utilization of satellite techniques (such as discussed under TOPEX below) to assist in a determination of the general circulation of the oceans, its effect on the redistribution of global heat, and the resulting influence on atmospheric climate.

In working toward the goal noted above, we have placed our top priority on converting existing satellite data into geophysical units, archiving them with NOAA/EDIS, and generally making them easily accessible. We feel that this is essential if oceanographers are to have an opportunity to assess their full potential utility. This reflects a critical aspect of the Seasat and Nimbus 7 missions, for which the emphasis was essentially a proof-of-concept demonstration of the technical feasibility of flying ocean sensors in space. Given this emphasis and the poor appreciation of subsequent data handling problems, insufficient funding resulted in there being neither developed and evaluated algorithms nor dedicated computing facilities in place and tested prior to the launch of these two satellites in 1978. As a consequence, we have had to concentrate the bulk of our resources on this data problem over the past three years. We now feel that we have made significant progress in this direction. Our recent accomplishments include conversion of the entire three-month set of Seasat ocean data into geophysical units and their subsequent archival with NOAA/EDIS. The archived Seasat Synthetic Aperture Radar (SAR) data are not actually in "geophysical units"; they are all in the form of optically processed images, of which more than 300 are also in the form of digitally processed images. For the Nimbus 7 Coastal Zone Color Scanner (CZCS), we have been able to implement procedures so that we now can essentially process and archive CZCS data as fast as they are taken by the spacecraft. Finally, we have been working with the Information Systems Office at NASA Headquarters to establish at the Jet Propulsion Laboratory an Ocean Pilot Data System for the purpose of helping develop techniques for easy user access to spacecraft data. The system is planned to be accessible via remote terminals, and the Seasat data set will be available initially.

In addition to the conversion and archival of the entire Seasat data set, we have brought the Seasat Data Utilization Project to its completion as planned. We, in concert with NOAA, have been able to provide support for the third and final year of the joint NOAA/NASA Seasat Announcement of Opportunity investigations so that they, too, may be brought to completion as planned. At the same time, we have been emphasizing the publication of results in the refereed oceanographic literature. For example, a special issue of the IEEE Journal of Oceanic Engineering (Volume OE-5, Number 2) has been published on the performance of the Seasat sensors, a special issue of the Journal of Astronautical Sciences (Volume 28, Number 4) has been published on Seasat ephemeris analysis, we have had a dedicated session at the Baltimore meeting of the American Geophysical Union on the performance of the Seasat algorithms (June 1981), a special issue of the Journal of Geophysical Research is in press covering results of this special session, and we are planning an invited session in the general area of oceanic remote sensing at the IOC/SCOR Joint Oceanographic Assembly in Halifax, Canada (August 1982). We have also seen the following books published: Spaceborne Synthetic Aperture Radar for Oceanography (edited by Bob Beal, Isadore Katz, and Pat DeLeonibus), Seasat Views Oceans and Sea Ice with Synthetic Aperture Radar (by Lee Fu and Ben Holt), and Oceanography from Space (edited by Jim Gower) which presents the proceedings of the recent COSPAR/SCOR/IUCRM meeting in Venice (May 1980).

We have seen considerable progress during the past year in our understanding of the overall performance of spacecraft sensors and algorithms, for which more information is given in Section II of this report. For example, the CZCS aboard Nimbus 7 has been shown capable of estimating near-surface chlorophyll concentration to $\pm$ 40% over a range of nearly three orders of magnitude; the Scanning Multifrequency Microwave Radiometer (SMMR) aboard both Seasat and Nimbus 7 has been shown capable of estimating sea surface temperature to better than 1^{o}C using algorithms tuned to specific broad oceanic regions; the Seasat Altimeter has been shown capable of measuring the temporal variability of the surface topography associated with geostrophic currents with a root-mean-square error of seven centimeters and the marine geoid with an error of about 3/4 meters; the Seasat Scatterometer has been shown capable of observing wind speeds with an error slightly less than 2 m/s; and the Seasat SAR has been shown capable of imaging the sea ice floe field.

Given our understanding of the performance of spaceborne sensors, especially as recently documented in the refereed literature, we feel that the technical feasibility of viewing the oceans from space has been established. We are now addressing the potential scientific utility of viewing the oceans from space, asking what we can expect if we use satellites deliberately and systematically to view the oceans. Toward this end, we are concentrating first on the definition of science questions addressable by particular ocean satellite sensors and then on the corresponding performance specifications for those sensors. We have seen the Topography Experiment (TOPEX) Science Working Group (Carl Wunsch, MIT, Chairman) report published, relating satellite altimetry to the circulation of the ocean. We are nearing completion and subsequent publication of joint mission requirements studies with Canada on synthetic aperture radar, known as Radarsat in Canada and Free-Flying Imaging Radar Experiment (FIREX) in the US. Included are studies related to sea ice (Willy Weeks, CRREL) and the open ocean (Owen Phillips, Johns Hopkins). We have science working groups currently studying scatterometers (Jim O'Brien, Florida State), color scanners (John Walsh, Brookhaven), and data collection systems/in situ sensors (Russ Davis, Scripps); these studies are well underway with reports due this summer. We have a study (Norbert Untersteiner, Washington) soon to be initiated, specifically looking at sea ice research needs which could be met by the microwave radiometer (SSMI) scheduled to fly aboard the US Air Force's DMSP series of operational meteorological satellites beginning in 1984. A science working group (Francis Bretherton, NCAR) for the recently cancelled NOAA/Navy/NASA National Oceanic Satellite System (NOSS) completed initial plans for a complementary science program, and their report is in press. A semi-popular overview entitled "Oceanography from Space" was published as a dedicated issue of Oceanus magazine (Volume 24, Number 3) last fall.

We have taken a preliminary look at these scientific requirements for viewing the oceans from space and find that they fall into the following three general areas: (1) studying the circulation (both geostrophic and wind-driven) and heat content of the oceans, and how they are influenced by the atmosphere, (2) studying the primary productivity of the oceans and how it is influenced by the physical/chemical environment and higher elements in the marine food chain, and (3) studying the growth and movement of sea ice and how they are influenced by the atmosphere and ocean.

As examples of specific research tasks which are being pursued in support of these areas, we are developing objective techniques for the removal of the directional ambiguity associated with scatterometer winds (and surface stress), as well as conducting quantitative studies to assess the impact of scatterometer winds on atmospheric forecasts. We are working on selected in situ sensors for the determination of ocean currents; data from such sensors is required both to evaluate the potential of spaceborne observations of surface currents, as well as to provide complementary subsurface currents. We are investigating the capabilities and limitations of spaceborne observations of chlorophyll concentration for estimating phytoplankton productivity; we are also looking at in situ techniques for the measurement of both phyto- and zooplankton patchiness. We are interested in defining the full potential of the SMMR aboard Nimbus 7 and Seasat for unambiguously resolving the relative contributions made by first-year and multi-year components to sea ice concentration images; and we are interested in establishing procedures to utilize successive SAR images to quantify the movement and deformation of the sea ice field.

Because there are potential near-term benefits to be derived from viewing the oceans from space, we have a number of studies related to future flight opportunities for the sensors noted above. We have completed Phase A (conceptual definition) studies for TOPEX with the determination that, while TOPEX is feasible, it is quite costly. We had hoped to initiate Phase B (detailed design) studies in FY 1982, but they have been deferred a year, during which time we will be studying options for significantly reducing the cost of TOPEX. Additionally, we are pursuing advanced technology developments related to precision orbit determination and the altimeter itself. The earliest possible launch for TOPEX is now late 1987.

We are also looking at the feasibility of flying a color scanner and/or scatterometer on the NOAA series of operational meteorological satellites. The initial results, particularly regarding the color scanner, look promising, and the study is due to be completed within the next few months.

As there are a number of ocean-related spacecraft currently in various stages of planning and development, we are exploring potential areas of mutual interest with their sponsors, being particularly interested in determining the extent to which it might be appropriate for us to pursue cooperative work. Depending on the needs of our community, we will be investigating options for obtaining access to data from these spacecraft and, for certain of them, the possibilities for flying one of our ocean sensors. These spacecraft include:

The US Navy's Geosat, a dedicated altimetric satellite for geodetic purposes; it is fully funded and scheduled to fly in 1984. The Geosat data classification policy is still an open issue. The Navy is also interested in a Remote Ocean Sensing System (ROSS) to carry an altimeter, scatterometer, and microwave radiometer. ROSS is in a pre-Phase A stage.

Japan's First Maritime Observation Satellite (MOS-1), which is fully funded and scheduled for launch in 1985. It will carry all passive sensors. They are also planning to fly an L-Band SAR in 1987; prospects for its funding seem good.

The European Space Agency's First ESA Remote Sensing Satellite (ERS-1), for which funding for Phase B activities most likely will be approved shortly, if it has not already been. Prospects for full funding for this spacecraft and its subsequent launch in 1987 appear to be reasonably certain. It will carry an active microwave instrument (AMI), an altimeter, and an as-yet-to-be-determined sensor(s). The AMI functions either as a C-Band SAR, a wind scatterometer, or a wave scatterometer.

Canada's Radarsat, which would carry a SAR (most likely C-Band) and an as-yet-to-be-determined sensor(s). As noted above, we are just completing a joint mission requirements study with the Canadians related to this mission. Canada would like to initiate Phase B activities in 1984, with a launch in 1990.

Under the current fiscally austere climate, particularly as exemplified by the cancellation of the National Oceanic Satellite System during the past year, we must work to prioritize our spaceborne observational requirements, while at the same time doing whatever is possible to minimize the cost of the overall spaceflight systems capable of meeting these requirements. Thus, in addition to looking at dedicated and piggyback deployment options for the flight of ocean sensors, we must explore with other sponsors of ocean-related spacecraft the extent to which data from their sensors can meet our requirements.

The development and evolution of an overall spaceflight system must involve the active participation of the greater US oceanographic community--whether academic, government or commercial. We have taken a big step forward with the understanding gained from the Seasat and Nimbus programs; the extent to which we can continue with another step will be dependent on the case which our community can make.

SECTION II--PROJECT AND STUDY SUMMARIES

NIMBUS-7 OBSERVATORY

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The Nimbus-7 Observatory Satellite, launched on October 23, 1978, carries two (2) instruments which provide measurements applicable to research into oceanic processes: the Coastal Zone Color Scanner (CZCS); and the Scanning Multichannel Microwave Radiometer (SMMR). Both instruments have provided continuous measurements since initial activation and have exhibited no serious degradation in performance as of the end of the third year of operation.

COASTAL ZONE COLOR SCANNER (CZCS)

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The objective of the CZCS experiment is to determine the contents of water quantitatively over large areas in short periods of time. CZCS discriminates between organic and inorganic materials in open water, determines the quantity of the materials in the water sample and identifies organic particulates, such as various types of red tide organisms.

CZCS has collected approximately 15,000 two-minute scenes per year of screened data. There are currently over 5000 scenes of Level-1 (Calibrated Radiance Tape) data archived with the NOAA Environmental Data Information Service (EDIS) and a start has been made on the archival of Level-2 (derived pigment and diffuse attenuation coefficent) data. Many "Sea-truth" cruises have been conducted with coincident Nimbus-7 over pass data collected and validation studies performed. These show that pigment and diffuse attenuation coefficients calculated from CZCS measurements are well within the accuracy goals set for all but cases of high pigment concentrations for Level-2 products.

Archival of the Level-1 products for the first year of operation is expected to be completed by April 1982--for the second year by September 1982. Level-2 products for 500 scenes selected from the first three years of data will be available by September 1982. Additional Level-2 products are planned in subsequent years.

Several significant contributions to both oceanographic and atmospheric optics have been published in addition to the Nimbus-7 Data Plan, User's Guide and CZCS catalogs. A composite list of CZCS related publications is available from Mr. Oakes. Also, an atlas will be prepared and archived in EDIS in 1982 with commentary on selected Level-2 scenes for U.S. coastal waters and open ocean areas.

SCANNING MULTICHANNEL MICROWAVE RADIOMETER (SMMR)

James R. Greaves, GSFC, Code 903, 301-344-9132

Development of the processing software for the Nimbus-7 SMMR is nearing completion. Routine production of microwave brightness temperatures and geophysical parameters for the first year of data is expected to begin in February 1982. Release of the first data products for archival in the National Space Science Data Center (NSSDC) should occur within four months after validation by the SMMR Nimbus Experiment Team (NET). The data will be available in both computer compatible tape and hard copy color picture formats. General tape and film ordering information is provided in the Nimbus-7 User's Guide available from the NSSDC.

The geophysical parameters to be produced are sea surface temperature (nighttime only), near sea surface wind speeds (not velocity), water vapor (over oceans), atmospheric liquid water (over oceans), sea ice concentration, multi-year ice fraction (Northern Hemisphere only), ice surface temperature, and a "snow parameter" (a linear combination of brightness temperatures indicative of the presence or absence of snow).

Based upon intercomparisons between several data months of SMMR retrieved parameters and conventional surface measurements over open ocean areas, the rms accuracies for the ocean/atmosphere parameters are as follows: sea surface temperature, ± 1.6K; atmospheric water vapor, ± 0.25 gm/cm^2; and near sea surface wind speed, ± 2.5 m/sec. Due to the relatively large sensor "footprint" (150 km) and the effects of land contamination, the sea surface temperature measurements are restricted to areas more than 600 km from shore. It is estimated that the sea ice concentration and multi-year ice fraction algorithms have archived their prelaunch goals of ± 5% accuracy for ice concentration and ± 15% accuracy for multi-year ice fraction. Accuracy estimates for the atmospheric liquid water and sea ice surface temperature parameters are based upon models which predict a ± 4 mg/cm^2 accuracy for liquid water and a ± 5K accuracy for ice surface temperature. The lack of conventional data sources precludes a quantitative verification of these values. The observed absolute values, dynamic ranges, and patterns for these parameters suggest that the predicted accuracies are in fact reasonable.

SEASAT DATA UTILIZATION PROJECT (SDUP)

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The Seasat satellite was launched from the Western Test Range, Vandenberg, CA on June 26, 1978. After 106 days in orbit a short circuit in the electrical power subsystem resulted in the loss of the satellite. During the three months of orbital operations, the satellite returned a very large volume of data from the worlds oceans. Many of these data had never before been available. Dozens of tropical storms, hurricanes and typhoons were observed, and two planned major intensive surface truth experiments conducted. A careful assessment of mission objective achievability suggested that the primary proof-of-concept objectives of Seasat would be achievable with the data set, both satellite and surface truth, in hand. The Seasat Data Utilization Project was formed with the general object of determining the utility of the Seasat-A microwave sensors as oceanographic tools, as expressed by the goals of the original Seasat-A Project.

The Seasat-A satellite was designed to carry five sensors including a radar altimeter (ALT), a Scatterometer (SASS), a Scanning Multichannel Microwave Radiometer (SMMR), a Synthetic Aperture Radar (SAR), and a Visible and Infrared Radiometer (VIRR). Precision of the altimeter height measurement was expected to be 10 cm RMS for sea states less than 20 m. The estimate of significant wave height was expected to be accurate to ±0.5 m or 10%, whichever was greater. As a goal, the SASS surface winds were to be detemined to ±2 m/s or 10% in magnitude, whichever was greater, and ±20 deg in direction. Two primary classes of data obtained from SMMR were sea surface temperature (SST) and surface winds. The SST accuracy was expected to be ±2K, an important first step in determining SST under cloudy conditions. The accuracy of surface wind measurements was expected to be ±2 m/s or 10%, whichever is greater. The SAR goal was to measure oceanic wavelengths and direction of 50 m or greater, sea ice features, iceberg detection, wave-land interfaces and penetration to the surface through major storms such as hurricanes. The VIRR was intended primarily for feature identification. Actual results of the geophysical evaluation are shown in the table.

The Seasat data are available through the NOAA Environmental Data and Information Service (EDIS).

SEASAT RESULTS

SENSOR	OBSERVABLE	DEMONSTRATED ACCURACY	DEMONSTRATED RANGE OF OBSERVABLE
ALTIMETER	SIGNIFICANT WAVE HEIGHT ($H_{1/3}$)	$\pm$10% OR 0.5 m	0 TO 8 M
	RANGE PRECISION	7 CM	$H_{1/3} \leq 5$ M
SCATTEROMETER	WIND SPEED	1.3 M/S	4 TO 26 M/S
	WIND DIRECTION	$\pm 16^{\circ}$	4 TO 26 M/S
SCANNING MULTICHANNEL MICROWAVE RADIOMETER	SEA SURFACE TEMPERATURE	1.0°C	10° TO 30°C
	WIND SPEED	2 M/S	0 TO 25 M/S
	ATMOSPHERIC WATER	$\pm$10% OR 0.2 GM/CM^2	0 TO 6 GM/CM^2
SYNTHETIC APERTURE RADAR	WAVE LENGTH	$\pm$12%	WAVE LENGTH $\geq$ 100 M
	WAVE DIRECTION	$\pm 15^{\circ}$	WAVE LENGTH $\geq$ 100 M

TIROS-N/NOAA SERIES

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PROJECT OBJECTIVES

1. To provide increased spectral radiometric information for more accurate sea-surface temperature mapping and day/night cloud cover information and to provide higher accuracy and yield of atmospheric temperature and water vapor soundings over the oceans.

2. To provide a remote platform location and data collection capability over the oceans.

INSTRUMENTATION

1. Advanced Very High Resolution Radiometer (AVHRR)

This scanning radiometer (4-channel on NOAA-6 and 5-channel on NOAA-7) provides stored and direct readout of radiometric data. The fifth channel was added to NOAA-7 to account for boundary layer water vapor and thereby increase the accuracy of sea surface temperature measurement in the tropics.

2. TIROS Operational Vertical Sounder (TOVS)

This sounder consists of three instruments:

High resolution Infrared Radiation Sounder (HIRS/2)
Stratospheric Sounding Unit (SSU)
Microwave Sounding Unit (MSU)

These instruments will provide better temperature and humidity sounding than previous sounders: The MSU measures the atmospheric temperature even in the presence of clouds.

3. ARGOS/DATA Collection System (ARGOS/DCS)

This system, provided by France, is designed to locate and collect and relay data from free floating balloons, buoys, floating ice platforms, remote weather stations, etc.

4. Space Environment Monitor (SEM)

The objectives of the SEM are to determine the energy deposited by solar particles in the upper atmosphere and to provide a solar warning system.

CURRENT STATUS

The original TIROS-N launched on October 13, 1978, was replaced on June 23, 1981 by NOAA-7 and is operating concurrently with NOAA-6 which was launched June 27, 1979. The NOAA-7 is in a 1430 LST ascending orbit while the NOAA-6 is in a 0730 LST descending orbit at the equator. Both are in sunsynchronous orbits at an average altitude of approximately 450 nmi (830km) with orbital periods of 102 mins.

DATA AVAILABILITY

Data from the AVHRR is available in 4 modes:

1. Direct readout to APT ground stations
2. Direct readout to HRPT ground stations
3. Global onboard recording readout to NOAA-NESS at Suitland, MD
4. Readout of onboard recording selected highest resolution (LAC) data

AVHRR and sounding data is archived at EDIS, World Weather Building, Camp Springs, MD and is available from January to February 1979 on. Both tapes, and picture imagery are available on request.

ADDITIONAL INFORMATION SOURCES

Satellite Data Users Bulletin (NOAA, EDIS)

Environmental Satellite Imagery (NOAA, EDIS)

NOAA Tech. Memo NESS 107, Nov. 1979 (Data Extraction and Calibration of TIROS-N/NOAA Radiometers)

NOAA Polar Orbiter Data - Users Guide, March, 1981 (NOAA, EDIS)

Program/Project responsibilities include: NASA Headquarters Environmental Observation Division Program Management, GSFC-Project Management, both in collaboration with NOAA National Earth Satellite Service.

ALTIMETRY

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Objective and scope of project

The Ocean Topography Experiment (TOPEX) Science Working Group was established in February 1980 by the Enviromental Observation Division of NASA. The group was asked to consider the scientific usefulness of satellite measurements of ocean topography by use of altimetry, especially for the study of ocean circulation. The Chairman of the group is C. Wunsch, MIT, and the Project Scientist is R. Stewart of JPL and Scripps.

The group produced a report in March 1981 entitled "Satellite Altimetric Measurements of the Ocean." The report concluded that a system capable of routinely measuring the world's oceans should be a high priority goal, and that satellite altimetry is the only method with a demonstrated capacity to meet the specific requirements for observing ocean circulation as mandated by pressing national scientific and operational requirements. The group also noted the need for other simultaneous measurements: an accurate geoid (from GRAVSAT), winds from a scatterometer, and *in situ* measurements for calibrating and interpreting the ocean topography measurements.

The specific objectives of the Ocean Topography Experiment are to calculate the global distribution and variability of surface geostrophic currents using satellite altimetric measurements, to distribute these data to users in a timely way, and to merge these surface observations with subsurface measurements over the global oceans in order to define and monitor the general circulation of the ocean.

Potential research and operational benefits

The report of the Science Working Group emphasizes that the major goal of TOPEX is to improve substantially our understanding of the ocean circulation and its behavior. Achievement of this scientific goal will provide the first comprehensive global picture of the ocean circulation which is fundamental to understanding the role of the ocean in a variety of areas including climate change, fisheries distribution and movements, and the fate of pollutants. A recent report from the National Research Council's Ocean Sciences Board underscores the central role of understanding the ocean circulation in the problem of predicting climate and the need for altimetry measurements to do so.

The January 1981 report of the National Advisory Committee on Oceans and Atmosphere emphasizes the central role of such measurements in operational needs. Such benefits include the collection of improved surface current and wave information for more efficient operation of commercial and naval vessels, charting areas of significant acoustic variations, better tidal predictions in coastal and deep-sea areas, and improved predictions of storm surges, flooding, and erosion produced by major storms.

