NASA Technical Memorandum 88987

NASA Oceanic Processes Program

Annual Report—Fiscal Year 1985

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NASA Oceanic Processes Program

Annual Report—Fiscal Year 1985

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

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TL521.3.I53 no.88987
#15174639 JUN 23 1997

National Aeronautics
and Space Administration

**Scientific and Technical
Information Branch**

1986

PREFACE

The present time is especially active regarding planning and implementation of capabilities for observing the oceans from space. The Navy's Geosat Exact Repeat Mission is due to begin this October and the prospect for data access appears good. We have signed an MOU with Navy regarding our provision of a NASA Scatterometer (NSCAT) to fly on their N-ROSS; also, the Navy will shortly issue an RFP to select the satellite contractor for N-ROSS. Implementation of ESA's ERS-1 mission is proceeding well, and ESA has just released an A.O. for the selection of science investigators. The Japanese have obtained approval for development of their ERS-1 mission. Implementation planning for our Alaskan SAR Facility (ASF) is proceeding well, and we have recently signed an MOU with ESA including the direct reception of their ERS-1/SAR data at the ASF. TOPEX, proposed as a joint mission (TOPEX/POSEIDON) with the French Space Agency (CNES), is NASA's highest priority science new start and is pending approval by Congress in the FY 87 budget; given Congressional guidance, we are prepared to issue an A.O. for selection of a science team and an RFP for the satellite contractor. We are supporting NOAA in their attempt to secure an industrial initiative for implementation of an OCI.

The heads of the ocean-related agencies, via the Ocean Principals Group, have agreed to develop a national long-range plan for ocean research, and we are supporting NSF as the lead agency in this endeavor. The greater oceanographic community is actively planning large-scale research programs--WOCE, TOGA, GOFS, and PIPOR--which will derive considerable benefit from the spaceborne capabilities described above. Within our own program at NASA, we have initiated an Ocean Data Systems Program and are working with the JOI Satellite Ocean Data System Science Working Group, in anticipation of the forthcoming flood of spaceborne observations. Finally, the two PBS-TV productions which were televised recently can only help in our collective effort to promote public awareness of the exciting opportunities and challenges, as oceanography moves into the next decade.

This, the sixth annual report for NASA's Oceanic Processes Program, provides an outline of our recent accomplishments, present activities, and future plans. Although the report was prepared for fiscal year 1985, the period covered by the introduction extends into June 1986. 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 to our report. We are particularly grateful to Penny L. Peters, Joint Oceanographic Institutions Inc., for editing this document.

Oceanic Processes Program
Code EEC
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Washington, DC 20546
202/453-1725

June 6, 1986

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SECTION I - INTRODUCTION

The overall goals of the Oceanic Processes Program are: (1) to develop spaceborne techniques and to evaluate their utility for observing the oceans, (2) to apply these techniques to advance our understanding of the fundamental behavior of the oceans, and (3) to assist users with the implementation of operational systems. We are working closely with the operational oceanographic community because many of the specific research questions being addressed by our program, when answered, will help provide an improved capability for the utilization of spaceborne techniques for operational purposes.

The program is organized into four components; they and their respective program managers are: (1) Physical Oceanography -- Dr. William C. Patzert; (2) Ocean Productivity -- Dr. Curtiss O. Davis; (3) Polar Oceans -- Dr. Robert H. Thomas; and, (4) Oceanic Flight Projects -- Mr. William F. Townsend and Mr. James R. Greaves. The science discipline program managers are rotators. In FY 86, Mr. Ernest T. Young and Dr. James G. Richman have taken over the Physical Oceanography Program, and Dr. Kenneth C. Jezek has taken over the Polar Oceans Program. Dr. Eni G. Njoku will be the program manager for the new Ocean Data System to deal with the growing activity in this area.

The distribution of NASA's FY 85 ocean-related funding is approximately as follows:

Jet Propulsion Laboratory	$ 5,700 K
Goddard Space Flight Center	4,700
Academic Institutions	4,900
Industry	500
Other Government Agencies	300
Miscellaneous	100
Total	$ 16,200 K

Additional funding that benefits the Oceanic Processes Program includes: $ 11.8M to initiate development of the NSCAT sensor and its associated data system, $1.0M for operational processing of NIMBUS-7 CZCS and SMMR data at Goddard Space Flight Center, and $2.0M for developmental activities related to the Pilot Ocean Data System (PODS) at Jet Propulsion Laboratory; this brings the total FY 85 budget of NASA ocean-related funding up to $31.0M.