In addition, offshore oil rigs, drill ships, mining operations, coastal nuclear power plants, and ocean thermal energy conversion facilities all need reliable estimates of wave and current climates which could come from the TOPEX altimetric observations.

Other benefits accruing from TOPEX come from the ancilliary measurements. The accurate geoid will be of use for improving inertial navigation systems and mapping of bathymetric features such as seamounts, of interest also to fisheries and naval operations. The determination of the electron content of the ionosphere, will be useful for the prediction of the propogation of short-wave radio signals used for communications and aeronomy.

Although not an operational mission, TOPEX could provide immediate access to information for those who must operate on the sea, and at the same time would be an informative forerunner for a truly operational optimally designed ocean satellite.

Present status of project

The Science Working Group report was produced in March 1981. This became the source document for updating the science requirements upon the TOPEX missions. The fourth quarter of 1981 was devoted to the development of the JPL Study Team Phase A Report presented by R. A. Neilson and C. A. Yamarone, Jr. in September 1981. The Phase A report describes the experiment, the mission, and the necessary systems. Conceptual designs for each of the systems are included. Cost information has been compiled on the basis of a FY84 start. Phase B studies will begin in FY82.

COLOR RADIOMETRY

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With successful operation of the NIMBUS-7 Coastal Zone Color Scanner (CZCS) and completion of algorithm development for data analysis, the potential utility of CZCS has been clearly demonstrated. A study team, the Satellite Ocean Color Working Group (SWG), has thus been assembled to address the data requirements of the oceanographic community for future flights of an Ocean Color Imager (OCI). The SWG consists of Bill Barnes-NASA, Otis Brown-U. Miami, Dennis Clark-NOAA, Wayne Esaias-NASA, Howard Gordon-U. Miami, Warren Hovis-NOAA, Rueben Lasker-NMFS, Jim McCarthy-Harvard, Mike McElroy-Harvard, Jim Mueller-NPGS, Mary Jane Perry-NSF, Al Pressman-NORDA, Ray Smith-UC Santa Barbara, and John Walsh-BNL (Chairman). The first meeting of SWG will be held on 2-3 November 1981 at BNL to consider 1) what time and space classes of scientific problems can be studied using satellite derived measurements of ocean color and, 2) what additional data are required from other satellite, airborne and in situ sensors to interpret the dynamic ocean processes captured by future time series from an OCI.

IN SITU/DATA COLLECTION SYSTEMS

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The utility of satellite remote sensing of the ocean surface has been demonstrated, and the future promises even more useful observations of this type. But it is recognized that remote ocean surface observations can be fully utilized only if they are accompanied by in situ observations of the subsurface ocean. Further, it is recognized that the global nature of satellite positioning and data transmission systems can significantly increase the scope and utility of in situ ocean observations.

In order to more clearly define the potential of in situ observational systems which make use of satellite data relay and positioning, an In Situ Ocean Science Working Group was established. It was charged with addressing the questions:

1. What are candidate problems and experiments that can be studied using satellite relay of in situ data and the satellite location of its source?

2. What improvements in relay and location systems are required to meet the needs of these experiments?

3. What, if any, new in situ sensors need to be developed to exploit data relay capability and support important experiments?

4. What are the options on accuracy, data rate, location ability, and revisit time to satisfy the major classes of scientific user?

5. What are the benefits to others, such as commercial users, operational forecasters, meteorologists, climatologists?

The Working Group is presently examing these questions and is expected to report their conclusions by October 1982. Their report is expected to include recommendations on what satellite and in situ systems look most promising, a technical discussion of data relay and positioning requirements, and a discussion of complete systems including data processing, delivery costs and user costs.

Synthetic Aperture Radar/Open Ocean

by O. M. Phillips

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Synthetic Aperture Radar imagery from SEASAT has revealed a surprising variety of oceanic structures. Different features of the imagery have been interpreted as current filaments, oceanic and atmospheric fronts, expressions of bottom topography, warm rings and oceanic swells. Variations in the intensity of the return signal are interpreted as variations in local short wave structure at the Bragg backscattering wavelength, so that oceanic structures which can be imaged are those that influence this structure.

Spatial patterns revealed by this imagery are striking, but their utility to oceanography would be enhanced enormously if these patterns could be interpreted quantitatively. The object of this research program is to develop the ability for this quantitative interpretation. The simple dynamical interactions between surface waves and currents in the absence of wind, wave breaking and longer waves, is well known. A survey is given by Phillips (1981). Among the phenomena that can be identified in this simple way are the appearance of caustics, blockage by adverse currents and short wave, long wave interactions. To achieve a reliable quantitative interpretation of this imagery, however, further research is needed on the influence of wind input, short wave breaking and its augmentation by swell and the determination of surface current fields (rather than velocities at singular points). Research into these areas is proceeding, some further results being given at the 1981 Symposium in Miami on Surface Waves and Radio Probing of the Ocean Surface.

The theoretical results being obtained should be tested by carefully designed field measurements supplemented with in-situ measurements of the current field. These field tests should concentrate on a very limited area in which variations in surface current are generated in a predictable manner (for example, by the tidal cycle) and ground truth measurements of the surface waves. The experiment must be carefully designed so that the results are transferable to more complex open ocean situations.

Ref: Phillips, O.M. 1981 The structure of short gravity waves on the ocean surface. Pp. 24-31 of Spaceborne Synthetic Aperture Radar for Oceanography, ed. R. Beal, P. DeLeonibus, I. Katz. Baltimore: The Johns Hopkins Press.

SAR/Sea Ice

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Based on experience with the utilization of aircraft- borne SLAR and SAR systems in the study of ice in the sea, it is apparent that such systems have much to offer both the operational and the research communities. This potential has been made clear by the success of the L-band SAR system on SEASAT in obtaining high resolution, all-weather imagery of sea ice. Not only can a number of distinctive ice features be identified, but identical features can be identified on images taken days apart. Therefore, the absolute and relative movements of such features can be utilized to delineate the drift and deformation of the ice; the openings, the closings, and the orientations of leads; and the detailed geometry of the ice edge. In addition, it is frequently possible to discriminate between first-year and multiyear ice. This is an important discrimination in that it corresponds to pronounced differences in both ice thickness and ice properties.

In view of the obvious operational and scientific advantages that could be obtained in the field of polar oceanography via the deployment of a SAR system in a polar orbiting satellite, a joint Canadian-U.S. program termed FIREX has been organized to explore such a possibility in some detail. Inasmuch as a SAR system in space would produce data of interest to a wide variety of different disciplines, several FIREX panels have been formed to consider different aspects of the problem.

The FIREX Ice Study Panel met during the winter of 1981 and discussed both the research and the operational aspects of sea ice. In the ice operations area, three general problems were considered.

- Navigation in ice-covered waters,
- Design of offshore structures for heavy ice areas, and
- Support requirements for general offshore activities associated with mineral exploration and production from offshore areas with heavy sea.

Almost every type of sea ice engineering problem occurs in some form in at least one of these three areas. It was found that the ice information requirements for such operations were quite demanding. A wide variety of data is required including information on "features" such as ice type, ice thickness, floe sizes, ridge and rubble heights and patterns, leads, ice movement, ice concentration, ice pressure, ice islands, and icebergs. The requirements on spatial resolution and repeat and processing times are particularly severe.

A similar analysis was conducted in the more basic science areas considering

- Sea ice as a material on the geophysical scale,

- The mass balance of the ice pack,
- The heat balance of the Southern Ocean,
- The role of sea ice in atmospheric and oceanic circulation,
- The terms in the energy budget at the ice margin and
- Requirements for improved short-term forecasting of ice conditions.

The ice parameters needed for studies of these problems are similar to the parameters of interest to the operational community. However, as science programs are commonly retrospective in nature, requirements for near real-time processing are less stringent.

It was concluded that a satellite-borne SAR system optimized toward the study of ice could provide information on ice edge location, ice type, ice properties, floe sizes, ridge and rubble distribution patterns, leads, ice motion, ice islands, icebergs, and wave period and direction. It was suggested that a nearly optimum sensor package would be achieved if a scatterometer and a multiple frequency microwave radiometer were part of the FIREX instrument package. These instruments would provide highly complementary data on ice boundaries and types, ice concentration, ice surface roughness, ice properties, wind velocity and ocean temperature. Missing items that would also be of interest are barometric pressure, air temperature, ocean currents, water column stability. All these parameters could, in principle, be determined via the deployment of specially designed data buoys.

The Panel also noted that there are many features in the SAR imagery of sea ice that are not clearly understood. Clarifying and quantifying the interpretation of these "features" would result in significantly increased information retrieval from SAR imagery. There is also a need to greatly sharpen capabilities for using a combination of passive and active microwave systems to classify sea ice. To help resolve such questions, a series of remote sensing experiments coupled with extensive ground-truth observations were outlined. The first of these experiments has just been completed at Mould Bay, NWT focusing on the characteristics of newly formed thin ice, second year ice, and multiyear ice at the start of the freezing season. During 1982, additional field programs are planned for the Gulf of St. Lawrence (February), the Labrador Sea (March) and the Beaufort Sea (April and July). The last exercise collects data on both first-year and multiyear ice during the melt season; information that is presently sadly lacking. These varied data sets will then be used to further sharpen instrument design and selection.

The Mission Requirements Document containing the results of the analysis by the Ice Panel will be completed by January 1982. The final report of the Study Team which will include results from the field programs is due in October 1982.

SCATTEROMETRY

by

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The SEA SURFACE STRESS (S-Cube) Committee was formed by NASA to conduct a scientific justification of a satellite scatterometer which can measure winds or stress over the ocean. The committee is composed of scientists from the academic community representing the specialties of micro-scale air-sea interaction, meteorological boundary layers and ocean circulation. Other members of the committee represent NAVY, NOAA and NASA laboratory and operational interests.

The committee will hold two meetings in late 1981 in order to organize the report to NASA Headquaters. The report is scheduled to be available in first draft in March 1982. The terms of reference are:

a) Investigating research requirements for measurements of surface stress to aid in describing and modelling the ocean interior and surface layers, including the atmospheric and oceanic boundary layers.

b) Recommending the type and quality of satellite data of stress and associated measurements to meet these requirements.

Specific questions to be addressed are:

1) What scientific problems can be studied using measurements of surface stress?

2) To what extent can accurate spacecraft measurements make a significant improvement over conventional observations?

3) To what extent can complementary data such as passive microwave, altimetry, surface temperature, or in-situ measurements significantly augment the scientific value of stress measurements?

4) What experiments need to be done to improve stress comparisons and data and scatterometer stress algorithms?

5) What accuracy, resolution, area coverage, and revisit time are recommended for the different research problems?

6) What systems are required for processing and delivering wind stress data to the users?

7) What are the benefits to other users in the commercial, defense, and government sectors?

It had already been ascertained that the Seasat SASS is not an acceptable instrument because of the wind direction ambiguity. It seems necessary to use an improved antenna (3-sticks) to be able to recover direction and magnitude. In addition there is a requirement for a single radiometer channel to be used as a rain flag to be used to discard bad data. A geographically-gridded product is desired with 100 km resolution, ten percent magnitude accuracy and reasonable direction determination. The important oceanographic modelling activities require a minimum revisit time of one observation every two days in any one degree square at 30° latitude.

NATIONAL OCEANIC SATELLITE SYSTEM (NOSS)

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The NOSS SWG concluded its preliminary assessment of the scientific opportunities and problems facing NOSS and other oceanographic satellites over the next decade, and the associated research program necessary to meet thie challenge. During the year the NOSS project was officially terminated, but it was felt important to complete this review regardless. It is being published by the National Center for Atmospheric Research.

NOSS Science Working Group Final Report, 1981
NCAR/TN 1-85+PPR

The issues however remain as important as before and need to be addressed at the earliest opportunity as part of a coherent ongoing program of oceanographic satellites.

Of major importance to understanding the ocean circulation and the interactions between the ocean and the atmosphere is the measurement of the wind stress on the ocean surface to provide a coherent, calibrated long-term data set on a global basis. The Seasat data offer an enticing glimpse of future routine observations, and hold great promise for this objective, but many special studies will be needed to complete the conversion of scatterometer observations to reliable, well understood measurements of surface stress. These include fundamental studies of the generation of capillary waves and the influence of geographically variable quantities like surface contamination, and carefully selected and controlled in situ measurements for intercomparison on a statistical basis for several years.

The transient response of the ocean to atmospheric forcing near the equator appears to be an important feedback in interannual variations of climate, not only in the tropics but to a significant extent in mid-latitudes in winter. The simultaneous determination of wind stress, sea surface temperature and sea level throughout the tropical belt would do much to test our numerical models of this response, and to turn them into valuable predictive tools. Ongoing efforts are needed to improve the accuracy of the large-scale monthly average sea surface temperature fields currently extracted from geostationary and polar orbiting satellites.

The determination of sea level by a program such as TOPEX, is, particularly in conjunction with other measurements such as wind stress, another important tool for the future. Besides, the tropical experiment just mentioned, central to testing and improving models of the ocean circulation are the statistical distribution of mesoscale eddies and the large-scale mid-ocean currents.

Satellite based location and data collection systems will also continue to be of fundamental importance to oceanography over the next decades. Many programs and projected experiments involve deployment of surface and subsurface drifters, and isolated buoys for which such capabilities are essential.

Microwave radiometry and synthetic aperture radar have unique potential for determining the coverage and structure of sea ice and its interannual variations. Satellite altimetry is also need for mapping the surface elevation of the ice caps.

The color scanner has proven to be directly applicable to many studies of biological processes in the surface waters. Particularly when related to simultaneous high resolution images of sea surface temperature, the patterns thus exposed clearly contain much information also about physical processes near the surface such as mesoscale eddies. Our tools for interpreting this are at present relatively undeveloped.

Throughout all these activities, a recurring theme is the need for a user oriented data system, that is able to absorb and profit from the experiences of the many scientists who have reviewed aspects of the data editing, calibration, validation and summarization process, and to provide a preferred source of information to the oceanographer for all oceanographic satellites and related data.

FREE FLYING IMAGING RADAR EXPERIMENT (FIREX)

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A significant part of the Seasat heritage is a wealth of information of value to both the operational research communities. In particular, through studies with Seasat's Synthetic Aperture Radar (SAR) data conducted in both the United States and Canada, there has been increased awareness of the utility and importance of this satellite-derived information for addressing ice, oceans, renewable and non-renewable land resources problems. Unfortunately, the Seasat SAR data set is limited. However analysis of a limited amount of that data indicates that the SAR has research and operational potential in a number of applications.

In the area of polar ice dynamics, it has been shown that repetitive SAR coverage will allow measurement of ice motion on a regional scale with relative accuracy better than 100 meters. In ocean surface observation, it was verified that the radar provides quantitative information about the surface waves wavelength, direction and pattern. In the case of non-renewable resources, it was shown that the SAR data provide valuable information for structural mapping and, in combination with Landsat, for lithologic mapping. In the area of renewable resources, the Seasat SAR data clearly illustrate that the radar is sensitive to soil moisture and vegetation cover, however further work is still necessary to quantify these measurements.

With this in mind, numerous discussions among representatives of NASA and the Canadian Department of Energy, Mines, and Resources (DEMR) have taken place, concluding that both NASA and DEMR have a mutual interest in undertaking bilateral studies to define a possible future bilateral NASA/DEMR SAR satellite program which would satisfy both US and Canadian requirements. These discussions have resulted in the recent signing of a bilateral plan to jointly conduct a 21 month Mission Requirements Study to define the operational and research requirements that might support such a possible future program. This study would address the data requirements for ice, oceans, renewable and non-renewable resources.

The mission requirements study was initiated with the first meeting of the ice panel held in Canada in February, 1981.

TIROS-N SCATTEROMETER AND/OR OCEAN COLOR SCANNER

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The purpose of the Advanced TIROS-N Scatterometer and CZCS Accommodation Study is to derive suitable scientific missions for the two instruments within the unallocated resources of the NOAA I & J Operational Satellites. The study was initiated during the Third Quarter of FY81 and will continue through the Second Quarter of FY82. Several small study contracts have been let with the instrument suppliers and the TIROS Prime Contractor. An initial in-house study of the Scatterometer Mission has also been completed.

The Scatterometer envisioned would support TOPEX requirements as well as advanced scientific studies of sea surface stress phenomena. Scatterometer mission data would be included within the spare capacity of the High Resolution Picture Transmission and Global Area Coverage data products. The study provides for several instrument options including various antenna arrangements to make maximum use of available spare capability.

The CZCS Instrument under study is similar to the intended NOSS Unit but without the thermal IR channel. The scientific data would continue and upgrade that now being provided by Nimbus-7 to support ocean productivity studies. The instrument under consideration provides data from five of any eight channels on a real time [illegible], or averaged data in a delayed playback mode. Instrument data will be digitized to ten bits. Two data transmission options are being considered one would use the existing TIROS data handling and communications subsytem on a noninterference basis with the existing meteorlogical requirements, the second option would provide an independent data storage and transmission subsystem for the CZCS data.

As part of the study additional instrument support efforts are underway to determine expected performance from the several options. Scatterometer studies will include swath width vs coverage time vs cell size trade-offs. CZCS studies will include sun elevation angle vs sunglint analysis for the range of orbits under consideration. A study to assess the impact on the HIRS/2 and AVHRR/2 instruments of a nearer noon nodal crossing time orbit is also being undertaken.

In order to best meet the needs of the ultimate users, ground data handling concepts will be studied leading to a cost effective means of processing and distributing the data products.

Science Working Groups are being established to explore the utility of sea surface stress and ocean color measurements from satellites. The instrument concept tasks will proceed in consort with these activities in order to assure mission compatability with the science requirements within the capability of the spare resources of TIROS.

OCEAN TOPOGRAPHY EXPERIMENT (TOPEX)

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Experiment Objectives

The primary goal of the ocean topography experiment is to measure the surface topography of the ocean over entire ocean basins for several years using a satellite altimeter. The measurements will then be integrated with conventional subsurface observations and models of the ocean's density field in order to determine the general circulation of the ocean and its variability. This information will be used to understand the nature of ocean dynamics, to calculate the heat transported by the ocean, the interaction of currents with waves and ice, and to test the ability to predict circulation from the forcing by winds (Reference 1).

Instrumentation

Two independent satellite measurements are required to measure the sea topography with sufficient accuracy to determine the mean circulation. The first measurement is the corrected altimeter measurement of the satellite height above the sea surface. The corrections made to the measurements remove instrument biases and atmospheric effects. The altimeter uses two frequencies to correct for the influence of the ionosphere. A microwave radiometer will correct for the influence of water vapor in the troposphere. Meteorological forecasts and models will provide other (minor) corrections. The second measurement provides a precision ephemeris for estimating the height of the satellite above a reference surface . Laser or radio ranging to the satellite are the primary sources of data for the calculation of the ephemeris.

A study of various options for implementing a radio tracking system is now underway (Reference 2). To further aid in the determination of an accurate aphemeris, the satellite must have a low area to mass ratio and a low variability of that ratio. This will allow the drag and radiation pressure on the satellite to be estimated accurately.

Current Status

TOPEX is a currently a candidate for a new start in FY84, with a planned launch in late 1987 followed by a five-year data-collection period. The planned orbit is circular at 1334 km altitude, inclined at 63.4° and has a 10-day recurrance period. During FY81 the TOPEX Study Team completed the Phase A Study of initial mission concepts (Reference 3). The principal activity for FY82 is to continue with the preliminary design or Phase B of the mission. We are now prepared to contract with industry for the satellite studies as a part of Phase B.

Data Availability

TOPEX will begin to provide geophysical data records (GDR) using verified algorithms within six months after launch and continuously thereafter. An interim GDR will be available with only a five-day delay in order to provide information for scheduling work and for verifying algorithms. In addition, we plan to produce quick-look data within hours after acquisition. This quick-look record will contain wind and wave data of immediate use. Other data will be available for assessing performance and for conducting the flight operations.

Additional Sources of Information

1. Satellite Altimeter Measurements of the Ocean, Report of the Science Working Group, March 1, 1981.

2. Research and Technology Objectives and Plans (RTOP) 146-40-13-01-00, Advanced Earth Orbiter Radio Metric Technology Develop-ment.

3. Ocean Topography Experiment (TOPEX), JPL Study Team Phase A Report, 633-2, September 1981.

4. A Preliminary TOPEX Orbit Accuracy Analysis, by the TOPEX Precision Orbit Determination Group, IASOM TR 80-4, December 1980.

(Copies of these reports are available from the TOPEX Project)

Program/Project Responsibilities

NASA Headquarters Environmental Observations Division, Oceanic Processes Branch - Program Management, JPL - Project Management.

SECTION III--INDIVIDUAL PROJECT SUMMARIES

Summaries of individual research projects are given on the following pages, alphabetically according to the name of the senior principal investigator. Included in this section are 12 investigations which are supported under the NOAA/NASA Seasat Announcement of Opportunity, for which contracting services are provided by NOAA.

THE INFORMATION CONTENT OF SPACEBORNE SYNTHETIC APERTURE RADAR OCEAN WAVENUMBER SPECTRA

Principal Investigator: Robert C. Beal
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Long Term Interests: Application of spaceborne microwave sensing to major ocean research problems, and understanding of governing physics.

Specific Task Objective: Determine performance range over which Seasat SAR accurately measures dominant wavelength and direction; investigate relative strengths of various backscatter modulation mechanisms, and how they might be optimally utilized in future SAR oceanography missions.

Approach: Using 1) field measurements of spatially modulated short wave spectra, 2) digitally processed Seasat SAR data from pass 1339, and 3) a number of auxiliary surface, aircraft, and spacecraft measurements, perform cross-correlations of spatially and temporally coincident data and interpret in context of established or improved models.

Status: The analysis has been completed for optically processed data over a large portion of pass 1339 and, even though suffering from inherently poor quality of optically processed data, has shown gross location of storm centers. In addition, intensive analysis of precision digitally processed data in a local region has shown significant evolution of the spectrum over just a few tens of kilometers. Finally, analysis of similar data with high wind and waves ($10 m/s < U < 20 m/s$; $3m < H_s < 5m$) reveals azimuth wavenumber cutoff for $\lambda \lesssim 150m$, a limit which can be lifted in future orbiting SAR's by either lower altitudes or shorter instrument integration times.

This work is continuing in the latter half of FY81 using a more comprehensive set of digitally processed data under NASA and ONR sponsorship.

Proposals for continuation of the work in FY82 are being submitted. This work was jointly sponsored by NOAA and NASA. Related work is being sponsored by ONR.

DETERMINATION OF TIME-VARIABILITY IN THE

TROPICAL PACIFIC CURRENT SYSTEMS

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My long-term research interests center on improving our ability to describe and understand the structure and dynamics of ocean current systems, with a focus on the use of space-based remote sensing methods. The objective of this particular investigation is to explore the capabilities and limitations of satellite altimetery in pursuit of that interest.

The approach is first to concentrate on SEASAT and GEOS-3 altimeter data sets which are spatially and temporally coincident with good quality oceanographic measurements, to quantitatively verify the altimeters' current measuring capabilities. For SEASAT, a set of air-expendable bathythermograph data was collected during September and Octover 1978 in the western North Pacific, using U.S. Navy P-3 aircraft. For GEOS-3, arrangements were made for the collection of its altimeter data to coincide with a NORPAX oceanographic experiment in November 1977 to March 1978, between Hawaii and Tahiti. These activities involve close cooperation with George Born and Mike Park at JPL.

Current status: all pertinent data are in hand, and much of it has already been analyzed. A manuscript summarizing the SEASAT western Pacific results has been submitted to the Journal of Geophysical Research. The global Seasat data set has been received, and is presently being analyzed for evidence of tropical Pacific current variability.

AN OCEAN MESOSCALE EDDY INVESTIGATION UTILIZING SEASAT-A SMMR DATA

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Objective: Production of sea surface temperature maps with spatial resolution as fine as possible from the Seasat SMMR data. The time sequence of maps will be used to study the evolution of eddying and meandering currents in the northwest Pacific Ocean.

Approach: Sea surface temperature data obtained by the Seasat SMMR will be assembled for the western North Pacific, and mapped in five-day blocks. The maps will be examined for internal consistency and compared with conventional XBT data obtained by ships-of-opportunity, to establish a confidence level.

Status: I have participated in all SMMR evaluation workshops sponsored by the Seasat project between January 1979 and May 1981. During this period the algorithms for extracting sea surface temperature have been improved to levels of slightly less than ± 1 C. With the final global data set production now in progress, the first full month of data became available to me. For the western North Pacific, these SMMR data were mapped into 10-day, 2 degree latitude-longitude maps, then time-averages of the maps were made to form monthly mean temperature, and temperature deviation from climatology. Ship temperature observations were analyzed in an identical manner, and their resulting maps compared with those from SMMR. They agree at the 0.5 C (one standard deviation) level, with no significant bias. The results have been reported at the Spring 1981 AGU Meeting, and a manuscript is in preparation. The analysis will be extended spatially and temporally when the global data set becomes available in Fall 1981.

This work is jointly sponsored by NOAA and NASA.

SCRIPPS INSTITUTION OF OCEANOGRAPHY

SATELLITE REMOTE SENSING FACILITY

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My long-term research interests have focused on bringing available space-based remote sensing data to bear on a range of oceanographic interests. It is recognized that these data are often difficult to obtain and process. The objective of this particular investigation, therefore, has been to establish a facility which provides marine scientists with the means to readily access data from the NIMBUS-7 and TIROS-N generation satellites, plus the ability to interactively process and extract useful information from their sensors. These include the Coastal Zone Color Scanner and Scanning Multifrequency Microwave Radiometer on NIMBUS-7, the Advanced Very High Resolution Radiometer, High Resolution Infrared Sounder, and ARGOS Data Collection System on the TIROS-N series.

Present status: the facility, consisting of a 5m tracking antenna and computer image processing system, was delivered to Scripps and declared operational in late 1979. Since then, two facility programmers have added considerable software for handling CZCS, AVHRR, and ARGOS data. Three Scripps graduate students are in the middle of pursuing their doctoral research using facility resources. Data has been archived for over 1500 NIMBUS-7, TIROS-N, and NOAA-6 overpasses. Data catalogs have been published, and a quick-look 35mm slide collection is in preparation. The facility has been used to support a number of major ocean experiments, including recently the Acoustic Tomography Experiment in the North Atlantic, and the Coastal Ocean Dynamics Experiment off northern California.

In addition to support from NASA and ONR, NSF provided funding to cover much of the operating costs for the first two years of facility operation. JPL supplied substantial help in the design and acquistion stages, along with the Navy Ocean Systems Center. The University of California also has provided funds for additional equipment, through its California Space Institute. The facility is now operating under a partial re-charge system.

THE RESOLUTION CAPABILITY OF THE SEASAT RADAR ALTIMETER

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Objectives: To determine the capability of the SEASAT radar altimeter to resolve short wavelength features in the ocean geoid and in the gravity disturbance vector. To develop techniques for automatic detection of seamount signatures in SEASAT data.

Approach: The geoid resolution capability of the SEASAT radar altimeter is determined by analysis of the altimeter data collected along nearly repeating satellite subtracks. These subtracks often repeat to within a spacing of less than 2 or 3 km, a small distance compared with the significant correlation distances of geoidal and gravity disturbance quantities. Accordingly, an analysis of the repeatable portion of the altimeter data collected along these subtracks affords a quantitative measure of the resolution capability. To explore the potential for detecting and locating ocean geoidal and bathymetric features whose physical dimensions may be smaller than the average resolution capability, TASC has initiated an effort to design a special class of matched filters for detecting seamounts. These filters incorporate models of seamount signatures and of the spectrum of SEASAT data.

Results: Pairs of repeat tracks have been analyzed in various ocean regions using parametric spectrum estimation techniques. Computations of the spectral coherence between repeat tracks show an effective resolution limit for geoidal variations of about 30 km (Brammer and Sailor, 1980). This means that the waveform of geoid features with significant wavelengths shorter than 30 km cannot be resolved (although smaller features may be detected and located). Further results have been: extraction of the geoid power spectrum from SEASAT data, estimation of the noise power spectrum (includes oceanography, orbit errors, and instrument noise), estimation of the signal-to-noise ratio, and new theoretical methods for comparing along-track undulation and gravity anomaly power spectra. Results in the area of seamount detection have shown the feasibility of detecting small seamounts, have shown the benefits of using repeat tracks in matched filtering, and have demonstrated the technique in an area of the western Pacific.

This work is jointly supported by NOAA and NASA.

USE OF RADAR ALTIMETER CROSS SECTION MEASUREMENTS TO INFER OCEAN SURFACE WIND SPEEDS AND ICE CHARACTERISTICS

Principal Investigator: Dr. Gary S. Brown
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Objective: Study the use of SEASAT radar altimeter average return power measurements to estimate surface wind speed and ice surface characteristics such as homogeneity and roughness.

Approach: Compare SEASAT altimeter-derived wind speeds to wind speeds observed at NOAA data buoys, and test a relationship derived from GEOS-3 satellite data which relates wind speed to scattering cross-section. Determine the precision of this technique. Obtain and validate a model for the behavior of the altimeter return over sea ice.

Status: After removal of the 1.6 dB bias in the SEASAT altimeter's measurement of $\sigma^\circ(0^\circ)$, comparisons with the NOAA data buoys obtained during 87 near overflights have produced very good agreement between the altimeter inferred wind speed and the corresponding *in-situ* (buoy) measurements. Over the range of 1 to 10 m/s, the mean difference was -0.3 m/s and the standard deviation of the difference was 1.6 m/s. Efforts will continue on extending this comparison to higher wind speeds. A scattering model has been developed to explain the altimeter measurements over sea ice. Problems have been encountered in applying this model to the SEASAT data. The problems result from the high return power level and the resulting nonlinear behavior of the radar receiver. Research continues on this problem. A technique has been devised for overcoming this particular problem in future altimeters.

This work is supported jointly by NOAA and NASA.

AIR-SEA INTERACTION STUDIES FOR SATELLITE MEASUREMENTS

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Objectives. The objectives of current tasks are 1) to establish the relationship between the atmospheric surface stress (or surface winds) and the sea state in order to evaluate satellite microwave wind measurement capabilities on the large scale, and 2) to study evolution of an oceanic front in the German Bight during the MARSEN (Marine Remote Sensing) Experiment, August 15-October 15, 1979.

Current Status. A program for processing surface pressure, air-sea temperatures and humidity measurements into surface stress and winds has been developed. Resulting windfields are compatible with measurements. They have been used to verify satellite optimal capabilities at ± 2 m s^{-1} and ± 20°. They are being used in conjunction with other data to investigate SASS ability to discern fronts and other dynamic surface regimes.

Direct measurements of wind stress and sea state were obtained during Phase II of MARSEN. In cooperation with the German Hydrographic Office and the Max Planck Institute of Meteorology in Hamburg, we obtained directional gravity wave spectra and high frequency wave height data to relate to our measurements of wind stress. Our contribution to the analysis of the frontal feature in the German Bight during Phase I of MARSEN consists of calculating radiative and turbulent heat fluxes as well as the momentum flux from the wind.

Computer software has been developed and data from other sources has been collected and interpreted.

RAPID SAMPLING VERTICAL PROFILER

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Our long term interest with which this project deals lies in the exploration of the variability of the upper ocean and in the elucidation of the processes which govern the distribution of heat, salt and momentum in near-surface waters. The objective of this particular project is to develop an instrument system capable of producing profiles of oceanic variables, initially heat and salt, when deployed from a moving ship.

Our approach to this task involves a small probe connected to a thin line which provides both data link and retrieval mechanism. The probe falls at several meters per second, trailing the line behind it, and then is winched back to the ship. A high-speed digital data acquisition system on board the ship records during descent. The probe is then retrieved and relaunched. A pressure signal is recorded as well as temperature and electrical conductivity, so that these variables can be plotted as functions of depth. Continuation of this process will then produce a map in two dimensions of the variations present.

In a test of a system recording temperature and depth only, in the North Pacific in January 1980, we were able to obtain a sequence of 25 profiles to 120m at the rate of a profile every five minutes, while the ship was under way at 10 knots. In further developments, a high-speed winching system is under tests, as is a lighter winch system suitable for ship speeds to 3 knots. Testing of a variety of data-links is proceeding, in the hope of finding a more reliable one. A data acquisition system based on an LSI-11/23 has been assembled.

A breakthrough in the application of turbulence theory to the ocean has been made, in work involving other agencies, which will make possible the calculation of microscale quantities such as kinetic energy dissipation rate from the structure observable by the RSVP through observation of the thickness of overturning eddies.

INVESTIGATION: Coupled Active/Passive Analysis

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LONG TERM INTEREST:

I am interested in developing applications of remote sensing to research science and operational problems concerning the sea ice of the North and south polar regions. Sea ice is itself an interesting part of the ocean-atmosphere, it plays several roles in sea-air interaction, and it has several characteristics which tend to enable remote sensing methods to work well and be essential; thus it is a useful research avenue.

OBJECTIVES OF THIS TASK:

The objective of this investigation is to improve the interpretation of active and passive microwave remote sensing data for sea ice. The two methods individually have strengths and limitations; this research is designed to reduce overall interpretation limitations by application of collective measurement strengths.

APPROACH:

The approach to be used is to test the hypothesis that active/passive analysis is a strengthened method by examining the Seasat data set augmented by other satellite images from Landsat, HCCM, and NOAA. The types of analysis to be used initially are:

1. Overlap of different data types for visual correlation.

2. Seasonal changes (summer to fall) in the emission and backscatter coefficients with concommittant changes in the ice cover.

3. Brightness and backscatter distribution analysis.

4. Comparison with surface data and aircraft data sets as available, principally from Canada.

CURRENT STATUS:

This task is new in FY'82.

INVESTIGATION: FIREX FIELD PROGRAM

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LONG TERM INTERESTS:

I am interested in developing applications of remote sensing to research science and operational problems concerning the sea ice of the North and south polar regions. Sea ice is itself an interesting part of the ocean-atmosphere, it plays several roles in sea-air interaction, and it has several characteristics which tend to enable remote sensing methods to work well and be essential; thus it is a useful research avenue.

OBJECTIVES OF THIS TASK:

The objectives of this task are to perform the studies needed to establish satellite instrumentation requirements and to develop specifications for a high resolution imaging radar instrument and program for research on sea ice science and operations problems. Specifically:

1. Determination of microwave properties of significant sea ice species.

2. Determination of effect of seasonal changes on instrument and mission design.

3. Determination of instrument parameters to resolve from imagery ice types and processes of significance.

4. Determination of instrument capability retained in sub-optimum instrument and mission parameter scheme.

APPROACH:

The approach to be used is to design and implement research flights with an instrumented aircraft coordinate with surface and helicopter supported examinations of in situ ice sample radar backscatter and physical-chemical characteristics, and to analyze the data to establish instrument parameters of wavelength, resolution, depression, and angle as well as overall mission requirements.

CURRENT STATUS:

This task is new in FY'82; a NASA Ice Study Team was formed in February 1981.

INVESTIGATION: MESOSCALE ICE DYNAMICS AND PROCESSES OBSERVATIONS/SEA ICE CHARACTERISTICS

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CO-INVESTIGATORS: Dr. J. Comiso, Dr. P. Gloersen,
Dr. C. Parkinson, Dr. H. J. Zwally/GSFC

Long-Term Interest: First, improve the physical basis for the interpretation and quantitative utilization of passive microwave space observations for studies of sea ice dynamics and processes in the polar oceans. Second, improve and verify methods for extracting sea ice parameters from multichannel microwave radiances.

Objective: The objectives of this study are (1) describe and interpret the observed spatial and temporal variations of the spectral microwave characteristics of sea ice and (2) improve methods for extracting ice concentration, age and temperature through the utilization of multispectral microwave sea ice characteristics.

Approach: The single frequency Nimbus 5 and multifrequency Nimbus 7 data sets will be used to study the variations in microwave sea ice signatures in the central Arctic and seasonal sea ice zones. Surface and near surface observations from the Bering and Norwegian Sea polar experiments, the Arctic Ocean buoy data set and ancillary remotely sensed data from the Nimbus 7 underflight mission will be utilized to improve and verify methods used for extracting the geophysical parameters.

Status: Four years of ESMR-5 imagery have been analyzed to determine the spatial distribution of ice which survives the Arctic summer. The results of this study will be submitted for publication. It is anticipated that after one year of effort a study of the retrieved ice parameters using Nimbus 7-SMMR data and coincident observations in both the Bering and Norwegian Seas should be completed. The results of the study are expected to provide a better understanding of the limitations of the current algorithm and lead to refinements which will maximize the retrieved sea ice information. In addition, it is expected that considerable progress will be made and preliminary results reported on the following problems: 1) Variation of multispectral brightness temperatures and, 2) Correlative analysis of Arctic Ocean buoy and SMMR data.

LARGE SCALE WIND DRIVEN OCEAN CIRCULATION

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Long-Term Interests: To incorporate satellite measured winds in statistical and numerical studies of the large scale, low frequency dynamics of wind driven ocean circulation.

Specific Objectives: There are two primary objectives of the present work. The first is to evaluate the scientific usefulness of the satellite wind estimates from the Seasat scatterometer, altimeter and scanning multichannel microwave radiometer. Since it is the only instrument capable of measuring both wind speed and direction (with up to a fourfold ambiguity), the emphasis is on the scatterometer. The second objective is to examine upper ocean response to wind forcing from existing historical data.

Approach: The approach of the first objective of this work consists of carrying out a statistical intercomparison of the three satellite wind speed measurements with each other and with available in situ measurements. Special attention is being focused on tropical and high southern latitudes because of an interest in the performance of the three sensors in regions of high water vapor and/or high wind speed. The approach of the second objective has been to form linear statistical predictors of the dynamic topography of the sea surface using wind stress and wind stress curl as forcing parameters. This part of the study has concentrated on the variability in the California Current region. The wind data used consists of the quasi-geostrophic wind fields produced by FNOC from ship reports of atmospheric pressure.

Current Status: The California Current study is near completion, and two manuscripts are presently in the review process. The results show that the dominant signal is a very large scale interannual variation in the flow of the California Current that is unrelated to wind forcing. A second mode of variability with shorter time scales has been identified also, and it resembles an Ekman suction response to the wind stress curl. The Seasat satellite wind study is presently in progress. Global maps of the wind speed and wind speed variability measured by the altimeter have been produced. The results are described in a manuscript presently in the review process. All of the classical features of the wind field are evident as well as a number of new features previously undetected from ship reports. Analysis of scatterometer data is presently in progress.

OCEAN CIRCULATION STUDIES USING SEASAT ALTIMETER PROFILES

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Long Term Interests

Satellite altimeters are unique in their ability to rapidly obtain precise measurements of sea surface height on a global basis. Proper analysis of these data can reveal important information about ocean circulation. Existing data from Seasat provide a basis for technique development and investigation of altimetric capabilities. Evaluation of these data must include thorough error analyses of geophysical corrections, models, and errors associated with the analysis techniques themselves. Such studies will have direct application to future altimeter missions.

Specific Investigation Objectives

Existing global geoid models are inadequate to permit determination of surface current velocities from altimeter data. Present emphasis is therefore on the use of geoid-independent methods to solve for mesoscale sea height variability. Meandering currents can be detected in this manner and the eddy field can be described in terms of dominant length scale, period, potential energy, and kinetic energy.

Approach

The Seasat collinear data set was used to determine mesoscale sea height variability during a period of 3 weeks. Because the gravity field is time-invariant, the geoid signal can be eliminated from profiles of altimeter data having identical ground tracks. The global data were sorted into 400 segments with lengths of approximately 2000 km so that orbit error and residual tides could be removed as linear trends. This process yielded values of sea height variability at 115,000 points evenly distributed over the world oceans.

Status

A global map of mesoscale variability derived from Seasat was presented at the 1981 Spring AGU meeting. Sixty-two percent of the ocean's surface displayed variability of less than 5 cm, a remarkable result which demonstrates the accuracy of the technique. With such low background noise, the major currents were easily distinguishable as variability maxima. The Gulf Strem, Kuoshio, Agulhas, Falkland, and Antarctic Circumpolar Currents had variabilities of 10-20 cm. Even some of the equatorial currents, which have relatively small surface topographies, were revealed as bands of 5-10 cm variability. These variability data will now be used to compute eddy parameters. Error analyses will focus on the possible effects of sea state bias, water vapor, and tides.

UNDERWATER LIDAR AND ACOUSTICS STUDY

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Objective: The principal objective of this program is to understand the dynamics of the food chain in the upper mixed layer. To achieve this goal, it is important to understand the relationship between phytoplankton productivity and the vertical and horizontal variability of the ocean on spatial and temporal scales which are large compared to the scales of the biology. Included in the study of phytoplankton productivity are the relationship between chlorophyll abundances and phytoplankton productivity, the productivity of zooplankton in the upper mixed layer and the dynamic interactions between phytoplankton and zooplankton and the roles that these trophic levels play in the dynamics of the food chain. The objectives of this task are to examine the need for *in situ* instrumentation and to assess the technology required to develop that instrumentation. The emphasis is on optical and acoustical techniques that will permit remote observation from *in situ* platforms.

Approach: The approach has been to examine the requirements for remotely sensed scientific measurements both from above the sea, using aircraft and satellite platforms, and from below the sea, using towed *in situ* platforms. This combination will provide three-dimensional insight into the relations between the physics and the biology of the upper mixed layer.

Status: The study phase is being concluded with specific recommendations for new approaches in *in situ* and airborne instrumentation, including recommendations for the development of chirp sonar as a tool for the *in situ* study of zooplankton populations. The study of phytoplankton populations, and of the temperature and salinity environments, will be examined using active LIDAR on board a towed submersible. A possible combination of Raman and Brillouin scattering techniques will be used to examine the temperature and salinity structures, and the chlorophyll *a* fluorescence will be excited by a pulsed laser to be developed for both the airborne and the *in situ* instrumentation. The technology for each of these instruments is in hand, and work is proceeding toward their development.

INVESTIGATION: MESOSCALE ICE DYNAMICS AND PROCESSES OBSERVATIONS/PARAMETER COMPARATIVE ANALYSIS

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CO-INVESTIGATORS: Dr. H. J. Zwally and Dr. D. J. Cavalieri

Long-Term Interest: In sea ice areas, for a given frequency, the observed microwave brightness temperatures, T_B, are influenced by a number of variables including ice concentration, ice thickness, ice type, snow cover, physical temperature and surface dryness. Existing techniques will be improved and new methods will be developed to quantify the contributions of each of these variables to the observed T_B. The results will be utilized in obtaining more accurate information about sea ice cover, and surface or subsurface characteristics of sea ice from microwave data.

Objectives: (1) Examine the validity of ESMR and SMMR sea ice algorithm by using high resolution LANDSAT (and/or SAR) images, (2) Determine the relationships between ice and snow surface temperature by concurrently utilizing Nimbus 7-Temperature Humidity Infrared Radiometer (THIR), Nimbus 7-SMMR and a thermodynamic sea ice model, and (3) Investigate the spatial and temporal variation of emissivities of different ice types in the Arctic and Antarctic regions.