Various Science Working Group (SWG) activities have been underway during the past few years and are outlined in Table 1. The focus has been on the definition of science questions addressable by particular ocean satellite sensors and the corresponding performance specifications for those sensors and/or associated data systems. A summary of the more recent SWG activities is given in Section II; written reports for each are available from NASA Headquarters.

Notable publications which have recently appeared include:

Baker, D. J. (ed.), 1985: Oceanography from Space: a research strategy for the decade 1985-1995, (Part II) proposed measurements and missions. Joint Oceanographic Institutions Inc. Special Report. 32 pp.

Brown, O. B., R. H. Evans, J. W. Brown, H. R. Gordon, R. C. Smith and K. S. Baker, 1985: Phytoplankton blooming off the U. S. East Coast: a satellite description. *Science*, **229**, 163-167.

Hovis, W. A., E. F. Szajana and W. A. Bohan, 1986: NIMBUS-7 CZCS Coastal Zone Color Scanner Imagery for Selected Coastal Regions. NASA Goddard Space Flight Center. 99 pp.

Maul, G. A., 1985: Introduction to Satellite Oceanography. Martinus Nijhoff Publishers. 599 pp.

Njoku, E., R. L. Bernstein, et al., 1985: Satellite sea surface temperature comparisons. Six articles presenting the results of the JPL sea surface temperature workshops. E. Njoku and R. L. Bernstein, (eds.). *J. Geophys. Res.*, **90**, C6, 11571-11651.

Stewart, R. H., 1985: Methods of Satellite Oceanography. Univ. of California Press., San Diego, CA, 360 pp.

PHYSICAL OCEANOGRAPHY PROGRAM

The Physical Oceanography Program continues to be focused on the oceanographic utilization of altimeter and scatterometer data. This Program emphasizes the development of improved spaceborne techniques to observe and study oceanic and meteorological parameters in the two areas of Ocean Circulation and Air-Sea Interactions.

The goal of the Ocean Circulation studies is to determine the global oceanic general circulation and its variability, heat content and thus, horizontal heat flux. The aim is to develop an improved understanding of the ocean's role in climate variability. The proposed TOPEX/POSEIDON altimetric mission, planned for launch in late 1990, forms the basis of this program. To provide a sound scientific framework for interpretation of the satellite data, emphasis is placed on theoretical analysis, modeling based studies aimed at assimilation of satellite and in situ data for research, and the analysis of historical data collected from space.

Significant accomplishments in Ocean Circulation studies during FY 85 include efforts from algorithm development to full utilization of altimeter data to investigate unique aspects of ocean variability. We are looking at pattern recognition techniques that can be used to identify and characterize eddy structure. Error analysis was, and will continue to be, an important part of the program. Error analysis includes: the identification of errors in precise orbit determination; and, the propagation of errors, generated in data assimilation, into ocean circulation models.

SEASAT altimeter data was used to determine the eddy distribution in the Southern Ocean. A new pattern recognition technique was used. A determination is being made as to whether mesoscale fluctuations provide the principle mechanism by which heat, salt and nutrients are transported meridionally across the Antarctic Circumpolar Current. Optimal filtering of altimetry data as input to various scales of ocean models was addressed. The value of integrating satellite infrared and in situ data with the SEASAT altimeter data for the purpose of studying mesoscale features has been demonstrated.

The Physical Oceanography Program, concentrating more of its resources on the analysis of satellite data and plans for future space missions, has phased out the development of in situ

instrumentation.

In mid-1986, NASA will release an Announcement of Opportunity (A.O.) soliciting science investigations that will utilize TOPEX/POSEIDON data. The investigations will be coordinated with the large, international oceanographic experiments planned for the early 1990's: the World Ocean Circulation Experiment (WOCE) and the Tropical Oceans Global Atmosphere (TOGA) Program.

The thrusts of the Ocean Circulation studies will continue to be: the analysis of historical altimeter data; the development of error analysis techniques; the development of optimum data assimilation; the development of ocean models primarily designed for using huge amounts of satellite data, particularly altimeter data. We must ensure that we are adequately preparing for full and effective use of TOPEX data.

NASA is anticipating the full release of all data from the Navy's GEOSAT Exact Repeat Mission. With raw GEOSAT data we will be able to test and evaluate new refinements in orbit determination. Our use of GEOSAT data to address ocean variability will provide assistance in preparing for TOPEX processing.