Approach: Near simultaneous images of ESMR and Landsat-1 (or 2), and SMMR and Landsat-3, respectively, will be utilized to investigate sea ice cover and ice edge results from microwave data. The Nimbus 7-THIR will be used to determine physical temperature of snow surface while an algorithm will be developed to extract snow ice interface temperature from SMMR. Results will be compared with existing or modified snow-ice interface models and ground measurements. Emissivities will be determined from SMMR and THIR using an iterative procedure to obtain consistency at all areas. Landsat images will be used to validate derived thin ice emissivities.

Status: Ice concentrations inferred from Landsat and ESMR images were compared quantitatively in several areas in the Southern Ocean. A paper was submitted about this study to the Journal of Geophysical Research (Oceans and Atmosphere). One year of Nimbus 7-SMMR T_B data have been mapped to polar stereographic grid. All channels were interpolated to the same grid size for easy application of ice algorithms and for convenience in analysis. THIR and other Landsat images needed in the project are currently being acquired.

Advanced Location and Data Collection Systems
RTOP-146-40-16

Investigator: Charles E. Cote
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TASK 01 - Advanced System Study

Objective:

The long term objective of this activity is to develop an advanced system meeting requirements for low-cost platforms and having sufficient capacity to meet ocean requirements projected for the next decade.

Approach:

Continue advanced system design studies to finalize performance and implementation for an ocean mission. Through consultation with ocean research community, insure that system meets anticipated growth requirements for global circulation studies. A system design will be completed having the required capability to support global circulation requirements.

Current Status/Progress:

A system concept and implementation plan for an advanced oceans system has been completed, and preliminary system specification has been prepared: "Project Plan for Advanced Location Data Collection System for the National Oceanic Satellite Systems Mission," GSFC, October 24, 24, 1980. A study contractor is being selected on a competitive basis to support definition of detailed specifications for an advanced instrument for a future mission; the contract should be let in September 1981. The system capability will be enhanced over the above concept to include a high data rate capability. An additional feature to be considered is the incorporation of limited capacity channel for "location only" of free drifters, but with buoy transmitter design based on modified but simplistic designs utilized in 121.5 MHz ELT's (Emergency Location Transmitters). Equally important is the need to continue efforts to translate new technology or capabilities into the corresponding increases in knowledge and science brought on as a result of improvements. Toward this end, participation in science working groups and continuing consultation with oceanographic organizations will receive a high priority.

Advanced Location and Data Collection System
RTOP 146-40-16

Investigator: Charles E. Cote
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Greenbelt, Maryland

TASK 02 - Existing Systems Improvement

Objective: Improve existing systems by reducing cost and complexity of buoy electronics which in turn permits expanded usage for ocean experiments using in-situ techniques.

Approach: In support of short and long term drifter experiments, techniques to reduce stringent specifications for carrier stability will be studied and tested with the Argos system. Low-cost buoy oscillator developments will permit near term applications with Argos while also supporting future goals.

Current Status/Progress: This activity is proposed as an FY82 new activity, however, due to the importance and impact of improvements on ocean experiments using the Argos system, efforts were initiated in June 1981. The immediate goal was to determine the frequency drift caused by unstable local oscillators; this would significantly reduce the cost of platform systems. Tests were conducted using Nimbus-6/RAMS equipment, wherein, transmitting signals were swept linearly in frequency during orbital overpasses. A correction algorithm was developed and applied to data with success. Although, the sample size was limited (10 orbits), the results showed 1-2 KM agreement with absolute known location of transmitters. A second phase was initiated and is currently underway. The procedure involves statistical characterization of frequency drift in commercially available low-cost oscillators. This data in turn will insert into computer location models simulating orbital conditions. The variance in accuracy is expected to indicate the feasibility of acquiring reasonable performance in ocean systems using similar components. To be statistically significant, drift data must be measured over periods of months; an automated computer sampling test configuration (HP-1000) was designed and is operating with data being stored on magnetic tape. Tapes will read into the location model for analysis; four classes of oscillators will be tested. Once characterizations are complete, correction algorithm development will be continued with the goal of preserving system accuracy through drift compensation as was demonstrated with linear models described above. Additional tests will be performed to demonstrate post-pass correction based on telemetry of buoy internal temperature data as a means of correcting frequency drift.

OIL SPILLS AND OCEAN WASTE MONITORING

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Long Term Interests: To provide a quantitative scientific basis for the detection and monitoring of oil spills.

Specific Objectives: (a) Conduct field experiments of accidental and controlled spills of oil on the sea using a variety of microwave and optical sensors in order to obtain a quantitative understanding of how images of pollutants are formed. (b) Analyze the experimental data to obtain overlayed imagery of near identical scenes in order to define possible relationships between physical oil temperature and thickness and image intensity.

Approach: A comprehensive series of field experiments were conducted in 1978 and 1979, in cooperation with the American Petroleum Institute, EPA, NOAA, USCG, the Canadian Centre of Remote Sensing, and NASA Wallops. Nearly simultaneous aircraft measurements were obtained with laser fluorosensors, meters, IR and MSS scanners, uv scanner, and color and IR photography. All of these sensors have previously detected oil in the laboratory or field. Sea truth samples were obtained from surface vessels as a function of depth along sea and atmospheric conditions. Key scientific investigators are R. A. O'Neill, CCRS, J. Johnson, JBF Scientific, F. E. Hoge, H. Maurer, NASA Wallops, J. Johnson, H-J. C. Blume, NASA Langley, and R. Rawson, ERIM.

Status: Data on scattering have been analyzed and submitted to Radio Science for review. A paper on thickness, oil volume, and fate has been completed and submitted to IEEE Transactions on Geoscience and Remote Sensing. The coregistration of SAR, AOL, Microwave Radiometer, MSS and uv line scanner data is proceeding well with excellent results. A preliminary draft of a joint paper is under preparation and will be completed this summer. The SAR analyses is completed pointing to the fact that absolute calibration is a significant problem. A complete SAR data report with available digital tapes is being written as a NASA report.

Warm Water Mass Formation

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The long range objective is to elucidate those properties of the upper ocean involved in the net heating of surface waters, i.e. the supply of colder water to the surface, advection and heating at the surface, and incorporation of warmed surface water into the essentially adiabatic interior.

Proximate goals are to understand along-isopycnal particle movements near a frontal outcropping, cross-isopycnal mixing in such a zone, and the behavior of wind drift in the presence of strong horizontal density gradients.

The problem is approached through the analysis and interpretation of existing data sets (notably those on transient coastal upwelling and on shelf-edge fronts) and the construction of simple analytical models of the key processes involved.

The project was funded May 15. A study entitled The Structure of Transient Upwelling Events (started earlier with joint funding from DoE) has been completed. This demonstrated the relatively large along-isopycnal movements of the thermocline layers in an upwelling event. Work is currently in progress on the two fronts bounding the slope water of the North American east coast, the shelf edge front and the Gulf Stream wall. An atlas of property distributions in all available transects of the upper slope water (to 350 m depth) is under preparation.

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The long range purpose of the investigation is a greater understanding of regional variation in the geologic properties of oceanic crust, and corresponding variation in the geoid or gravitational field. An accurate representation of the correspondence between the satellite-measured geoid (sea surface) and underlying geologic structure is important from several aspects. First, a well-described geoid can be subtracted from satellite altimetry to yield oceanographic (time varying) data. Secondly, in unsurveyed oceanic areas such as the south-central Pacific, the satellite data can be interpreted to yield new geologic (e.g. bathymetric) information.

The specific research objective in our first year is a quantitative description of the correspondence between Seasat altimeter data ($\simeq$ geoid) and bathymetry at short to medium wavelengths (30-300 km) in well surveyed oceanic regions. The form of this correlation function will probably not be constant in different parts of the ocean. Rather, it should vary systematically with age and thickness of the oceanic lithosphere, and possibly other geophysical parameters. It may also vary in a non-systematic spatial manner due to the influence of certain geologic characteristics, such as seamount abundance. We will therefore investigate and describe the correlation of geoid anomalies and bathymetry in several oceanic regions and attempt to model any variations by comparison to systematic and non-systematic parameters.

The derived filter will then be applied to satellite altimeter data in poorly surveyed regions of the south-central Pacific. This will allow us to define targets for detailed surveys, indicated by major bathymetric-geoid "anomalies," i.e. regions where significant departures exist between known and predicted bathymetry.

Research over the last six months has concentrated on the development of a linear transfer function which quantitatively describes the relation between one-dimensional (along-track) Seasat altimeter data and bathymetry. Our test area is the Musicians Seamounts region of the north-central Pacific, where high quality bathymetric data are available.

This task began in March, 1981 as a pilot study. We have completed the comparison of one-dimensional geoid-bathymetry correlation in the Musicians Seamounts. These allow a crude comparison of the relative effects of high versus low seamount number density on the correlation.

DYNAMICS OF PHYTOPLANKTON PATCHES ON NANTUCKET SHOALS

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This research is directed toward understanding the interactions between physical and biological processes in the ocean, on spatial scales of 1-1000 km and time scales of days to months.

This task investigated the Nantucket Shoals system as a representative mesoscale ecosystem. Previous studies of the system were severely limited by lack of synopticity in data collection.

The approach used was to initiate an interactive in situ mooring, Lagrangian drifter, shipboard, aircraft, and satellite study of the physics, chemistry, and biology (primarily phytoplankton) of the Nantucket Shoals area. This intensive study over 2 weeks employed aircraft to measure surface distribution of temperature, salinity, lidar chlorophyll fluorescence and light attenuation, and high altitude color scanner imagery at sub-tidal to event scale frequencies.

The first field experiment was highly successful. Over 30 hours of aircraft data were collected, 160 oceanographic stations were occupied, 6 current meters were deployed and recovered, and 4 drifters tracked. Preliminary results indicate all objectives were achieved. The second and third year activities have been curtailed due to a phaseout of ocean remote-sensing research at Langley.

Portions of this program were supported by NOAA/NMFS, Northeast Fisheries Center.

STUDY OF SURFACE WINDS AND SEA SURFACE TEMPERATURES OVER THE INDIAN OCEAN USING SEASAT-A DATA

Principal Investigator: Dr. Mariano A. Estoque
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Long-Term Interests:

1. Validation, including calibration, of surface winds and sea surface temperatures obtained by Seasat-A against independent observational data.

2. Detailed study of the synoptic features of the surface wind field associated with the monsoons.

3. Corresponding study of sea surface temperatures and study of the interrelationships between the surface wind and the sea surface temperatures

Objective of this specific task: To devise a method for analyzing Seasat wind observations which does not require independent (conventional) surface wind observations for eliminating the indeterminacy of the Seasat observation.

Approach: The Seasat wind indeterminacy is eliminated with the aid of wind information from the following sources:

1. GOES satellite-derived winds at low levels

2. Winds inferred from cloud patterns based on still satellite pictures

3. Climatological surface wind distributions

4. Wind maps from a previous synoptic time

Status: The approach was tested by analyzing observational data over the Atlantic Ocean. The accuracy of the analysis technique has been evaluated by comparing the analyzed winds with independent wind observations from ships. The comparison shows that the analysis technique produces winds which are comparable in accuracy with ship winds. A scientific report which describes the analysis has been prepared.

Current Status: Further tests of the analysis techniques are being done.

This work is supported jointly by NOAA and NASA.

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My long term interests are in theoretical marine ecology, especially understanding spatial patterns in plankton: their causes and effects within the marine ecosystem.

Vertical structures and processes in the sea are believed to play an important role in determining horizontal plankton patterns. This project is aimed at developing techniques for measuring the vertical distribution of chlorophyll rapidly enough that a detailed two-dimensional (vertical-horizontal) distribution can be obtaind from a moving ship.

The project uses a pulsed laser as a remote-sensing fluorometer. By using a sufficiently short pulse (10 ns or less) and time gating the return signal, one can in principle identify the chlorophyll signal returned from a small depth increment. Under ideal conditions this approach might measure concentrations with 1 m resolution, down to 15 m, ten times per second.

We are using a laser system developed by Computer Genetics Corporation (Wakefield, MA). Two tests have been made at the WHOI dock, comparing laser measuremens with those of conventional oceanographic techniques like <u>in situ</u> fluorometry. Some discrepancies exist; reasons are being sought.

OCEAN SAR ATLAS

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This research program has the long term objective of exploring the usefulness of a spaceborne synthetic aperture radar (SAR) in studying oceanographic problems. The Seasat SAR has demonstrated that a spaceborne SAR has the potential to provide high resolution images of a variety of phenomena on the ocean surface: surface and internal gravity waves, large scale currents and eddies, bathymetric signatures, atmospheric features, sea ice, etc. What kind of information one can extract from these images and apply to oceanographic problems is the subject I would like to investigate.

Specific objectives of the Ocean SAR Atlas currently being compiled by the principal investigator are the demonstrations of the Seasat SAR imagery of (1) oceanic phenomena at various scales, (2) sea ice--its different types and motions, and (3) various atmospheric signatures on the sea surface.

Shown with most of the SAR images in the Atlas is at least one piece of corroborating information which includes in situ observations, observations by other instruments on board Seasat and other satellites (Landsat, NOAA-5, etc.), bathymetric charts, weather charts, model predictions, and historical observations.

Most of the analysis work has been finished. Graphics lay-out and caption writing are underway. A final version of the manuscript is scheduled to be ready by the end of August, 1981. The Altas will be published as a JPL document for external distribution by the end of November, 1981.

NOSS RESEARCH MODE

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Long Term Interest: The long term interest is to incorporate the in-track beam as part of a satellite scatterometer design in order to improve radar signature definition for ocean, ice, and land targets. From these improved signatures more effective remote sensors can be designed and more accurate algorithms developed to interpret the geophysical data.

Objective: 1) To determine NOSS sensor performance characteristics for an in-track scatterometer beam (Research Mode); determine whether nonstationary FFT techniques are acceptable for Doppler filtering. 2) Determine sensor operation in orbit required to minimize impact on global wind vector mode.

Approach: 1) Conduct computer experiments simulating ocean scatterometer signal returns and evaluate their power spectral distribution using FFT Doppler filtering techniques. 2) Use scatterometer swath prediction program to determine optimum sensor operation for avoiding loss of global wind vector data, and at the same time, allow in-track research mode operations.

Status: 1) Computer experiment results are now in hand that define FFT trade-off parameters which must be considered in a high resolution in-track scatterometer Doppler filter design. Hanning window modification appears feasible and desirable to reduce potential interference from adjacent resolution cell returns. 2) Calculations have been made showing significant swath overlap between consecutive orbits for latitudes above 60°. As a result, sensor dedication to the research mode for ice studies every other orbit would still provide wind vectors of polar ocean coverage every 12 hours.

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Our long term interests are the intermediate and large-scale effects of sea ice on the interaction between the ocean and atmosphere, and the influence of the polar regions on global climate. The large-scale energy exchange is governed by the ice thickness distribution and is very sensitive to the fractional area covered by thin ice and open water where exchange rates can be as much as two orders of magnitude larger than over thick ice. One of the greatest needs at present is a method to routinely determine spatial variations in ice concentration and ice type distribution and to establish how these quantities vary throughout the year.

The objective of our present work is to determine the extent to which passive microwave data from satellite borne sensors can be used to study ice concentration and ice type distribution on scales of 10^4 km^2 and above. Since the interaction of shortwave radiation with the ice and upper ocean is strongly affected by the type of surface, we wish to find out how accurately passive microwave techniques can distinguish among surface types from the beginning of summer melt through fall freezup. We feel that a multifrequency analysis from 6 to 94 GHz is necessary to extract the maximum information using radiometry techniques.

Our approach is to employ a "handheld" multichannel radiometer system to obtain ground based signatures of different ice types, with special emphasis on summer ice. Concurrent data on microscale ice structure will also be obtained. In conjunction with the observational work, we are formulating a frequency dependent radiative transfer model for microwave emission by sea ice based on detailed absorption and scattering by microscale inhomogeneities in the ice (brine pockets, vapor bubbles, and ice grains). The model should allow us to understand observed variations in brightness temperature in terms of physical changes in the ice and to interpret airborne data for which surface truth data are unavailable.

To date we have contracted with Honeywell Spacekom to have the radiometers built. The promised delivery date is December 1981. We have carried out a preliminary field study from the USCGC Polar Sea to investigate photographically the microstructure of ice types in the southern Chukchi Sea. The theoretical study is underway. The computer code includes multiple ice layers and is operating correctly for representative values of scattering and absorption. We are in the midst of including the detailed physics of these processes and calculating test cases.

This work is being sponsored jointly by NASA and ONR.

OCEAN MODELING AND DATA ANALYSIS STUDIES

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Long term interests center around understanding the physical processes that are important in the low frequency ocean general circulation, in learning how to model the ocean on these scales and in using ocean models to investigate the role(s) of the ocean in the earth climate system. This requires knowledge of the air-sea interaction processes which produce the surface heat, salt, mass and momentum fluxes that drive the ocean and also how to parameterize the effects of ocean "turbulence" on the flow scales of interest.

Specific investigation objectives are of two types. The first involves the development and use of numerical ocean models with various degrees of physical sophistication, in order to study the effects of different ocean processes in sufficiently idealized circumstances to make their effects understandable. The second involves ocean data analysis projects directed at determining how well the ocean wind stress and sea surface temperature fields are known on different space and time scales from conventional and satellite observations. These fields are needed for various modeling studies and also establish the standards that satellite observing systems should meet for maximum utility.

The first modeling results on the circulation of the subtropical and subpolar gyres have been obtained, using a very simple barotropic vorticity equation model, and have been submitted for publication. These results emphasize the critical importance of vorticity transport, either by the mean western boundary current systems (the model "Gulf Stream" system) or by eddy processes across the "Gulf Stream" front, in establishing the dominant qualitative flow behavior of the system. Further, they illuminate why conventional coarse resolution ocean models do not satisfactorily reproduce many important features of the observed ocean circulation. Further studies, to investigate the effects of different subgrid scale "turbulent closures" on the flow pattern , are being carried out. Other modeling studies concerning the predictability of sea surface temperature anomalies and the seasonal heat budgets of the equational ocean are also under way. Evaluation of the climatological surface temperature, wind and wind stress fields for the Atlantic Ocean is now complete and analysis of this data is underway. This is the first part of a projected high spatial resolution climatology for the world ocean, done in a consistent analysis. Variability studies will follow completion of the climatology.

This work continues to be done in close contact with scientists and staff of the Goddard Laboratory for Atmospheric Sciences. Other support for the investigator is received from the National Science Foundation and the National Oceanic and Atmospheric Administration.

Calibration Procedures and Standards
for Active Microwave Remote Sensors

Principal Investigator: Daniel N. Held
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Long Term Objectives

Spaceborne missions for the remote sensing of earth resources and oceanic processes which will fly in the late 1980's will probably include Synthetic Aperture Radars (SAR) as well as other active microwave sensors. For many applications it is essential that these sensors be radiometrically calibrated to facilitate the accurate interpretation and intercomparison of the resultant data.

Specific Task Objectives

The objective of this task is to develop and test techniques and standards applicable to the calibration of Synthetic Aperture Radars, and in addition, to develop the techniques and standards necessary for the cross-calibration of SAR imagery with other active microwave sensor data.

Approach

Over the three year period scheduled for this task we will: 1) conduct a thorough literature search; 2) analyze and simualte the effects of system nonlinearities; 3) develop specific techniques and standards for calibrating SARs; 4) aid in the design and implementation of the aforementioned techniques on the JPL CV990 radar; 5) evaluate data from the calibration efforts presently being conducted by ESA; 6) evaluate any pertinent SEASAT SAR data; 7) sponsor a multi-sensor field trip to cross-calibrate synthetic aperture radar(s), scatterometers, and spectrometers.

Current Status

The literature search is underway, and an extensive program of analysis and simulation has been conducted to assess the effects of system nonlinearities on SAR calibration. Two meetings have been held between the PI and various groups involved in scatterometry and radar spectrometry with the aim of developing a plan to mount a joint, multisensor field trip for the purpose of cross-calibrating the various active microwave sensors.

SEASAT Synthetic Aperture Radar:
Engineering Performance Evaluation

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Long Term Objectives

Most of the SEASAT Synthetic Aperture Radar (SAR) data has now been correlated into images, however there is little documentation generally available relating to that imagery. It is therefore extremely important to review the performance of the SEASAT SAR and the quality of the resulting imagery in a complete and well documented study.

Specific Task Objectives

Specifically, we are performing the following three tasks: (1) describe and document the entire SAR system in a manner which will allow future investigators to understand both the potential of the data set and its limitations, (2) investigate and document the limits of the radiometric and geometric accuracies of the imagery, (3) and investigate the limitations of the data set by performing limited "precision" optical and digital processing of the data.

Approach

The work will be carried out here at JPL as well as by two Co-Investigators: J. Bennet, McDonald Dettwiler & Associates Ltd; and R. Shuchman, Environmental Research Institute of Michigan.

Current Status

The documentation of the SAR system is well underway, and contracts between JPL and the two Co-investigators are currently being negotiated. A significant amount of progress has been made into defining and refining the limits on the position location and amplitude calibration accuracies. In particular, the SEASAT SAR absolute position location accuracy appears to be significantly better than 1 Km, with a potential accuracy in the vicinity of 100m to 200m. The pass-to-pass relative calibration accuracy has been measured to be better than 1.0 dB for some passes.

NUMERICAL MODELING OF SEA ICE DYNAMICS
AND ICE THICKNESS CHARACTERISTICS

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This research effort is motivated by a long term interest in air/sea interaction in the presence of an ice cover. The main objective of this specific program is the development and verification of numerical models for simulating the large scale dynamics and thermodynamics of sea ice. Particular emphasis in this work has been placed on developing a sea ice circulation model suitable for simulating the dynamic/thermodynamic behavior of sea ice over a seasonal cycle.