The goal of the Air-Sea Interaction studies is to determine the winds over the world's oceans with an accuracy sufficient to advance our understanding of the physical processes occurring in the layers of the oceans and atmosphere close to the sea surface. Specific objectives are to determine surface wind stress, ocean surface waves, air-sea fluxes of momentum and heat, and wind-driven ocean currents. The NASA Scatterometer (NSCAT), planned for flight aboard the U.S. Navy's Remote Ocean Sensing System (N-ROSS), scheduled for launch in late 1990, forms the basis for this program.

One of the main accomplishments in Air-Sea Interaction in mid-FY 86 was the selection of a Science Definition Team for NSCAT. This team was selected following rigorous competition in response to a NASA Announcement of Opportunity. During the NSCAT Program pre-launch phase, the Science Definition Team will make recommendations to the project engineers to optimize the design characteristics to best meet mission objectives. They are also charged with the responsibility for development of a Science Plan for the Mission.

In preparation for NSCAT, projects were undertaken to determine the intrinsic properties of gravity/capillary waves in the presence of gravity waves and wind field. In order to describe the statistical characteristics of the ocean surface, we are investigating the various dynamic processes that control the surface geometry.

Participating in the Frontal Air-Sea Interaction Experiment (FASINEX), NASA investigators collected data to study the dependence of electromagnetic scattering by the ocean surface at different microwave frequencies. (They will also determine the effects of large wave slopes and atmospheric stability on different Bragg scatterers.)

In support of the TOGA program we are studying the upper layers of the tropical ocean with the broad goal of understanding and learning to model the processes that determine sea surface temperature, with our focus on simulating those features that influence the atmopshere. Investigators are also forming an understanding of how errors, introduced in measuring wind stress, propagate through atmospheric model forecasting.

As with altimeter data, the Air-Sea Interaction program is dedicated to ensuring complete, effective use of scatterometer data. Individual projects deal with all aspects of this from error analysis to atmospheric model development which will have the potential for time continuous

assimilation of scatterometer winds.

The thrusts initiated for the Air-Sea Interaction program last year will continue. We will work to improve our understanding of the relationship between scatterometer winds and the sea surface wind field. Of particular interest will be the establishment of a sound physical basis relating radar backscatter to sea surface stress. We will soon be in a position to distribute SSM/I data (scheduled for launch in January 1987). The Ocean Energy Flux Science Working Group will assess the useful ocean parameters obtainable from SSM/I data. We are starting now to look at the entire scope of the effort required to first obtain air-sea data, put it in a usable form, ascertain its accuracy and then use it to drive simulation and analysis.

OCEAN PRODUCTIVITY PROGRAM

The goal of the Ocean Productivity Program is to improve our capability to measure the primary productivity of the oceans, its variability, and how it in turn influences the marine food chain, and global CO2 and biogeochemical cycles. Specific objectives are focused on improving the capability to determine phytoplankton abundance and primary productivity based on complementary satellite, aircraft, ship, and in situ obervations. The primary spaceborne measurements are ocean color from the present NIMBUS-7 Coastal Zone Color Scanner (CZCS) and the proposed Ocean Color Imager (OCI) and sea surface temperature from the NOAA Advanced Very High Resolution Radiometer (AVHRR). The NASA Ocean Productivity program focuses on maximizing the utility of these spaceborne and supporting aircraft measurements. Experiments are closely coordinated with Navy, National Science Foundation, and Department of Energy supported shipboard and in situ measurement programs to provide maximum scientific benefit.

In the last three years, major advances have been made in techniques used to determine chlorophyll pigment concentrations from the CZCS ocean color measurements. Among these improvements are the refinement of sensor degredation and calibration corrections, understanding the effects of enhanced scattering by particulates, and understanding the effects of absorbance by dissolved organic material on in-water algorithms. Processing capability for CZCS data has increased substantially with improved image processing techniques, software, and additional processing facilities. Procedures are being developed for compositing data from numerous satellite passes to produce ocean basin and global images. The availability of data is also rapidly improving with the establishment of a dial-up catalog and microfilm browse file search capability. Laser disk browse files are being developed which will greatly improve this process.

It is clear we can estimate chlorophyll pigment concentrations from CZCS data. The next step is to estimate primary productivity from ocean color and other remotely sensed parameters, with a minimum of in situ measurements. Several modeling efforts are underway to address this question.

An empirical model for estimating the vertical profile of ocean productivity from CZCS data has been developed using large in situ data sets. Several existing analytic productivity models are being investigated to see if they will work with only satellite data as the input. Regional scale modeling efforts focus on how to simulate intermittent time series of CZCS data in areas such as New York bight where there is frequent cloud cover. These models use in situ data from moorings to supplement satellite ocean temperature and color data. The models simulate the circulation and productivity between passes and then reset the model with each subsequent CZCS pass. Finally, we have initiated the development of basin scale models to assess the role of primary productivity in the ocean in the global CO2 budget.

Satellite ocean color and sea surface temperature distributions are now regularly used to guide seagoing oceanographic studies and to help put shipboard measurements in a larger oceanographic context. Beyond this, the processing and analysis of time series of temperature and pigment concentrations on a regional basis has been initiated. A five-year color and temperature time series for the West Coast of the U.S., and a similar time series for the entire North Atlantic are underway. The eventual plan is to process all available CZCS data to maps of chlorophyll distribution.

The third and final Sea Surface Temperature Workshop was held in February 1984 at the Jet Propulsion Laboratory (JPL). Workshop participants assessed the relative accuracies of various techniques used to derive mean sea surface temperatures and identified some systematic inconsistencies between observations. Reports from these workshops are summarized in a set of papers in the Journal of Geophysical Research, as listed on p. I-2. A follow-on International Sea Surface Temperature workshop was held in May 1985 in conjunction with the Spring American Geophysical Union meeting in Baltimore, Maryland. Results from that workshop should be available by summer 1986.

The development of airborne techniques to aid in oceanographic process studies, satellite ocean color algorithm development, and satellite data validation continues at the Wallops Flight Facility. The Wallops P-3 is equipped with an Airborne Oceanographic Lidar (AOL) which measures passive spectral radiance and laser-stimulated fluorescence emission spectra. This unique instrument is supported by a PRT-5 for surface temperature measurements, AXBT for temperature profiles, and ship to aircraft communication and data telemetry. The AOL is an expensive one-of-a-kind system. To make ocean color measurements more generally available, we have refurbished the Multichannel Ocean Color Scanner (MOCS) with a new state-of-the-art data system and it is available to fly on a variety of aircraft in support of oceanographic studies. Also, in a joint effort with NOAA, we are developing an inexpensive, reliable Oceanographic Data Acquisition System (ODAS) to make aircraft color and temperature data widely available to the oceanographic community.

POLAR OCEANS PROGRAM

The goals of this program are to use spaceborne sensors to determine the characteristics of the polar sea-ice cover, and to understand how sea ice is influenced by, and in turn influences, the atmosphere and ocean. Our immediate objective is to improve our capability of measuring from space the extent, type, movement, and surface characteristics of the ice cover. This involves detailed analysis of existing data from SEASAT and the NIMBUS series of spacecraft, airborne testing of new sensors, and collection and analysis of ground-truth data from the ice surface. In addition, we are supporting modelling programs which address two distinct problems: improvement in our understanding of remotely-sensed data, and large-scale modelling of sea-ice behavior. A major component of the program is to develop and assess interpretive algorithms for translating passive microwave data into estimates of sea-ice concentration and surface characteristics. The multi-frequency SMMR on NIMBUS-7, and SSM/I on upcoming DMSP missions, show greatest promise, and data from these sensors will have broad applications in both the scientific and the commercial communities. Consequently, our studies are closely coordinated with associated NOAA and ONR research and with Canadian investigators. We are also working with Synthetic Aperture Radar (SAR) data from SEASAT. These provide excellent high-resolution imagery of sea ice, and our next opportunity for acquiring similar data will be from ESA's ERS-1 mission with a planned launch in 1990. In addition, we have been investigating research applications of altimeter and SAR data over the ice sheets of Greenland and Antarctica.

The immediate objectives of the polar program are the development of techniques for extracting geophysical variables from satellite imagery. To that end, a prime focus of this year's activity has been research on algorithms for calculating sea ice concentration, type and velocity from active and passive microwave data. Considerable progress was made in using the statistical variation in brightness temperature between first year and multiyear ice to calculate ice type concentrations. Improved algorithms to correct for the effect of weather on the microwave signature have been used to better identify the ice margin. Attempts to enhance our understanding of basic scattering processes from sea ice were made by the analysis of data collected during in situ and airborne measurements completed during MIZEX. In addition, extensive use of a controlled environment facility at the Cold Regions Research and Engineering Laboratory was made to examine the radiometric properties of new thin ice, desalinated ice and snow-covered ice. These studies have increased our confidence in applying microwave techniques to oceanic problems such as polynya formation and their contribution to deep-water formation, the role of the marginal ice zone in vertical transport processes and the identification of leads and floe structure in support of operational programs through the ice pack.