The approach in this work is to combine parameterizations of various physical processes to form a model. The resulting model is then examined numerically to determine its agreement with observations and to identify the role of different processes in the model results. In numerical investigations this year, emphasis has been placed on seasonal equilibrium simulations of the Antarctic ice cover.

For a first test of an Antarctic sea ice model, the two level dynamic thermodynamic model developed by Hibler (1979) has been extended to include free ice edge characteristics and applied to the Weddell Sea ice pack. The model includes a fixed depth oceanic mixed layer and a complete surface heat budget computation for the determination of ice growth and melt. Heat absorbed by the mixed layer is also included in the ice decay. The Weddell Sea was chosen for initial tests because of available ice drift and atmospheric temperature taken during the 1979 FGGE period. Observed time-varying wind, temperature, and humidity fields based on the 1979 Australian analysis together with empirical radiation fields and fixed ocean currents were used to drive the model.

Initial results of the simulation show that inclusion of realistic ice dynamics causes a greatly enhanced seasonal swing of sea ice extent in agreement with observation. Also it was found that with the fully coupled dynamic thermodynamic model it was not necessary to increase the oceanic heat flux above typical Arctic values to obtain a realistic seasonal cycle of ice extent. This is in contrast to earlier calculations based primarily on thermodynamic considerations which have suggested the need for a larger oceanic heat flux to explain the ice decay. Further simulations are in progress to examine the behavior of this Antarctic pack ice model in more detail. A description of the model and an examination of initial simulation results have been submitted for publication.

APPLICATIONS OF LASER TECHNOLOGY

Principal Investigator: Frank E. Hoge, NASA Wallops Flight Center, Wallops Island, VA 23337. (804) 824-3411, Ext. 567, FTS 928-5567.

Long Term Interests: To demonstrate that existing airborne laser technology and electronic systems can provide valuable, synoptic quantitative physical and chemical oceanographic data and scientific understanding of the subsurface water column.

Specific Objectives, Approach and Progress: A. Physical Oceanography. (1) To demonstrate the remote measurement of water column diffuse attenuation coefficient by using laser-induced water Raman backscatter decay as a function of depth. Better quality airborne Raman bathymetry data complete with diffuse attenuation sea truth is needed together with better deconvolution algorithms to remove lidar system response time. Depth resolved Raman backscatter data has now been obtained at 380, 493.5 and 650 nm as a result of stimulation by airborne lasers operating at 337, 422.6 and 53? nm. (2) To demonstrate the detection and measurement of warm core rings (WCR) and ocean frontal regions by means of laser induced chlorophyll a and organic material fluorescence and water Raman backscatter signal gradients. Estuarine front and WCR data has now been obtained and is undergoing analysis. Comparison of the chlorophyll a measurements with CZCS data for calibration and validation of the latter instrument is considered high priority. (3) To demonstrate the depth resolved measurement of ocean water temperature by remote airborne laser induced Raman scatter techniques. No method currently exists to remotely measure the subsurface ocean temperature profile. Laser induced Raman backscatter spectral bandshape and isomer/dimer depolarization techniques are utilized to extract the remote temperature profiles. Water Raman backscatter signals have been observed by NASA/WFC from airborne platforms over ocean water. To date these signals have only been used to remotely measure oil film thickness absolute dye tracer concentration and normalize and remove water transmission variations. B. Chemical Oceanography. (1) To demonstrate the accurate, calibrated integrated water column measurement of phytoplankton by observing the airborne laser induced fluorescence emission of chlorophyll a at 685 nm. This work is in conjunction with NASA/LaRC, The Johns Hopkins University, and W. Chester St. College. Good correlation of water-Raman-normalized airborne chlorophyll a fluorescence emission at 685 nm has been made with chlorophyll a extractions of grab samples taken along the flight lines. (2) To demonstrate the accurate, calibrated, integrated water column measurement of dissolved organic matter (DOM) and particulate organic matter (POM) in near-shore oceanic regions by laser-induced fluorescence. Recent important research results indicate that these DOM humic polymers may be produced and recycled by phytoplankton thus entering into primary marine productivity schemes.

MICROSCALE OCEAN SURFACE DYNAMICS

Principal Investigator: N. E. Huang, NASA Wallops Flight Center, Wallops Island, VA 23337. (804) 824-3411, Ext. 357, FTS 928-5357.

Long Term Interests: These air-sea interaction processes control the flux of momentum, energy, mass, and heat from air to water and vice versa; therefore any changes either in the air or in the water will be reflected in corresponding changes of the surface microscale structures in the form of wind waves. Consequently, the study of the microscale ocean surface dynamics will not only increase our understanding of the air-sea interaction processes, but also provide us with the foundation for proper interpretation of microwave remote sensing data.

Specific Objectives: (1) To study the detailed statistical characteristics of the ocean surface, (2) To study the spatial and temporal relationship of the wind waves, and (3) to study the evolution of the wind waves and their relationship to the turbulence intensity in the surface layer. The approach adopted here is to conduct a selected number of carefully controlled experiments first in the laboratory at the wind-wave-current interaction facility at WFC and then to check these results out in the field. At the same time theoretical analysis will also be emphasized. Our aim is to understand the basic physics of the processes. Therefore the approach will be more analytical and physical rather than empirical. This study is conducted as a joint effort between NASA Wallops Flight Center and Profs. O. M. Phillips and S. A. Kitaigorodskii of The Johns Hopkins University, Prof. E. Mollo-Christensen of MIT and Prof. C. C. Tung of the N.C. State University.

Progress: All the studies are in progress. The major findings are: (1) From theoretical and experimental studies, we established a new spectral model. The inputs to this model are the total energy content of the wave field and the dominant frequency. Both of these quantities can be derived from the data obtained by a satellite altimeter. This new spectral model not only fits field data better, but also correctly models the variable bandwidth of the spectrum. (2) From analysis of data from the laboratory and field, we proposed a new empirical formula that relates the nondimensional energy, peak frequency and fetch in a single equation. This formula demonstrates the importance of the significant slope in wave studies. It also shows that the difference between the laboratory and field data is solely due to the different steepness, which in turn can be measured by the significant slope. Thus, we established an equivalence between the field and laboratory experiments. (3) From experimental studies, we found that the statistical properties of the wind waves deviate systematically from the classical Gaussian processes. The degree of the deviation can be parameterized again by the significant slope.

Partial support for the studies comes from the Department of Interior, Bureau of Land Management.

Microwave Radar Oceanographic Investigations

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Long term interests: These focus on the end objective of this task which is the development of a spaceborne microwave radar capability for global measurements of ocean wave directional spectra.

Specific objectives: Research carried out to date indicates that these measurements can be made using rather simple, real aperture pulsed microwave radars operating in a conical scan mode near vertical incidence ($\theta \sim 10°$). Both theoretical and experimental work indicate that absolute directional wave height spectrum measurements with 1°-2° resolution can be made using existing short pulse altimeter hardware (the Seasat-1 altimeter). The scan on the surface occupies a ~130 km square and is commensurate with the FNOC grid. In this task we are concerned primarily with providing a firm theoretical and empirical basis for the design of a spacecraft system. However, in addition, we intend to capitalize on the proven ability of the Goddard 13.9 GHz short pulse radar to measure directional spectra by applying it to various basic waves investigations.

Approach: The basic principle of measurement involves the directional discrimination that occurs automatically through the wave-front matching of the broad electromagnetic phase front with that of a Fourier component ocean wave. Only those surface wave vectors that are aligned with the beam direction can contribute to a detectable range modulation signal. In principle, the range modulation signal can be detected by either short pulse (range resolution) or dual-frequency (wavenumber resolution) techniques; however, our work has shown that the short pulse approach is generally more practical, especially as it can be implemented with existing altimeter hardware. In the specular backscatter regime we have determined that the range modulation is due primarily to a simple geometrical tilting effect and that the range reflectivity modulation spectrum closely approximates the directional slope spectrum over a wide range of conditions.

Current Status: The theory of measurement is now well evolved. The theoretical work involving the analysis of the short pulse and dual frequency detection approaches and the specular scatter solution will be reported in Radio Science. The validation phase of the Fall '78 Mission data analysis is essentially complete: we have found excellent agreement of radar and buoy absolute wave height spectra over a range of sea states from 1.9 m to 9.4 m SWH. In terms of SWH, the agreement is to within $\pm$ 13 cm. Work will now concentrate on (a) making synoptic comparisons of the Fall '78 data set with FNOC wavefields, (b) preparing the GSFC radar for future flights in FY 83, and (c) systems studies for a space experiment.

MESOCALE OCEAN DYNAMICS - SAR SYSTEM TRANSFER FUNCTION

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Long term interests: Our long term interest is to define and understand the relationship, in an unambiguous and quantitative way, between the ocean surface and the SAR image as obtained from spacecraft.

Scientific objectives: The present phase of research is aimed at developing the mathematical transfer function relationship between an ocean wave on the sea surface and the Fourier transform of the image of an ocean wave, and verifying this with existing data.

Approach: Previous work at JPL has led to a relationship between a surface whose cross-section and profile may be described by a wave equation and its SAR image. We intend to modify this to develop a description of the wave image from a description of the ocean surface, and include both the horizontal and vertical components of the orbital velocity in arriving at this description. The SAR system transfer function will be obtained from this result. Theory will be compared with experimental observations as obtained from the MARSEN, SEASAT, West Coast and Marineland experiments. These observations include measurements of large scale wave parameters as obtained by the surface bouys, laser profilometers, pressure sensors and the HF and 2-frequency radars and the fine scale capillary and ultra short gravity wave structure as measured by the capillary (laser-optical) wave instrument. Work is being done in conjunction with the JPL Oceanography Team, and the Max-Planck-Institute, Federal Republic of Germany.

Progress: Theoretical relationship between ocean surface and the radar image have been derived, some functional predictions verified (results accepted for publication).

OCEAN WAVE HEIGHT DETERMINATION WITH SAR

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Long term interests: The long term goal of our investigation is to develop radar instrument concepts that would provide the capability for quantitatively monitoring ocean surface phenomena from space.

Specific objectives: The particular objective of the current phase of research is the operational implementation and understanding of the physical phenomena for a method for measuring ocean wave heights utilizing radar speckle, the concept for which was previously developed at the Jet Propulsion Laboratory This method involves obtaining SAR images utilizing small sections of the total signal bandwith, determining the normalized average intensity of pairs of such images as a function of frequency separation of the bandwidths used, and measuring the rate of which this curve falls off.

Approach: SAR data obtained from previous JPL flights has been used for the concept verification of the wave height measurement technique. These include data obtained from the SEASAT experiment. Surface truth is available for this data and will be compared with wave height measurements obtained by the radar. This work was done in cooperation with Dr. Robert Stewart, JPL/Scripps Institute of Oceanography and Dr. Omar Shemdin JPL/University of Florida. The results obtained have shown good correlation. Work is presently planned to implement this technique for operational use on SEASAT data, and develop the physical relationship between ocean surface processes and this technique.

Status: Continuing. Paper on initial results submitted for publication.

Remote Sensing of Oceanic Currents

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Long-term Interests: The study of coastal surface currents and their relationships to wave fields, wind stress, mesoscale phenomena, subsurface currents and bottom topography. To develop applications for a high resolution surface current measuring system, the Coastal Ocean Dynamics Application Radar (CODAR), and to promote CODAR as an everyday oceanographic tool for direct measurement and as ground truth (e.g., for SAR and SLAR).

Specific Objective: The Coastal Ocean Dynamics Experiment (CODE) provides an opportunity to make surface current measurements in an area of relatively simple bottom topography and large wind stress events. With complementary data sets of wave fields, wind, hydrography, subsurface currents, and bottom stress, the relevant physical parameters needed to construct accurate kinematic and dynamic descriptions of the response of shelf-water to strong wind forcings can be thoroughly examined. SAR and SLAR data sets from CODE will be used to access CODAR as an instrument for the evaluation of these observation techniques.

Approach: CODAR is a high-frequency, ground-wave mode, radar that measures the Doppler shift of the sea echo from which one can calculate high-resolution, accurate, surface currents for a coastal area on the order of 10^3 km. CODAR sites, establis'^d as part of the integrated CODE measurements, can help to test i 'stem during the pilot effort, CODE-1. With a sufficiently lon, .me series, CODAR measurements can be used to identify and separate tidally-driven from wind-driven currents, and to define the temporal and spatial scales of the response of surface waters to strong wind forcing.

Status: During CODE-1, CODAR measurements were taken for 16 days at an interval of 15 minutes. The data quality is excellent, there was little interference in our area, and there were no hardware failures. We are repacking the data into intervals of one hour; from the hourly time series, we can calculate tidal coefficients and quickly identify any periods of significant wind events for detailed examination. The software also exists to treat CODAR data in an Eularian manner for complementary studies with moored and airborne instrumentation, or in a Langrangian manner for complementary studies with drifter instruments.

WAVE-WAVE INTERACTIONS AND THE DELTA-K MEASUREMENT OF OCEAN WAVE SPECTRUM

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Long Term Interest: The study of a variety of active microwave techniques with potential for remotely sensing the properties of ocean surface currents and waves by exploiting the interactions between the "long" and "short" wave systems. This includes two-frequency (Δk) scatterometry plus both real and synthetic aperture radar imaging, all of which actually sense variations in the microwave reflectivity of the surface due to the long wave modulation of the small scale scatterers.

Objective: The primary objective of this task is to investigate application of the Δk technique to the measurement of the directional ocean surface wave spectrum, with the ultimate goal of development of a satellite ocean wave sensor in mind. A secondary objective is to study the feasibility of mapping ocean surface currents from space using the Δk technique.

Approach: The approach being taken involves both theoretical analyses and aircraft and ground based field experiments. The fundamental issue of optimizing post detection signal-to-noise ratio is being studied analytically, and a formulation that allows optimization of system parameter "details" for broad beam and shallow incidence angle measurements is being developed. These analyses are pertinent to both current mapping and wave measurements. Two aircraft experiments were conducted in 1979 and 1980 as part of the MARSEN and ARSLOE projects to first demonstrate the Δk concept from a moving platform and then to study incidence angle effects and the measurement of directional wave characteristics. Wave-wave modulation studies have been conducted from a variety of fixed platforms in cooperation with the Naval Research Laboratory.

Current Status: The signal-to-noise analysis is well underway and an improved detection scheme is being investigated. The "detailed" model has been completed for the one dimensional case and applied to the MARSEN data and is now being extended to two dimensions. Final analysis of the MARSEN results is complete and the first draft of an article is in typing. The ARSLOE data has been reduced with apparently excellent results and the analysis has begun. This work will be submitted for publication during the next year. L-Band data gathered on the NORDSEE research tower during MARSEN is being analyzed with respect to the modulation transfer function under high wind and high sea state conditions. Also, an experiment will be conducted during the next year from the Duck, N. C. Army C.E.R.C. pier to study the double-modulation effect at L-Band and Ka-Band.

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Oceanic fronts occupy scales smaller than synoptic scale eddies, yet are often associated with these disturbances when water mass contrasts are present. Mechanisms by which these fronts are formed and are dissipated are among the long-term interests of the principle investigator. The ability to survey upper ocean currents greatly improves the chances to gain new insight into the dynamics of upper ocean fronts.

The objective of this research task is to be able to routinely and accurately measure upper ocean currents from a ship using acoustic doppler techniques. The principle field activity will be associated with the National Science Foundation study of Warm Core Gulf Stream Rings. A preliminary cruise in May, 1981, was supported by NASA. During this short cruise, the R/V OCEANUS performed doppler current and XBT surveys near Nantucket Shoals, in support of an on-going NASA experiment in the area, in a Warm Core Ring, and across the Gulf Stream south into the Sargasso Sea. Our profiler system operated the entire eleven days and data are now being analyzed.

The heart of the system is a microprocessor-based data logger which collects and formats data from a 300 kHz, four beam, Ametek-Straza acoustic transducer, ship gyro, Northstar 6000 Loran-C set and a Magnavox 706 satellite navigation unit. The formatted data are written onto a nine-track digital tape for later processing and to a small computer for real-time vector averaging and listing at selected depths. A data record is written every 30 seconds and consists of navigation data followed by 25 sets of doppler pings and ship headings; thus, two data rates are recorded: 1.2 seconds and 30 seconds. The system records approximately eleven hours of data onto a 1200 foot digital tape.

The data collected on the OCEANUS cruise in May are now being analyzed, and programs are being written to display and average these data. Our preliminary analysis of the Loran time delays while the ship was underway shows a 0.1 μsec noise level in a ten-minute fit to a linear trend. This will limit our estimation of absolute currents to ± 5 cm/sec. The internal consistency of the four-beam doppler velocity calculation appears to be a factor of five better than this: ± 1 cm/sec. The 300 kHz system was capable of penetrating to depths of 100 meters. We are now making preparations to modify the R/V ENDEAVOR for the profiler so that our system can be used to map currents associated with the Gulf Stream and a Warm Core Ring on a 22-day cruise this September-October, 1981.

Scatterometer Applications to Numerical Weather Prediction

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The object of this investigation is to determine the improvement on numerical weather prediction that can result from scatterometer wind data. There are four main tasks: (1) Development of a 4-dimensional Seasat data assimilation scheme. The GLAS Analysis/Forecast system (Halem et al. 1981) is modified to include analysis levels near the surface and in the PBL. The forecast models include both the uniform vertical resolution 9-level model and a model with high vertical resolution near the surface making use of Monin-Obukhov, Richardson number and Mellor-Yamada parameterizations of the surface and internal fluxes. (2) Dealiasing and filtering system, including methods developed subjectively on the McIdas system and automated into the objective analysis/forecast system, and a variational analysis scheme which will make use of cloud fields to impose constraints on the divergence fields of the SASS winds. (3) Forecast impact studies in which numerical forecasts will be calculated from initial analyses with and without SASS data, and then compared with the actual observations to evaluate the impact of SASS winds. (4) SASS simulation studies in which a high resolution model will be used as "nature" to generate simulated data, and the forecast model will be used to assess the impact of future systems containing up to three SASS observing systems.

The GLAS Fourth Order Model with a new PBL has been completed and the new model has shown significant improvements in the forecast of a case of explosive cyclogenesis off the coast of Japan

The analysis cycle has been modified in order to produce an accurate global surface wind field using SASS, ship, and Rawinsonde data and the model 6 h first guess. A three pass procedure is employed with the least ambiguous SASS winds dealiased first. The subjective enhancement of the dealiased wind field is performed in regions of meteorological interest where the objective procedure may be deficient.

A paper "SASS wind removal by direct minimization" by Ross Hoffman describing the new variational method developed to remove SASS wind aliases has been accepted for publication by the Monthly Weather Review.

An extensive development of software to process Seasat data interactively using the McIdas system has been completed. The techniques developed using the interactive system are incorporated into the objective analysis. The system is used to correct and enhance regions of meteorological interest in the objective analysis cycle.

NIMBUS 7 - SMMR ATMOSPHERIC WATER

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Long term interests. I am interested in exploring the possibilities inherent in the totally new information of distributions of atmospheric and oceanic parameters that a scanning multichannel microwave radiometer can provide.

Objective of this specific task. The objective of this project is to test for accuracy of existing algorithms and possibly develop new ones for obtaining atmospheric water as vapor and liquid from the Nimbus 7 SMMR's brightness temperature measurements.

Approach. This project was started to take advantage of the information gathered by the University of Washington Cloud Physics Group during SMMR overpasses of the ocean west of the Washington coastline in February 1979. Comparison with radar coverage at a coastal station, aircraft cloud physics information and careful synoptic analysis is planned.

Current status. We have just begun to attempt reading the IBM-packed tape of the relevant orbits of SMMR data. Some work on organizing the cloud physics data has also been done.

VALIDATION AND APPLICATION OF THE SEASAT-SMMR GEOPHYSICAL ALGORITHMS

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Long term interest. Remote sensing of atmospheric and oceanographic parameters over the ocean from satellites.

Objectives of this specific task. In the present work we are emphasizing the validation of the SMMR channels producing information about atmospheric water in vapor or liquid form with the aim of describing their distribution in a mid-latitude cyclone, which crossed the Pacific Ocean in September 1978.

Approach. We have selected portions of SMMR orbits which intersected the particular cyclone in question, and are gathering all available support information such as synoptic maps, satellite and ship data.

Current status. We have received a SMMR data tape from JPL with both brightness temperatures and geophysical parameters for the locations of interest including a particular rain rate algorithm developed by T. Chester (JPL). We are at the stage where we have just learned to read the tape on the University of Washington computer.

This work is sponsored jointly by NOAA and NASA

ENHANCEMENT OF SAR IMAGERY TO OBSERVE SPATIAL CHARACTERISTICS OF GROUPS OF WAVES

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Long Term Interests

Medium frequency waves with periods of 50 to 500 seconds are observed in many ocean environments, in the deep ocean at depths to 4000 meters, in fluctuations of the Arctic Ice Cap, and on continental shelves. Medium frequency waves have been shown to promote offshore sediment transport on continental shelves and in addition, are a natural source of energy for excitation of harbor and harbor entrance oscillations in sea level and currents. The source of the energy in these waves is thought to arise from the modulation structure of ocean waves. The goals of this research are to understand the mechanisms responsible for the generation of medium frequency waves.

Objectives of This Specific Task

SAR imagery with its large spatial coverage offers a unique view of the ocean swell structure. Because the SAR emphasizes the strong radar targets, the images should contain information on the amplitude structure of ocean swell. The objective of this study is to determine the digital techniques needed to extract information on the modulation patterns of ocean swell from digitized SAR data. The first goal is to obtain statistically valid one-dimensional spectra from digitized SAR data.

Approach

My initial work demonstrated that the radar return constitutes a non-Gaussian signal with the data having large 4th moments. Thus, the data produces false low wavenumber information when processed by classical techniques. I have applied robust statistical methods to the data demonstrating significant improvements in the quality of spectral information obtained from digitized SAR data. These techniques are applicable in general to data containing glitter noise.

Current Status

This study was initiated on June 15, 1981. I have demonstrated that significant enhancement of the wave signatures in SAR data can be obtained. Furthermore, I have also demonstrated that wave signatures can be found in areas of images where the waves are not visually discernable.

GEOSTROPHIC MESOSCALE EDDY INVESTIGATION

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Co-Investigators: N. E. Huang, NASA Wallops Flight Center, Wallops Island, VA 23337. (804) 824-3411, Ext. 357 FTS 928-5357. C. C. Parra, NASA Wallops Flight Center, Wallops Island, VA 23337. (804) 824-3411 Ext. 562 FTS 928-5562.

Long Term Interests: Our long term interests are directed to the study of the ocean surface geostrophic mesoscale eddy motion using measurements from satellite altimeters aboard GEOS-3 and Seasat.

Specific Investigation Objectives: Our short term objectives include the statistical analysis of data using correlation and structure functions to evaluate the properties of mesoscale eddies embedded in the measurement data.

Approach: Our approach is to correct the complete GEOS-3 and Seasat altimeter data base so as to eliminate all inconsistencies. Then we will construct a three year mean and a standard deviation surface. The mean surface, an estimate of the mean circulation flow in the region, will then serve as the input for the structure function. The analysis of the structure function will yield the sectors where the oceanic baroclinic eddy field is most intense.

Progress: At present all GEOS-3 data have been corrected and a mean and standard deviation surface have been computed at ¼ degree cell resolution. The software necessary to compute the structure function has been developed and is presently been tested.

INTERPRETATION OF SEASAT ALTIMETER DATA

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Long Term Interests: To develop methods for increasing the accuracy in altimeter measurements of mean ocean surface level so they may be used for the determination of ocean surface currents. This requires accuracies of 5-10 cm. At present, we estimate that the bias in the altimeter measurement can exceed 40 cm.

Present Objective: To model sources of systematic bias in the estimate of the surface position produced by SEASAT on-board instruments, and to develop methods for reducing the resulting error.

Approach Utilized: We have simulated the SEASAT tracker using system specifications. Tracker bias is completely removable using parameters measured by the altimeter. A more important bias (known as EM bias) is produced by the higher order coupling between wave height and slope. We have modelled this effect using higher oder nonlinear wave theory. The EM bias depends on the disectional ocean wave spectrum and cannot be obtained directly from altimeter measurements. We have developed empirical methods to reduce it.

Current Status: We have shown how to derive the waveheight-slope probability density function from the altimeter waveform. From this, the rms waveheight, mean surface position and waveheight skewness coefficient are readily obtainable, together with their statistical accuracies. For SEASAT, acceptable accuracy arises from averaging over 50 km of satellite path (for wave height and mean surface level) and 200 km (for height skewness). Our simulations of the SEASAT tracker show that the tracker bias is produced by two mechanisms-the method used to normalize the waveform under conditions of changing sea state, and the finite waveheight skewness. The tracker bias can be completely removed by using the mean of the derived probability density function. This is unfortunately not true of the EM bias. We have developed and evaluated expressions for this bias using realistic models of the directional ocean waveheight spectrum. It is proportional to the waveheight and also dependant on directional properties of the wavefield. We have developed a method to reduce the EM bias below 10 cm using approximate linear relationship between the waveheight-slope squared skewness parameter and the waveheight skewness coefficient which is measured by the altimeter.

This work was jointly sponsored by NOAA and NASA

OCEAN CIRCULATION AND TOPOGRAPHY

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Long Term Interests

To provide a physically unambiguous basis for the interpretation and quantitative utilization of satellite altimetry observations of sea surface topography and to assess the impact of this on relevant problems in oceanography. To develop analytical and interpretative techniques for determining the contributions of the ocean geoid, tides, barotropic effects and dynamic topography due to general and mesoscale ocean circulation phenomena to satellite radar altimeter measurements of the sea surface geometry. To conduct simulations and real data analyses, to identify and formulate ways of achieving improvements in the computation of satellite orbits so that global orbital accuracies of 10 cm. or better can be achieved.

Specific Investigation Objectives

The specific objectives of the present work are to develop global as well as detailed regional maps of the mean sea surface topography from satellite altimeter data and to use these data to derive information on dynamic ocean processes. In support of the computation of the sea surface topography, the orbits of GEOS 3 and Seasat are being studied in great detail in order to provide accurate determinations of the satellite positions which are required for the analyses of the altimeter data.

Approach

Models for the major perturbing forces on Seasat and GEOS-3 are being assessed and techniques for either improving the models or minimizing the model error are being implemented. During the past year, Seasat radial orbit errors have been reduced to the sub-meter level (80 cm.) through force model improvements. The orbits computed using the upgraded models are being combined with the altimeter data and the data are being gridded and contoured in the form of topography maps.

Status

Global maps of the mean sea surface topography have been computed by combining the GEOS-3 and Seasat altimeter data with the most recent ephemeris computations. The sea surface topography data have been presented in the form of contour maps and also on magnetic tape in the form of a $1^{o} \times 1^{o}$ grid. The accuracy of the global maps is about a meter. Regional Seasat mean sea surface computations have been performed in the N.W. Atlantic and N.E. Pacific on a 0.25^{o} grid with an accuracy of about 30 cm.

MICROWAVE SEA ICE SIGNATURES

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Objectives

Identify first-year ice types using surface truth and aerial photography taken at the ice edge in the Bering Sea in 1979; correlate these types with ice signatures from aircraft-mounted active and passive microwave sensors; then compare these ice signature returns to similar data taken in Davis Straits.

Approach

Four different approaches to ice identification are employed: surface truth, aerial photography, aircraft remote sensing, and statistical comparison of ice signatures. The surface truth and air photos provide the ice type identification. The computed sensor footprints for the radiometer and scatterometer, plotted by time on the photomosaic, show when the signal is filled by a given ice type. Several of these events, when averaged, give a characteristic signal return for ice identification. These characteristic signatures exist for similar conditions in Davis Straits, and first-year ice results will be compared for the two areas.

Current Status

All data are at the University of Washington, and analysis of radiometer data has begun on completed photomosaics for selected flightlines.

THE USE OF NIMBUS-7 IMAGERY TO STUDY THE BERING SEA ICE

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Long Term Interests

To provide a year-round sea ice algorithm from SMMR data for ice-forecasting use in the Bering and other marginal seas.

Specific Task Objectives

To complete our comparison of SMMR data and a variety of surface truth data gathered in the Bering Sea during March 1979.

Approach

Between 1-14 March 1979, we carried out a field study of the Bering Sea ice edge on board the helicopter-equipped NOAA ship SURVEYOR. Using the helicopter, we carried out ice property surveys along four lines extending 50 km into the pack. From the ship, we recorded oceanographic and meteorologic data. During this period, there were also several aircraft overflights of the ice edge. On our return to Seattle, we also gathered together all available NOAA and TIROS imagery for March 1979. Using the satellite and aircraft data, we prepared detailed ice charts for four days, March 2, 9, 15, and 25, covering a period at which the ice reached its maximum extent (March 15), to a time of dramatic retreat (March 25). For the same four days, comparison of the radiances from the 18 and 37 GHz channels on the SMMR showed that the SMMR resolves both the ice edge position and many of the interior ice features, such as the regions of low ice concentration south of St. Lawrence Island. Also, in cooperation with Drs. Per Gloersen and Donald Cavalieri, we are presently testing various sea ice algorithms against the March data set.

Current Status

At present, there is some ambiguity in the 37 GHz sea ice algorithm. The cause of this ambiguity is that the water vapor in storms which generally occur south of the ice edge appears in the algorithm as regions with low to medium ice concentration. This problem will be resolved by either a two-day average at the 37 GHz frequency, or by using the less sensitive to water vapor 18 GHz channel to filter out the clouds.

This work was jointly sponsored by NOAA and NASA.

ADVANCED OCEAN SENSOR SYSTEMS DEVELOPMENT

Principal Investigator: J. T. McGoogan, NASA Wallops Flight Center, Wallops Island, VA 23337. (804) 824-3411, Ext. 405, FTS 928-5405.

Long Term Interests: To further develop satellite altimetry and related instrument techniques towards supporting future missions and Oceanic Processes Program objectives. To advance the key technology required and to develop a physical unambiguous basis for interpretation and quantitative utilization of these microwave observations.

Specific Objectives: (1) Design end-to-end altimeter simulation system. (2) Begin development of new radar altimeter system exercisor for laboratory altimeter testing. (3) Identify hardware requirements for beamsteering. (4) Design new AGC scheme for future altimeters. (5) Simulate new tracker design for increased accuracy. (6) Update long range plans.

Approach: GEOS-C and SEASAT-A satellite altimeter performance data will be used as a basis for developing new AGC and satellite tracking concepts. These will be tested against known target areas to optimize the parameters for future missions. The Johns Hopkins Applied Physics Laboratory (Dr. Chuck Kilgus) will be involved in all the hardware developments, (beam steering, laboratory altimeter system), Applied Science Associates (Dr. Gary Brown), Apex, North Carolina will support theoretical studies for (multibeam and tracker design). Software developments and simulations will be investigated by David Hancock (WFC). Ray Stanley (WFC) will be the investigator for the AGC study. Craig Purdy (WFC) will be the investigator on all other tasks.

Current Status. A rough draft of 10 Year Plan will be available in August. AGC anomalies have been found and are being characterized from GEOS-C and SEASAT-A data. A new altimeter receiver has been purchased and is being tested.

Reply to EBC-8

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The long term objective of this program is the development and use of surface drifting buoys for empirical studies of the general circulation of the upper ocean and lower atmosphere, their exchanges of heat, momentum, and energy, and their low frequency, large-scale variability (i.e., climate).

The objective of this specific research task is a one-year planning study for the development and use of surface drifting buoys.

Six scientists and four engineers from seven institutions have joined in a collaborative effort to refine the scientific objectives, assess the state of hardware, communications, and data handing as applicable to measurements from surface drifting buoys, and to develop a plan and organize a cooperative effort to address the above objective.

The group's activities include two meetings, January and September 1981. The first meeting outlined the general approach to be taken, and individual and working group assignments were made. The final plan will be developed in the fall meeting. In the meantime communications between group members by the telemail system have been effective. The program is on schedule.

This work has been jointly sponsored by NOAA and NASA.

SHIP NAVIGATION WITH GPS IN SUPPORT OF PHYSICAL OCEANOGRAPHY

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Precise ship navigation is a key element in the success of shipborne acoustic profilers designed to observe near surface ocean currents. A "global" observation set describing ocean circulation can be generated if acoustic profilers can be integrated with a high performance navigation system designed ultimately for routine shipboard use. The NAVSTAR global positioning system is to be used for deducing relative ship positions; and hence, an averaged smoothed velocity estimate over a preselected time span. The shorter this time span, the higher will be the spatial resolution of the resulting ocean current data base. Achievable navigation accuracy levels will determine the time interval for differencing ship positions.

The long term objective of this investigation is to develop an integrated system which will 1) acquire acoustic profiler data, 2) acquire and process all navigation data with an onboard microprocessor, 3) apply a navigational correction to the acoustic profiler data; and, 4) display corrected ocean current velocities as a function of depth, in space and time. A GPS receiver set with suitable digital interfaces to a microprocessor incorporating advanced estimation and smoothing algorithms for precision navigation fixes is envisaged as the hardware system to perform the total navigation function. Integration of the navigation information with the acoustic Doppler log is to be accomplished by an independent processor which will interface with the navigation computer and the Doppler log.

Statistical analyses have been completed to assess accuracy levels achievable under state-of-the-art assumptions regarding GPS information available to the User. The analyses show that accuracies in the range of 1cm/sec to 2 cms/sec in smoothed ship velocity determinations over a 5 minute interval of active GPS coverage are realizable. In view of the encouraging result with regard to the accuracy of ship navigation using the global positioning system, it is imperative to demonstrate the navigation process in a real environment. The requisites of any demonstration are: 1) acquisition of raw data during sea trials, 2) overlapping coverage with an independent observation set, 3) comparative evaluation of the precision of navigation fixes and their differences over preselected time intervals. Conventional GPS operation will yield instantaneous position fixes which are prone to an uncertainty of 20 meters stemming from the various error sources inherent to the received GPS signals. The approach used in the investigation will account for dynamic motion of the ship at sea; and, will in an autonomous fashion yield smoothed position differences with an uncertainty in the range of 3 - 6 meters for sea states likely to be encountered during any experimental cruise.

"GPS Aiding of Ocean Current Determination" American Astronautical Society Paper 81-208 accepted for oral presentation at the AAS/AIAA Astrodynamics Conference, Aug 3-5, 1981, Lake Tahoe, Nevada.

ADVANCED EARTH ORBITING RADIO METRIC TECHNOLOGY DEVELOPMENT

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To realize the full scientific potential of the TOPEX altimeter requires knowing the radio position of the satellite to the decimeter level. Providing such high precision orbit determination with existing navigation systems (e.g., lasers) would require extraordinary improvements in some elements of these systems. The two major problems with the current baseline laser system is poor coverage (~20%) and relatively large uncertainties in the gravitational field and other dynamic parameters.

During the past year a survey of radiometric tracking techniques was taken to see if any would be capable of providing 10 cm TOPEX position determination at a reasonable cost. Techniques that were selected for further preliminary study involved conventional Doppler using many (~35) stations and several interferometric techniques using the GPS Navstar satellites with either a few (~8) or many (~35) stations. Preliminary analysis shows that with nearly continuous (~80%) Doppler data it may be possible to obtain adequate orbit determination if some clock difficulties can be avoided and if the data can be used to tune the gravity field to the subdecimeter level.

The gravity field and other dynamical parameters can be eliminated from the orbit determination process if at least three range or range type measurements to TOPEX from different directions are made simultaneously. These range type measurements allow the position of TOPEX to be determined instantaneously from pure geometry. It appears that the most economical method of providing such range type data is to make measurements from the GPS Navstar satellites to TOPEX and to ground stations. If the data can be used to also solve for various clock parameters approximately eight ground stations will be needed. The influence of TOPEX, Navstar, and ground clock on the range type measurements can be essentially eliminated if 30-40 ground stations are needed. Preliminary analysis indicates that decimeter TOPEX postion determination is possible if the position of the GPS Navstars are known to approximately 1m. FY'82 studies will develop orbit determination capabilities, cost estimates, preliminary system designs, and demonstration plans for several candidate navigation systems.

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Long-term interests are directed to ascertaining quantitatively the ability of radar systems to measure relevant properties of sea ice and to determine the optimum parameters for radar systems that can make such measurements.

Little is known about the ability to use a C-band imager for monitoring sea ice. A C-band system is a requirement for the determination of soil moisture and it is possible that it might be useful for sea ice measurements. Numerous measurements of the radar backscatter from ice have been made in other frequency bands, but no data are available between 1.5 and 9 GHz. Our task is to acquire backscatter data of sea ice over a frequency range from 4 to 8 GHz to fill in the gap of missing data.

The University of Kansas helicopter-borne microwave active spectrometer (HELOSCAT) developed under ONR sponsorship is being modified to include operation in the 4 to 8 GHz frequency range. A cooperative series of experiments with representatives of the Canadian DEMR and other U.S. agencies has been planned to take place beginning in October 1981. In these experiments, backscatter measurements will be supported with intensive surface measurements.

At present, modifications to the HELOSCAT system are underway to add the C-band capability. The RF and system-control circuitry modifications, and new software for the microprocessor-controlled data acquisition system, have been completed. The work that remains between now and the first experiment includes final testing of the radar, packaging, and interfacing with the FAA and Canadian MOT to obtain a flight-worthiness approval for the modification to the HELOSCAT system.

ALTIMETER TIME DEPENDENT CURRENT STUDIES

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Long Term Objectives: To understand and develop techniques for the long-term monitoring and mapping of ocean current surface topography.

Specific Objectives: In the absence of an accurate geoid, the specific objectives are: (1) To investigate two-dimensional mapping of time-varying ocean current topography using Seasat data. (2) To use near-repeat altimeter passes in the Seasat data plus available ancillary data to investigate regions of known oceanographic signal. The bottom line is to determine limiting factors in the altimeter data for use with future altimetric missions.

Status: In order to map two-dimensional ocean current surface topography, it is necessary to combine data from different arcs. This involves removal of orbit error. Thus a small region crossing arc program was written to solve for a bias assigned to each arc by minimizing the crossing arc differences. Simulated orbits (such as Cutting, Born, and Frantink, 1978, JAS, XXVI, 315-342) indicate that for length scales less than 10000 km the radial orbit error is less than 10 cm, and hence sampling the orbit error over a 10-15^{o} box involves sampling at a length scale much smaller than the Nyquist length scale. Solutions over 10^{o} boxes in the Southeast Pacific between 10^{o}S and 40^{o}S, 220^{o}E and 250^{o}E show residual crossing arc standard deviations of 6-10 cm after calculation of bias corrections. With bias estimates removed from the data, small area mean sea surfaces can be constructed.

TIDES FROM SATELLITE ALTIMETRY

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Long Term Objectives: To solve for tides via satellite altimetry measurements, to convert these results to an estimate of the observed ocean tide as seen by conventional gauges, and to use the calculated results to estimate the energy balance, Q, and global dissipation of the tide.

Specific Objectives:

(1) Patagonian shelf: To compare an empirical solution for the M2 tide using Seasat data with a barotropic model of the tide using adjustable dissipation with a fit to near tidal frequency shelf modes calculated using the finite element method of Platzman. A key objective is an estimate of the shelf dissipation.

(2) Global tide: To compare an empirical solution for the M2 tide using Seasat data for areas of the world where the tide is large with a fit to the altimeter data using the test functions used in generating the M2 model of Parke and Hendershott with a fit to the altimeter data using the near tidal frequency global normal modes of Platzman.

(3) Pre-TOPEX: The models of Schwiderski and Parke and Hendershott will be compared. These models will be used as a test bed for calculation of energy fluxes from a tidal elevation field that is almost, but not quite, a solution to Laplace's Tidal Equations. Based on the results, locations for pre-TOPEX bottom pressure gauge measurements will be recommended.

Status: The complete Seasat altimeter data set was received in February. An initial empirical solution of the M2 tide on the Patagonian shelf has been obtained. The numerical shelf model awaits bathymetry data which is currently being digitized. It has been shown that it is possible to get a partial solution to the M2 tide whenever the tidal amplitude is large -- irregardless of orbit error. Final global results will await the anticipated improvement of the radial component of the orbit from 1.5 m RMS to 0.5 m RMS.

SENSITIVITY STUDIES FOR A SEA ICE MODEL

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Long-Term Interests: The long-term interests for which this task is a preliminary study include improved sea ice modeling, coupled ice-ocean modeling, and coupled ice-atmosphere and ice-ocean-atmosphere modeling.

Objective: The objective of this task is to determine the sensitivity of the sea ice thickness and concentration calculations in the model of Parkinson and Washington (1979, JGR, 84, 311-337) to such parameters as ocean heat flux, surface air temperatures, incoming solar radiation, incoming longwave radiation, shortwave albedo, longwave emissivity, atmospheric humidities, drag coefficient, and turbulent heat coefficients.

Approach: The Weddell Sea region of the Parkinson and Washington (1979) grid has been selected for a sequence of 14-month computer simulations with varying input values for the parameters of interest (ocean heat flux, surface air temperatures, etc.). Ice concentrations are initialized with values derived from ESMR satellite data, and ice thicknesses are initialized with values calculated from an earlier model run. The program generates plots of time sequences of calculated ice thicknesses and concentrations for two individual points and for averages over the entire grid. These plots, plus time sequences of total ice area, are compared to determine the most realistic outputs and those coming closest to reaching an equilibrium annual cycle.

Current Status: The computer program has been implemented, with the desired input fields. The computer runs for the ocean heat flux -- the first of the parameters to be examined -- are nearing completion. The heat flux was varied from 0 W m^{-2} to 40 W m^{-2}, with the result that the value yielding the most realistic simulation is 25 W m^{-2}. Ocean heat fluxes below 20 W m^{-2} do not provide sufficient energy to prevent the ice from attaining an unstable, continuing-growth curve; while ocean heat fluxes of 30 W m^{-2} and above result in almost the total disappearance of ice in the Weddell Sea by February of the second simulation year.

OCEAN WAVE MEASUREMENT BY ANALYSIS OF RADAR IMAGES OF THE OCEAN

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Long-Term Scientific Interests: Synthetic aperture radar (SAR) images collected by aircraft or satellite contain information on ocean surface phenomena on spatial scales from ~ 10 m to ~ 1000 km. Image brightness corresponds directly to the energy density (Ψ_{res}) of short gravity waves (~ 30 cm for SEASAT SAR) and to surface motions through Doppler effects. Our objective is to interpret brightness variations in terms of ocean phenomena which cause surface motion and spatially modulate Ψ_{res}, e.g. long gravity waves, current gradients, sea surface temperature gradients, winds, internal waves, ship wakes and surface films.

Research Task Objective: We are investigating the measurement of long ocean waves, particularly the directional wavenumber spectrum $\Psi(k,\theta)$, over the wavelength range from 80 to 600 m. Our objective is to assess the limitations of Ψ measurement by SAR and, within these limitations, to put SAR measurements of Ψ on a firm quantitative footing, both theoretically and experimentally including applications to wave evolution in coastal waters.

Research Approach: Our approach to wave measurement by SAR is to: i) compare Fourier transforms of SAR images with surface truth data to establish experimentally the conditions required to make ocean waves visible in SAR images and the relationship between the SAR image and Ψ, ii) model the radar wave-ocean wave interaction and; iii) apply the model to estimate Ψ from SAR images, comparing the results with buoy measurements. This research is done in collaboration with Drs. R.H. Stewart (Scripps/JPL), R.A. Shuchman (ERIM), F.I. Gonzalez (PMEL) and O.H. Shemdin (JPL).