We are continuing to prepare for the SSM/I by transferring the final software packages for the NASA Ocean Data System from JPL to the World Data Center-A (WDC-A) at Boulder, Colorado. Delays in the launch of SSM/I opened a window for testing the software on existing SMMR data. An added benefit of these tests will be to incorporate a complete set of SMMR antarctic data into the WDC-A archive by the end of this year.

The development of a research facility at the University of Alaska at Fairbanks was initiated to receive, process, analyze and archive SAR data from spaceborne instruments. Known as the Alaskan SAR Facility (ASF), the ASF will be capable of acquiring data from ESA's ERS-1, Japan's ERS-1, and Canada's RADARSAT. To that end, an agreement between NASA and ESA to provide for acquisition of ERS-1 data was signed in January, 1986; negotiations between NASA and the Canadian and Japanese governments are underway. The development of a key element of the facility, the SAR processor, has been undertaken by JPL. The processor will be a flexible, robust system operating at a one-tenth real time throughput rate. Speed is achieved by relying on custom hardware developed for the JPL Advanced Digital SAR Processor, while flexibility is maintained through the use of off-the-shelf computing and array processing hardware. NASA is preparing to issue a "Dear Colleague" letter that describes research opportunities for utilizing the ASF and invites the submission of research proposals in response to same. Successful respondents will constitute a science team who, along with their roles as research investigators, will also be responsible for guiding the development of the ASF, particularly the archival systems and the analysis function for extracting geophysical variables from SAR images.

Several groups are in the process of preparing responses to the ESA Announcement of Opportunity for acquiring ERS-1 data. The Programme for International Polar Oceans Research (PIPOR) published a description of its interest in SAR data over the Arctic Ocean and surrounding seas, and PIPOR as well as groups interested in polar glaciology and geology are actively drafting proposals to utilize SAR, radar altimeter and passive microwave radiometer data.

The Satellite Remote Sensing for Ice Sheet Research Working Group published its report in November 1985. The report details several new applications of satellite technology for studying the extent, topography and variability of the polar ice sheets. Satellite altimetry was recognized as a principal technique for ice sheet investigations and we are happy to announce that the Navy has agreed to release GEOSAT data collected over ice sheets. This

is an important data set that will serve as a bench mark for future altimetry missions such as ESA's ERS-1 and Japan's ERS-1.

Communications between surface field parties and ships at high latitudes to the rest of the world are limited by propagation disruptions and inaccessibility to most geosynchronous communications satellites. This year a plan was put forth to place radio transponders on polar orbiting satellites, the concept being to improve and complement existing communications channels by using the transponders as high data rate, high quality links. We are presently forming a science working group to determine the requirements of the user community and to assess the practicality of meeting their needs with a transponder system.

In the coming year, we look to several developments designed to ensure the continued acquisition and distribution of satellite data over the polar regions, the analysis of those data to geophysical variables and the application of that analysis to ocean and ice problems. In particular, the expected launch date of the SSM/I is mid-FY 87 and we are beginning to prepare a comprehensive validation plan for that project. A joint German/U.S. expedition to the Weddell Sea is scheduled that will provide a unique opportunity for collecting in situ observations of surface brightness temperature, dielectric properties and morphology of sea ice in the southern ocean. Most importantly, we look to continued progress in developing the Alaskan SAR Facility and anticipate increasing involvement of the scientific community for guiding its evolution.

OCEANIC FLIGHT PROJECTS

The objective of the Oceanic Flight Projects effort is to develop and implement major flight experiments and supporting instruments that meet the observational requirements of the Oceanic Processes Program. Currently, our major flight projects include the NASA Scatterometer (NSCAT) for flight in 1990 on the U.S. Navy Remote Ocean Sensing System (N-ROSS) and the Ocean Topography Experiment (TOPEX/POSEIDON), planned for flight in 1991. NSCAT, approved in FY 85, will provide accurate wind field measurements over the global oceans for three years while TOPEX/POSEIDON, a collaborative effort with the French Space Agency (CNES), being proposed as a new start for FY 87, will provide accurate surface topography measurements of the global oceans, also for three years. From a knowledge of the surface topography, it is possible to estimate ocean currents. With surface winds being a primary driving force for ocean currents, it will be possible to investigate wind forcing and the response of ocean currents. Together, NSCAT and TOPEX/POSEIDON will allow us to better understand how the atmosphere drives the circulation of the oceans, how the oceans in turn influence the atmosphere, and ultimately, the role of the oceans in climate.