Current Status of the Project: We are currently finishing our analysis of wave observations by SEASAT SAR and surface buoys during the 1978 JASIN experiment. Major conclusions are as follows:

1. SAR images yield estimates of dominant ocean wavelength and direction to accuracies of ~ 12% and 15° respectively.

2. Visibility of ocean waves in SAR images is largely limited by three factors: $H_{1/3} \lesssim 1$ m, inadequate SAR resolution caused by wave orbital motion and wind speed < 3 ms^{-1}.

3. For waves visible in SAR imagery, the simple assumption that SAR image brightness fluctuations are proportional to ocean-surface-height fluctuations is not far wrong and slightly better than proportionality to ocean-wave-slope fluctuations.

4. Focusing tests during the imaging process can resolve the 180° ambiguity usually present in SAR wave direction estimates.

5. Signal to noise ratio of Fourier transforms of SAR images correlates with $H_{1/3}$ allowing measurement of $H_{1/3}$ to ±3/4 m.

This research was jointly sponsored by ONR, NOAA and NASA.

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The long term interests of the principal investigator include the development of quantitative relationships between signals obtained by remote sensing, particularly synthetic aperture radar, and the properties and structure of surface waves and surface currents in the ocean.

This specific research task is concerned with the interaction of short wave components (at a fixed wavelength, as sensed by SAR) with longer waves and swell and with surface current shear. The investigation involves both theoretical analysis and experimental investigation, the latter in collaboration with Dr. Norden Huang's group at NASA-Wallops.

A number of results have been obtained at this point. One important finding is that the average energy level of these short waves is not influenced by the presence of swell, provided the regeneration time from the wind is long compared with the swell period. The importance of this result is that it enables the average return signal to be interpreted directly in terms of variations in surface current, whether or not a swell is present. We have also shown experimentally that if the regeneration time is short compared with the swell period, the short waves are suppressed on average by the swell. Further experiments and theoretical analysis will be required to quantify this effect. The presence of swell produces, in addition, modulations of the short wave energy density about the average (expressed by a modulation transfer function). This can be calculated successfully in some instances but not in others, particularly when the swell is short and steep. We are continuing work to resolve this problem.

OPTIMIZATION OF ACOUSTIC BACKSCATTER TECHNIQUES
TO MEASURE CURRENT PROFILES FROM MOVING VESSELS

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We seek to describe the variability of ocean currents on vertical scales longer than a meter and horizontal scales longer than a kilometer. We have developed an acoustic instrument which measures the relative velocity between a ship and the water by measuring the Doppler shift in acoustic energy which is reflected back to the ship by plankton drifting in the water. Time gating the echo allows the relative velocity to be determined as a function of depth. By adding the velocity of the ship over the earth to the relative velocity, the vertical profile of currents relative to the earth is obtained.

Our aim is to identify those factors limiting the accuracy and spatial resolution of measurements obtained with this system and to optimize its overall performance. High frequency motions of the ship caused by waves are known to produce a serious contamination of the data which must be reduced. We continue to explore methods to alleviate this noise.

The research consists of theoretical and field studies. The instrument has been deployed in conditions ranging from tranquil Equatorial waters to the heavy sea states of the winter time central Pacific. In most cases we have simultaneous observations from the acoustic instrument and a[illegible] iner[illegible] instrument from which the ship's motions may be deduced [illegible] current profiles obtained are being compared with simul[illegible] observations obtained with classical oceanographic tools.

We have demonstrated the capability to remove the [illegible]ation of current measurements due to wave-induced ship [illegible]. We are continuing to refine the processing and to e[illegible] means to include this processing within the acoustic ins[illegible]ment. The data obtained on our many cruises is under analysis and the results, both scientific and engineering, will be presented when complete.

DYNAMICS AND EVOLUTION OF GULF STREAM MEANDERS AND MID-OCEAN EDDY CURRENTS

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Long term interests are the dynamics of ocean currents and circulation and their variability: the elucidation of basic physical processes, the description and prediction of fields, modeling, and the application of physical dynamics to other oceanic scientific and practical problems. The long term goal of this research project is the development of a descriptive-predictive system for meso and large scale ocean currents in the near surface, thermocline and deep layers. The system is conceived to consist of an observational network (comprised of remote and subsurface sensors) and dynamical models (for interpretation and interpolation of measurements) united via the techniques of optimal estimation theory and four dimensional data assimilation.

Objectives: The research being conducted consists of dynamical and statistical modelling studies, and simulated and real oceanic field data interpretations relevant to regions of the western North Atlantic Ocean to contribute to i) an understanding of the local dynamics of the variable currents and to the role of these currents to the dynamics and transports of the general circulation, ii) the development of data acquisition assimilation and schemes for ocean models, and iii) the development of practical techniques for real time synoptic descriptions and forecasts for an arbitrary block of ocean.

The approach adopted involves the formualtion of optimal estimates for the state of the system and its evolution, derived from a combination of dynamical and statistical model forecasts with observations analyzed from a real time or simulated network (satellite observations and subsurface measurements). The dynamical model serves as an interpolation and extrapolation scheme for the observations, and as an interpretative device for relating sea surface information to subsurface currents and related fields. Studies are being carried out on existing data sets (POLYMODE and archived Satellite) and on model generated computer simulations. The simulation studies parallel the methodology developed recently within meteorology for satellite data assimilation.

Status and Progress: The dynamical models consist of a quasigeostrophic (q.g.) open ocean model to be coupled to a near surface layer model. The statistical model consists of a mixed space time objective-analysis scheme. The barotropic version of the q.g. model is applicable to altimetric studies, since surface height and stream function are geostrophic pressure fields; it has been used to develop the combined statistical and dynamical approach to optimal estimation and updating. Near surface layer modelling is underway and coupling experiments will be initiated shortly (collaboration with Dr. W. Garwood, NPS). With the baroclinic q.g. model a simulation of a mid-ocean western North Atlantic region is being carried out and real data analysis initiated. A composite real data set consisting of XBTs, floats and current meter measurements (POLYMODE) and GEOS-3 altimeter and archived satellite SST has been collected (collaboration with Drs. N. Huang, NASA, and G. Maul, NOAA, AML). Interaction with scientists at NASA Goddard SFC is ongoing both because of overlapping interests and because of the expertise in Dr. M. Halem's group in analogous problems of atmospheric modelling and data assimilation. This research is supported approximately ½ NASA, ½ ONR, exclusive of computer time.

Remote Sensing of Floe Size Distribution and Surface Topography

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We wish to define and observe physical parameters which affect the large-scale state and behavior of sea ice. Remote sensing is a promising tool for making ice observations over suitably large regions and with enough repetition to document changes in ice conditions. Many properties of the ice cover are irregular and can be studied by stochastic rather than deterministic models. Useful measurements require that attention be given to sampling procedures.

The present research concerns two geometrical aspects of sea ice: the distribution of floe sizes and the properties of the ice surface. The first topic has application to questions of heat exchange and ice melt; the second to ice thickness and to the appearance of the surface to sensors such as radars. Related work, sponsored by ONR, has used SEASAT-SAR data to study the piece-like structure of the ice velocity field, which affects both the momentum balance and the mass balance of the ice.

The ice surface is rough and disorderly. Profiles of the surface h(x) have been studied previously. The interest here is to develop a two-dimensional stochastic model of the surface h(x,y), and to test it with surface data. Are the height distribution and spatial autocorrelation function sufficient to characterize the surface, or is there some additional property that describes the linear nature of pressure ridges? This work has not been started.

The study of floe size distribution has several objectives: to interrelate the several useful definitions of floe size distribution; to relate various procedures for sampling (at points or along a line, or within an area); to clarify how large samples must be to give satisfactory estimates of the underlying distribution; and to document from satellite and aircraft images the change in the distribution as break-up and melt proceed. The work is largely completed, using LANDSAT and U-2 images. The measurements involve sizing each floe by finding the largest circle that can be inscribed and counting floes in several size categories. Observed distributions are close to power laws with the smallest floes most numerous, and becoming more numerous as the break-up proceeds.

INTEGRATION OF NAVIGATION INSTRUMENTATION (RTOP No. 146-40-16(B))

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Long-term interests are centered on applications in physical oceanography and marine geology/geophysics. In the first field, the focus is on the measurement of open-ocean currents. This is in cooperation with Scripps Institution of Oceanography (SIO) where an acoustic doppler log is being developed for this application. In the other fields, the emphasis is on marine gravimetry and seismology and on detailed seafloor investigations. This is a cooperative effort with Lamont-Doherty Geological Observatory (L-DGO). In all of these activities, precise knowledge of ship velocity and/or position is required. The necessary accuracies are approximately 1 cm/s and 10 m, respectively. These accuracies are now approaching attainability on a routine daily basis using the NAVSTAR Global Positioning System (GPS), which is presently in a developmental stage as an outgrowth of the TRANSIT system.

The objective of this task is to provide an integrated NAVSTAR GPS navigation system to support oceanographic research by a variety of investigators. This involves minimizing the volume and weight of the GPS user equipment which consists of a user navigation set and a support system. The equipment is being packaged for transportability, with specific goals of low shipping costs and good shipboard accessibiity. The objective also involves a management and maintenance responsibility over the equipment and software.

The approach has been to obtain a GPS user set and supplement it with a Hewlett Packard 1000 F series computer system and peripheral hardware for support, data logging, and investigators' use as a tool for near-real-time processing and display. Ultimately, the H-P computer will replace two digital processors that normally are part of the standard configuration. The functions of these processors; i.e., navigation equation solution (YASCP) and user test data formatting and display (UFTIN); are to be combined within the H-P system.

A GPS Y-set has been received under an agreement between the Office of Naval Research (ONR) and the Air Force Space and Missile Systems Office. Provided by the latter agency, it is one of the GPS Phase I Magnavox user equipment sets. The H-P 1000F system, including a floppy disk, graphics printer/plotter, graphics terminal, and a 1600 cpi magnetic tape transport, has been integrated with the set. Until FY-82 the GPS navigation processor will remain in the configuration. It will output data to the H-P computer which will display and record user desired information. The GPS equipment has been shipped to L-DGO for test and preparation for deployment near the start of FY-82. The next known deployment following this will be by SIO in the Spring of 1982.

C-2

SAR Sensing of Ocean Surface Roughness

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Long Term Interests: To better understand the transfer function between the ocean surface wave field and the wave-like patterns observed in Synthetic Aperature Radar (SAR) Imagery.

Objective: Develop an ocean/SAR expression such that the received radar signals can be interpreted in terms of the ocean surface wave field and ocean currents.

Approach: Development of a two-dimensional model relating the ocean wave field to the SAR received signals, including the effects of ocean wave motion and ocean currents on the image formation process. Futhermore, the feasibility of developing a generalized radar cross-sectional modulation expression in terms of radar wavenumber direction relative to the wave field wavenumber direction and the anisotropy of this field will be investigated. This expression will be evaluated for a range of ocean and radar parameters for comparison with specially processed intensity modulation measurements furnished by ERIM.

Status: The two-dimensional model has been developed. The generalized radar cross-sectional expression is currently being investigated.

DIAGNOSIS OF OCEAN CIRCULATION AND
APPLICATION OF RADAR ALTIMETRY

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The main objective of this investigation is the development of techniques for determining the ocean general circulation with the application of radar altimetry and other advanced data-collection systems. The promise of radar altimetry is that the surface pressure field of the ocean can be known, and the application of geostrophic flow theory is hoped to greatly improve our ability to know the general ocean circulation, particularly the vast transports of heat and water masses accomplished by the oceans. This study specifically examines the nature of the geostrophic and Ekman relations in the upper ocean, and the expected quality of their application to the problem of determining near-surface currents, upwelling and heat transport.

A high resolution numerical model simulation of the Atlantic Ocean was obtained from NOAA/GFDL through Dr. K. Bryan. The surface pressure is calculated from the model output to simulate the data available from satellite altimetry. Subsequent application of the geostrophic and Ekman theories is used to re-construct a surface flow field which can be compared to the original model output. We are examining the quality of the surface flow diagnosis, the calculated upwelling, and the heat advection at the surface. A high degree of skill is seen throughout the basin, both in the flow itself and in the evaluation of advective heating of the surface waters.

This work is being transferred to another task which will explore the effects of time-averaging, and which will examine deep diagnostic procedures such as the beta-spiral and geophysical inverse techniques.

UPPER OCEAN DYNAMICS

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The long term objective of this study is the development of means for understanding sea surface temperature distributions so that application can be made of an enhanced ability to monitor SST and surface winds from space. This includes a study of the role of ocean dynamics in driving SST away from a thermodynamic equilibrium with the atmosphere, and the concomitant sensitivity of such ocean flow to variations in the wind field. Specifically, we are interested in the dynamics and thermodynamics of the upper ocean, and especially the tropical Atlantic - through involvement in the Seasonal Equatorial Atlantic (SEQUAL) and French Atlantic Ocean Climate (FOCAL) field experiments.

Three lines of inquiry are being followed:

a) Long-term mixed-layer modeling utilizing an analytic time-marching technique which allows multi-year runs. Studies of the effects of the diurnal cycle and of initialization methods have been made. The technique allows for use of a time history of SST and wind stress to initialize temperature profiles down to 150 m to 50.

b) Hydro- and thermo-dynamic modeling of tropical flow. A primitive equation layered model has been developed which uses 1-dimensional mixed-layer physics to control the surface layer thickness. This model calculates temperatures and currents for two layers above the main thermocline. Mutli-year runs are being made of the tropical Atlantic with wind stresses which repeat the mean annual cycles. Sensitivity of the results to the wind specification is determined through perturbations to the "normal" wind field.

c) Studies of satellite retrievals of SST. The NIMBUS-7 SMMR and Meteosat IR SST retrievals are being examined in collaboration with the NIMBUS project team and French experimenters on FOCAL. The onset of cooling in the Gulf of Guinea is being studied.

MESOSCALE OCEAN DYNAMICS: MARSEN

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Long Term Interest: (1) Investigate the dynamics of capillary and short gravity waves and their dependance on wind speed long ocean waves, current, atmospheric stability and surface contaminants. (2) Understand the mechanisms of radar backscatter from the sea surface. (3) Provide insight on SAR imaging of ocean surface features. (4) Utilize SAR for investigating near-surface oceanic processes such as surface waves, wind and current.

Specific Investigation Objective: (1) Provide a data library for U.S. investigators. (2) Analyze data acquired with the JPL Wave Follower on short wave slopes and near surface wind profile. (3) Process L-Band SAR images collected during the MARSEN experiment.

Approach: The approach followed is one of a coordinated set of investigations on both theoretical and experimental grounds to understand the dynamics of surface waves, radar backscatter from the sea surface and imaging of ocean surface features with real and synthetic aperture radars. The approach requires careful planning in advance of the field operations and continued coordination in the data analysis and reporting phases of the effort.

Current Status: The data reduction phase is completed; the MARSEN investigators are now preoccupied with data analysis and reporting of results. It is anticipated that 35 papers will be produced on various aspects related to MARSEN scientific objectives. The U.S. investigators will present their contributions at a Special Session on MARSEN at the 1981 Fall American Geophysical Union meeting in San Francisco.

DETECTION OF OCEANIC CURRENTS USING SEASAT SAR DATA

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Objective: To investigate techniques for detection of oceanic current motion by measurement of the SAR azimuthal Doppler frequency shift. This shift is caused by radial (line of sight) velocities. Results of this study will be the evaluation of an algorithm for current measurements using SAR. Included in the evaluation will be measurement accuracy estimates, and current values for the test areas.

Approach: The azimuthal frequency spectrum of the SAR data is measured using optical or digital techniques. Shifts in the position of this spectrum are used to infer the radial current velocity. Calculated velocities have been compared with *in situ* measurements and sources of error have been investigated.

Status: Currents on the order of 0.5 - 2.0 m/sec have been measured using aircraft X-band data with optical processing techniques. Distortions in the optically processed Doppler spectra for SEASAT data cause errors which mask the current measurement in most cases. The primary source of this distortion appears to be non-uniform illumination of the signal film. Preliminary experience with digitally processed SEASAT data indicates that currents on the order of 1 m/sec may be measurable under some conditions, although the SEASAT design is not optimal for this purpose.

This work is supported jointly by NOAA and NASA.

SAR DETECTION OF OCEANIC FRONTS

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Objective: The purpose of this pilot study was to begin to evaluate the utility of synthetic aperture radar (SAR) to detect oceanic fronts. The ability to remotely sense oceanic fronts provides useful information for studying biological productivity, pollution dispersion, and sonar propagation changes.

Approach: The study area for this work was at the mouth of the Chesapeake Bay. This site was chosen because the formation of fronts in the area is predictable. UPD-4 SAR data was collected by the U.S. Marines from 8-10 October, 1980, over the test area. Scatterometer, radiometer, laser profilometer, and side-looking airborne radar (SLAR) data was collected coincident with the SAR by other aircraft, while *in situ* oceanographic measurements were being made. In January, 1981, several passes of SAR data were collected over the test site by the Canadian Centre for Remote Sensing (CCRS) CV-580 aircraft equipped with the ERIM four-channel SAR. Surface observations for these flights consisted of surface and aerial photography.

Status: The above data set is currently being studied to determine the ability of a SAR to detect fronts. This study considers data collected both under a variety of radar system parameters, and varying environmental conditions. Once a detectability criterion is established, it is hoped that this knowledge will aid in the interpretation of existing SEASAT data. The analysis to date indicates that SAR can accurately image frontal boundaries under certain radar system and environmental conditions. It is hoped that additional analysis will better define the limitations of when SAR can be used to image fronts.

SEASAT SAR COASTAL OCEAN WAVE ANALYSIS

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Objective: The purpose of this study was to further evaluate the utility of the SEASAT SAR to image coastal gravity waves. The main objective of this past year's effort was to determine if the spatial variations in wavelength and direction observed over a 200 km area of SAR imagery could be explained by wave/current interaction theory.

Approach: Several methods of extracting gravity wave data from SEASAT SAR data were further evaluated. These included optical Fourier transforms, digital Fast Fourier transforms, and semi-causal (maximum entropy) techniques. Results obtained from each method were compared. Dominant wavelength and directional data was extracted from some 120 deep water points to document the wave field variability in the deep water areas of SEASAT Rev. 974.

Status: Further reduction of SAR data collected during Rev. 974 off Cape Hatteras, NC, revealed significant changes in wavelength and direction in deep water (>200 m) areas. Because of their location in deep water, these changes could not be explained by wave interactions with the bottom. It was determined, however, that the changes could be explained by several different factors. First, the source of the deep water swell was Hurricane Ella, which at the time of the SEASAT overpass, was located some 400 kilometers southeast of Cape Hatteras. The waves appear to be radiating from this source, with the longer waves arriving ahead of the shorter ones due to their greater phase velocity. Second, it was shown that the deep water gravity wave field interacted with the Gulf Stream current, resulting in a change of that field. These newly acquired deep water wave data were used as inputs into shallow water wave refraction models to test how well the SEASAT SAR imaged shallow water wave fields.

SHIP AND SATELLITE BIO-OPTICAL RESEARCH IN THE CALIFORNIA BIGHT

(Raymond C. Smith, Scripps Institution of Oceanography, University of California, La Jolla, California 92093, 714-294-5534).

The objective of this research is to observe, and subsequently to predictively model, the response of phytoplankton to oceanic processes by use of complementary ship and satellite (Nimbus 7-CZCS) data.

It has been demonstrated that data from the Coastal Zone Color Scanner (CZCS) on the Nimbus 7 satellite can be processed to provide quantitative chlorophyll maps of an oceanographic region that are consistent with independent shipboard chlorophyll determination within ± 40% (Smith and Baker (submitted for publication)). Also, the issue of how chlorophyll, as estimated from CZCS imagery, is related to the water column chlorophyll concentration has been described (Smith, 1981).

An optimized chlorophyll algorithm has been used to calculate the chlorophyll concentration in the Southern California Bight Region. A time series of chlorophyll images from this region, covering a three week period and concurrent with two oceanographic cruises, reveals complex and changing chlorophyll patterns and significant shifts in the mean chlorophyll concentration. We have examined the statistical properties of these chlorophyll distributions and addressed the question "how synoptic are shipboard measurements of chlorophyll based on a standard grid of sampling stations?" Further, these data have been used to develop an algorithm for estimating primary production from CZCS chlorophyll images (Smith, Eppley and Baker (submitted for publication)). In addition, the CZCS imagery has been shown to be a valuable tool for the study of mesoscale ecology of cetacea in the California Current (Dustan et al., in preparation).

Continuing objectives include a quantitative assessment of the spatial and temporal variability (patchiness) of chlorophyll over the entire California Bight region which will be used: to study the physical and biological processes leading to chlorophyll variability· to investigate the ecological and evolutionary significance of this variability, and its relation to the prediction of fish recruitment and the abundance of marine mammals; to investigate how phytoplankton patchiness affects our ability to detect significant spatial and temporal changes in abundance; and to study physical and biological phenomena that manifest themselves by changes in near surface chlorophyll concentrations including red tides, island mass effects, upwelling and excursions of current boundaries.

RADAR STUDIES OF THE SEA SURFACE

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Long-Term Objectives: Radio signals scattered from the sea surface carry information about processes operating at the surface and about undersea phenomena which influence the surface. My long-term objective is to use scattered radio signals to study surface waves, current shear at the surface, geostrophic currents, and oceanic rainfall.

Specific Objectives (Waves and Currents): Working with colleagues at Stanford University, we observed backscattered dekameter radio waves from the sea surface at grazing incidence during the Jasin experiment in the NE Atlantic, together with wind speed and wave height using anemometers and buoys. The radar observations show that the directional distribution of freshly generated waves is narrow and closely aligned with the mean wind direction. The current shear in the upper few meters of the sea, calculated from the radar observations of wave velocity, is consistent with theoretical estimates based on wind and waveheight measurements.

(Oceanic Rainfall): The development of techniques for remotely measuring oceanic rainfall is hampered by a lack of accurate means for calibration. Rain gauges on ships are notoriously inaccurate, and shipborne radars are expensive and not sufficiently developed to yield accurate measurements. Noise produced by rain falling on the sea may offer a new method for calibrating rain rate. A graduate student working with me at the Scripps Institution of Oceanography, J. Nystuen, has surveyed the literature and concludes the technique has merit. He is now measuring rain noise in a laboratory tank and expects to begin a field study upon completion of this work.

(Geostrophic Currents): I am at present the development flight project scientist for TOPEX, a proposed new altimetric satellite for measuring surface geostrophic currents. (See Yamarone: TOPEX).

Development of An Algorithm for Removal of Directional Ambiguity From Microwave Scatterometer Surface Wind Measurements For NOSS

V. E. Suomi, Principal Investigator
D. P. Wylie and B. B. Hinton, Co-Investigators

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The general objective of this task is to study the characteristics of an improved scatterometer. Like the scatterometer on Seasat the directions of the recovered surface winds are ambiguous. Specifically, our objective is to devise a reliable method of removing this ambiguity without the use of an external data source.

The approach is to combine the skill of the instrument and statistical properties of wind fields. The best alias is selected as that closest to an objectively analyzed wind field at each measurement point. The analyzed field is formed from the most probable vectors. Final choices are the result of an iterated application of the process outlined.

Currently the algorithm is undergoing final evaluation on a set of simulated NOSS scatterometer data.

Enhancement of Seasat Windstress Measurements
Using Data from GOES

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Long-term interests include the extension of the coverage and improvement in the quality of meteorological data and the development of new methods of extracting information from the observations.

The objective of this program is to enhance the utility of the Seasat scatterometer. The approach is the provide external directional information from tracking low-level cloud motions which is used to remove the directional ambiguity from the scatterometer winds. A semi-automated editing scheme has been developed allowing us to study the application of larger scatterometer data sets to air-sea interaction "events" (i.e. storms) and as a climatological data source. Currently information on the validity of using cloud motions to infer information on surface winds has been obtained (Wylie, Hinton, Millet 1981), and a case study of storm Hope completed.

This work is jointly sponsored by NOAA and NASA.

ADVANCED OCEAN SENSOR SYSTEMS DEVELOPMENT

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The interest has been to develop precision passive microwave devices and algorithms for the remote sensing of the ocean and ice. Aircraft were utilized as platforms to collect field data for developing unambiguous and accurate geophysical retrievals. The activity will be phased out during the next fiscal year.

Examples of specific investigation objectives include the development of specialized sensors to measure ocean temperature to within an absolute accuracy of 1°C: salinity to well within an accuracy of 1 ppt. By utilizing a two frequency radiometer system, it has been demonstrated that temperature and salinity can be synoptically measured to within the accuracy cited above. This was first shown in 1976 during overflights of the Chesapeake Bay, and more recently during four flights conducted at the mouth of the Savannah river. The latter flights were conducted at various times of the tidal cycle in order to observe the dynamics of the salinity wedge. These flights were conducted in the fall during low run-off conditions. In the spring of 1980, similar measurements were made over the Georgia Cost during high run-off conditions to complete the Georgia activity. A follow-up mission was conducted to support the Nantucket Shoals experiment, and to participate (with Woods Hole Oceanographic Institution) in a pilot Warm Core Rings experiment.

In order to improve the accuracy of salinity measurement ($\sim$ 0.1 ppt.), a UHF radiometer was designed and components have been ordered. This radiometer will be completed and flight tested in a Warm Core Rings experiment during the phase-out period.

MICROWAVE REMOTE SENSING OF ICE PROCESSES

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The objective of this research was to develop combined active and passive microwave remote sensing techniques for classification of polar ice, and will be phased out as a Langley activity during the next fiscal year.

The objectives are to analyze active and passive microwave data in hand. The specific data of interest relate to a 1979 expedition to the Arctic in the vicinity of Alaska and the Northwest Territories, the 1979 Norwegian Sea Experiment (NORSEX), the 1981 Great Lakes Mapping Mission, and a limited amount of Satellite Measurements (SeaSat).

The approach to the data reduction has been to work closely with the other principal investigators to establish priorities, agree on the data products to be supplied by each investigator, and to conduct workshops to report the data.

During the past fiscal year, a NORSEX data book has been prepared and distributed to all principal investigators. Based on these results, a NORSEX I paper has been prepared for submission to a journal. This paper supports the notion that combined active/passive microwave techniques can be used in concert to subclassify ice types. Additional activity has included the preliminary analysis of SeaSat active/passive signatures, analysis of an anisotropic active/passive signature associated with the Greenland ice sheet, and investigation of a passive stepped-frequency technique of subclassifying ice types.

APPLICATION OF SURFACE CONTOUR RADAR TO OCEANOGRAPHIC STUDIES

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Long Term Interests: Establish in the oceanographic community the validity of the directional wave spectra produced by the SCR and to investigate such things as electromagnetic (EM) bias, SAR and SLAR data interpretation.

Specific Objectives: (1) Finalize the computer processing techniques so that SCR elevation data from multiple flight lines may be processed in a "hands-off" mode to produce a composite spectrum whose quality has been verified through comparison with in-situ sensors. (2) Determine the evolution of the directional wave spectrum under fetch-limited conditions for winds of approximately 10 and 20 m/s. (3) Acquire additional simultaneous EM bias data with the NRL 10 GHz radar under a variety of conditions. (4) Acquire additional 200 m altitude data in a 13° bank for generating the transfer function between sea surface topography and radar backscattered power to be used in SAR and SLAR data interpretation. (5) Acquire simultaneous data with a SAR.

Approach: Utilize the unique capability of the SCR to produce two perfectly registered maps, one of topography and another of radar backscattered power to: (1) measure oceanographic parameters directly and (2) evaluate the ability of satellite systems to measure them remotely. SCR data will be compared with in-situ sensors, other remote sensors, and the results of simulations.

Progress: (1) Preliminary reduction of all data taken during ARSLOE has been accomplished and programs has been developed to correct the spectra in k-space for the effects of aircraft ground speed and drift angle. A procedure has been developed and demonstrated graphically which combines the corrected spectra from orthogonal flight lines to produce a composite spectrum without the poor lateral resolution of an individual spectrum due to the narrow swath (100-400 m) compared to the 5 km along-track dimension. (2) All of the appropriate SCR data to date have been processed to extract EM bias values. Using mean values for each of 12 observational days to more nearly represent a satellite altimeter average over a large area. there was no apparent trend with either SWH or skewness but the magnitude of EM bias tended to increase with increasing kurotsis. The magnitude of the EM bias also tended to increase with increasing wind speed and increasing significant slope and decrease with increasing dominant wave length. The mean EM bias value was -1.1% of SWH and the standard deviation was 0.35% of SWH. A linear regression analysis in terms of kurtosis and wave length reduced the standard deviation to 0.14%. (3) At ARSLOE there were 3 coincident flights of the SCR and Army SLARs. Dave Lichey of CERC recently turned over the photographic SLAR imagery to F. I. Gonzalez of NOAA PMEL for processing and interpretation. A joint paper on the SLAR-SCR spectra intercomparison should be ready for publication sometime this Fall.

OPTICAL PROPERTIES OF TURBID COASTAL WATERS

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Our long-range interest is the development of reliable data analysis procedures for the identification and quantification of various water constituents from passive remote-sensing data. One reason for unreliability of most present concepts is the lack of detailed scientific understanding of the two-fold marine optical physics process in which changes in water chemistry and physics create changes in underwater optical properties which in turn cause changes in the upwelled radiance being measured by the remote-sensing instrument.

The major objective of this investigation is a fundamental understanding of the marine optical physics process. Definition of the effects of various major water constituents on the remote-sensing signal and the development of a technique for monitoring remote-sensing penetration depth are also objectives.

The approach for this investigation is to make both laboratory and field measurements of four underwater optical parameters, three remote-sensing parameters, and a number of physical-chemical properties for each sample of water at visible and near-infrared wavelengths. Tests have been conducted on a number of water samples representing a wide variation in water chemistry and turbidity. Underwater optical parameters have been input to several existing analytical models to test their validity and limitations for calculating reflectance.

The initial phase of the investigation has been development of a system of instruments for measurement of the spectral variation of beam attenuation coefficient, absorption coefficient, and volume scattering function for turbid waters to complement existing instruments. This phase is essentially complete. Measurements have been completed on waters with beam attenuation coefficients between 1 m^{-1} and 75 m^{-1} with different combinations of inorganic suspended sediment, particulate organic carbon, dissolved organic carbon, and chlorophyll *a*. These data are presently under analysis. During 1980 and 1981, five journal articles have been published (or accepted for publication) describing results of this research.

SMMR ALGORITHM REFINEMENT TASK

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Long-term interests: The precise measurement of sea surface temperature and wind speed at the ocean's surface are critical elements in understanding the global energy and momentum balances which, in turn, determine the Earth's climate.

Specific objectives: The purpose of this task is to refine the algorithms used for retrieving the temperature and wind speed at the ocean surface, to improve their accuracy, to understand their limitations and, where possible, to reduce those limitations.

Approach: A calibration algorithm was derived for the Nimbus-7 SMMR based on available pre-launch instrument measurements. This calibration was incorporated into somewhat cleaned-up programs to reprocess the same two-month data set which had been processed earlier. New Geophysical algorithms were generated wherein the known correlation between water vapor and sea surface temperature was exploited to reduce the number of degrees of freedom and thereby reduce the sensitivity to errors in the brightness temperatures. This was accomplished by not permitting the air and sea temperatures to differ by more than 8°C in the ensemble of geophysical models used in generating the algorithm constants.

Current Status: Sea surface temperatures retrieved from SMMR were compared with GARP data buoys in the southern hemisphere. The RMS retrieval accuracy for three 1 month periods was approximately 1.5°C on a single pixel basis. The month-to-month bias change was only ±0.25°. For each month there were approximately 1000 independent comparisons extending over approximately a 0-30°C range.

In collaboration with Dr. J. Miller of Rutgers University wind retrievals were compared with the U.S. Navy Fleet Numerical Oceanography Center operational objective analysis products. Although the quantitative agreement was poor, the patterns were found to agree quite well although there were some spatial offsets. It is reasonable to assume that the feature locations in the SMMR data are more accurate than in the objective analysis for the particular time at which the SMMR observations were made.

THE USE OF SATELLITE REMOTE SENSING FOR THE IDENTIFICATION OF OCEAN FRONTS AND ITS APPLICATION TO ATLANTIC BLUEFIN TUNA UTILIZATION AND MANAGEMENT

Principal Investigators: Dr. Francis Williams, Professor, Division of Biology and Living Resources (305-350-7315) and Dr. George A. Maul, Adjunct Professor and Fellow, Cooperative Institute for Marine and Atmospheric Science (305-350-7384), Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, Florida 33149.

Long-Term Interests: To contribute to fisheries forecasting, and resource utilization and management through use of satellite remote sensing of the ocean as a primary input source.

Specific Investigation Objectives: Using available satellite systems, e.g. NIMBUS-Coastal Zone Color Scanner; TIROS, GOES, NOAA-infrared and visible; to integrate multispectral with infrared and visible remotely sensed data for the identification and study of such environmental dynamics as circulation, frontal history and ocean productivity. These ocean conditions are being correlated with distribution, movements, availability, catch, and spawning success of Atlantic bluefin tuna in North Carolina-Virginia coastal waters and in the Gulf of Mexico. Similar fisheries data are also being analyzed for other species including skipjack tuna (Katsuwonus pelamis), bluefish (Pomatomus saltatrix) and the sand lance (Ammodytes americanus).

Approach: Derived apparent relationships between environmental and fisheries variables will be cross-correlated with forcing mechanisms, such as surface transport, upwelling, mixing, winds, insolation, etc. Appropriate satellite imagery tapes, including CZCS, are being processed using the RSMAS-University of Miami's interactive computerized display system (black and white and color enhancement). Mr. Mitchell Roffer, a graduate student at the RSMAS, is involved in the project for his Ph.D. dissertation.

Status: Third year of project commenced 21 July 1981. Priority has been given to data analyses related to the rod and reel and purse seine fisheries for bluefin in North Carolina-Virginia coastal waters; in particular timing of "onset" and "end of season" and the distribution and availability of the tuna during the season. "Onset" of the fishing season appears to be related to formation of the surface mixed layer during spring warming and water column stratification. Arrival of bluefin tuna (and end of season) appears to be related to a surface mixed layer of approximately four meters (eight to ten meters) with sea surface temperatures of 19.0° C (24.0-26.0°C) and 17.5°C (24.0°C) at the top of the thermocline. Daily movements during the season appear to be related to changes in concentrations of forage (sand lance), which appear to be mediated by Chesapeake Bay plume frontal history and productivity. Analyses related to daily and weekly changes in the Japanese longline fishery for bluefin tuna in the Gulf of Mexico have shown that effort and catches have not been concentrated in areas of maximum sea surface temperature gradients i.e. the Loop Current. In addition to bluefin tuna, all other tunas, billfishes, and sharks caught on the longlines are being considered in the analyses.

DETERMINATION OF THE GENERAL CIRCULATION OF THE OCEAN AND THE MARINE GEOID USING SATELLITE ALTIMETRY

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Objective: The overall objectives of this project are to understand the capabilities of satellite altimetry and related measurements (e.g.; scatterometry) for the purpose of determining the general circulation of the ocean and its variability. We are exploring existing data and examining the prospects of future data--both altimetric and conventional--in order to determine optimum experimental schemes and optimum data handling procedures.

Specific Objectives: There are several specific tasks undertaken in the past year: (1) Determination, with the TOPEX Science Working Group, of an optimum set of scientific requirements for a future altimetric satellite mission. (2) Construction, by inverse methods, of an optimum gravimetric geoid in the North Atlantic for use with the altimetry. (3) Examination of the long wavelength components of SEASAT altimetry in the Pacific Ocean. (4) Construction of sea surfaces from hydrographic data for future use with altimeter surfaces. (5) Examination of accuracy and precision of scatterometer winds.

Approach Used: Our general approach to most of these problems is in the general context of inverse theory; i.e., a form of systematic model making.

Status: (1) The TOPEX Science Working Group has published its report and the PI remains in touch with current NASA efforts to examine the feasibility of a mission. (2) V. Zlotnicki is continuing his thesis work on constructing a gravimetric geoid. The procedure is described in a paper by Zlotnicki, Parsons and Wunsch (1981) and involves using inverse theory to produce an optimum surface. The thesis should be complete in 1982. (3) A part-time, post-doctoral staff member, C-K. Tai, is comparing the long wavelength components of the GEM10 geoid, which are known with high accuracy, with the long wavelength components of the altimetric surface constructed by cross-arc methods from SEASAT, to see if the overall trans-Pacific oceanographic "head" is apparent. This work is at too early a stage to know the outcome. (4) Our model making of hydrographic circulation continues (jointly supported by NSF). Roemmich and Wunsch (1981) have elaborated on the methods described by Wunsch and Gaposchkin (1980) to show how altimetry and hydrography would be combined together. (5) We are awaiting the release of direction corrected SEASAT scatterometer data before attempting any intensive look at the scatterometer winds.

TIMING AND DYNAMICS OF THE SPRING AND AUTUMN BLOOM IN THE GULF OF MAINE AND GEORGES BANK: ECONOMIC RAMIFICATION TO PELAGIC FISHERIES

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Perhaps the most exciting aspect in studying the Gulf of Maine is the diversity one finds in oceanographic features. Henry Bigelow, fifty years ago, made the point that it was this diversity operating in a semi-enclosed basin which gives rise to the immense and lucrative fisheries. The ability to study an area of this sort illustrates the difficulty which the oceanographer has in studying time and space problems. It is this difficulty which makes the satellite a valuable tool. Although the development of algorithms for measuring phytoplankton chlorophyll and resulting CZCS image processing have been slow, the images that have been processed have sent a message to the biological oceanographer: it is shear ignorance of ocean systems which allows us to make sweeping generalizations for major areas with a few scattered discrete sampling sites.

Within the Gulf of Maine we have identified the principal sites of intense primary production using shipboard and satellite, CZCS, images. Almost exclusively these are areas of intense vertical mixing where tidal activity interacting with the bottom is a principal source of energy. Most of the highly productive areas are productive because the frontal edges are baroclinic, that is, high density nutrient rich water is transferred upward into the frontal regions by considering light and nutrients as the primary regulations. The principal goal was to arrive at an estimate of the depth to which vertical mixing is optimal for phytoplankton growth and to verify this estimate using CZCS imagery. To do the latter we have measured radiance along pixels which transverse specific depth regions along the fronts. The imagery and the model agree that the optimal depth is about 60 meters. This is the depth where vertical mixing is arrested by bottom depth. We can only account for one half of this being the result of tidal energy. This is an important observation in that it is this depth of mixing which dictates the upper level of phytoplankton production. In the Gulf of Maine region four frontal regions have been tested; all have shown the same optimal mixing depth.

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Long-term interests of the Investigator

To understand the photochemical and photophysical behavior of dissolved organic matter and other photochemically reactive components of natural waters, especially of seawater.

Objective of this specific research task

"Initial investigations of seawater fluorescence/absorbance properties and their relevance to oceanic LIDAR interpretation" is an effort to understand the origin, nature, and natural variability of the fluorescence, absorption, and photochemistry of dissolved organic matter in surface seawaters. Oceanic LIDAR signals show strong but ill-understood return due to non-chlorophyll fluorescence of organic matter.

Approach utilized for this task

A variety of surface water samples are being taken from various open-ocean regimes for determination of fluorescence and absorption spectra and of fluorescence decay lifetimes. To compare the fluorescence/absorption properties of marine-derived vs. land-derived dissolved organic matter, open-ocean samples and samples with high marine input and little land input are stressed.

Current status and progress

A series of samples from the highly productive Peru upwelling region was obtained on Leg 3, Cruise 108 of R/V Atlantis II during March, 1981. In addition, extensive hydrographic information will be available for interpreting the chemical and biological state of the waters sampled. Initial results suggest that relatively stable, longer-lived materials dominate the fluorescence signature even at a site that is an intense source of marine-derived organic matter.

INITIAL INVESTIGATIONS OF SEAWATER FLUORESCENCE/ABSORPTION PROPERTIES AND THEIR RELEVANCE TO OCEANIC LIDAR DATA INTERPRETATION

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Long Term Interests of the Investigator:

Uncharacterized organic materials are one of the primary constituents responsible for the absorption of light and the abiotic fluorescence of seawater. The same materials possess interesting chemical properties which could make them significant modifiers of the chemistry and biology of the ocean's surface. The capability to use remote sensing monitors (i.e. LIDAR) to make large scale measurements of the fluorescence and absorbance contributions by these materials could greatly enhance our ability to understand their role in biological and chemical processes as well as, provide an additional tool for measuring physical oceanographic features.

Objective of Research Task:

The initial objectives were to determine the consistency of the fluorescence spectra in the excitation and emission bandwidths of interest. The dark and sunlight stability of the fluorescence and absorbance was also to be determined from both laboratory and field measurements.

Approach Utilized for This Task:

Seawater samples from various depths were collected from the Florida Current, the Gulf Current Loop, the Peruvian Upwelling region, the region of the Cromwell Current upwelling, and coastal waters of South Florida. The samples were characterized for abiotic fluorescence intensity, light absorbance, and for dark and light induced transformations of these properties.

Current Status:

This study was only recently started and much of the data has not yet been processed. The preliminary observations indicate that the abiotic fluorescence of seawater may provide a way of detecting upwelled-water. Fluorescence detection should provide two distinct advantages over temperature monitoring of upwelling: deeper survey measurements, and the ability to differentiate between true upwelling and ridging which is encountered in equatorial counter currents.

INVESTIGATION: ICE SHELF/ICE SHEET DYNAMICS AND SURFACE ELEVATION DATA SETS

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Long-Term Interest: This study has direct application for: (1) determining ice sheet mass balance; (2) monitoring changes in ice sheets and ice shelves; (3) understanding ice sheet/ice shelf dynamics; and (4) deducing past, present and future ice sheet/ice shelf behavior.

Objective: The main objectives are: (1) establishment of a readily accessible data set of ice sheet surface elevations; (2) delineation of major drainage basins and flowlines; and (3) investigation of the dynamic significance of surface undulations on ice rheology.

Approach: Altimeter recorded waveforms must be reprocessed to produce a corrected set of accurate surface elevation measurements. Corrections of measurement displacements, due to non-zero slopes, and orbit adjustments are applied to produce surface elevation maps with contour intervals consistent with data density. The fact that ice flows along the direction of maximum regional slope will be used to determine individual flowlines and delineate drainage basins. Spectra of surface roughness will be examined and compared with bed roughness spectra in corresponding regions to infer certain rheological parameters of ice.

Status: All Seasat data over Greenland and 80% over Antarctica have been corrected for tracker inadequacies in following a rapidly undulating surface. A preliminary elevation map of Greenland (<72°N) at a contour interval of 50 m has been produced. Map elevations agree well with available surface-based measurements. A second preliminary elevation map of Greenland (<65°N) from GEOS data has been prepared and differences between the two have begun to be examined for possible measurable changes in the ice sheet. A detailed 20 km x 200 km strip at 72°N has been contoured at the 2 meter elevation level to reveal a surface undulation field. Over 90,000 Greenland elevation measurements from Seasat have been organized into a data base comprised of latitude-longitude blocks of nearly constant data density to facilitate ease of data access for future analyses.

SECTION IV--BIBLIOGRAPHY

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