OCEAN TOPOGRAPHY EXPERIMENT (TOPEX)

For the first time since inception of TOPEX definition studies in 1980, TOPEX was included in the President's budget submission to the Congress. It was proposed as a candidate new start for FY 87 to be conducted as a collaborative effort (TOPEX/POSEIDON) with the French Space Agency (CNES). Obviously, we are extremely pleased with the progress made with TOPEX/POSEIDON during FY 85, and we are hopeful that the Congress will approve the program as proposed thus permitting full-scale development of TOPEX/POSEIDON to be initiated this fall.

More specifically, during FY 85 the Phase B Satellite Definition studies with Fairchild, RCA,

and Rockwell were completed; the Geopotential Model Development effort being conducted as a collaborative effort between GSFC and the University of Texas was continued; the final report for the joint Phase B Study with CNES confirming the technical feasibility and scientific benefits of the proposed collaborative TOPEX/POSEIDON mission was published; the fabrication phase of the Altimeter Technology Model development effort was completed; a successful Cost Update Review and a successful New Start Presentation to the Administrator were conducted, both in support of consideration of TOPEX as an FY 87 candidate new start; and a Project Initiation Agreement (PIA) was prepared. All-in-all, it was a good year.

For FY 86, it appears that the key activities will be the continuation of joint studies with CNES; the selection of a single satellite contractor for the implementation phase; the release of an Announcement of Opportunity for selecting research investigations in support of achieving the scientific objectives of TOPEX/POSEIDON; the completion of Altimeter Technology Model performance testing; the continuation of Precision Orbit Determination and Geopotential Model Development work; the preparation of an RFP for a precision GPS receiver in support of the GPS Demonstration activity; and preparation of a Project Plan. In general, all of this work will be focused on preparing for a possible FY 87 new start. If FY 87 new start approval is obtained, TOPEX/POSEIDON could be launched in mid-1991, thus providing good overlap with NASA's Scatterometer (NSCAT; see below) planned for launch on N-ROSS in September 1990. Such a schedule would, for the first time, permit extended intercomparisons of the ocean's response (topography, as measured by TOPEX) to its fundamental driving force (winds, as measured by NSCAT).

NASA SCATTEROMETER (NSCAT)

FY 85 was a difficult first year for the NSCAT project, partly due to the announcement by Navy, mid-way through the Fiscal Year, that the N-ROSS launch date was being slipped some fifteen months, to September 1990, and due also to the fact that Navy has not yet contracted for the N-ROSS satellite development, thus forcing the NSCAT Project to make assumptions about the interface with the satellite in order to proceed with the development of the Scatterometer instrument. These problems, while outside NASA's control, led the Congress to "cap" NSCAT at $14M for FY 86, a reduction of $17.7M from our original request. The associated replanning efforts have resulted in our making significant adjustments to the Scatterometer instrument sub-system procurement approach, as well as stretching out the instrument development schedule by some six months and deferring full scale initiation of the data system development effort. Nonetheless, significant progress was made in FY 85 with contracts being awarded to Hughes for the TWT's and to Harris for the antennas. The first of three computers (a VAX 11/785) comprising the data system was delivered and is currently in active use. An Announcement of Opportunity to select a Science Definition Team was issued, leading to selection of fourteen Principal Investigators in mid-FY 86, who will, in addition to conducting specific research investigations with the data, advise the Project on implementation matters crucial to the scientific success of NSCAT. In early FY 86, a Project Requirements Review, as well as a Preliminary Design Review for both the instrument and data system were held.

For the balance of FY 86, the emphasis will be on continuing the development of both the instrument and the ground data system, as well as beginning the process of refining the science plans for NSCAT, based on the investigations actually selected for further definition. A contractor for the TWT High Voltage Power Supply will be selected and an RFP for the balance of the Radio Frequency Subsystem (RFS) will be released. Planning for a Project Confirmation Review will be initiated, in conjunction with the finalization of the Project Plan.

Support will be provided, as needed, to Navy, for their satellite contractor selection process. Generally speaking, all these activities will be directed at supporting the Navy's planned September 1990 launch date for N-ROSS.

Given the launch delay and funding limitations, NSCAT is off to a good start. The solid response from the community to the NSCAT Announcement of Opportunity was very encouraging. We are looking forward to an equally productive FY 86.

OCEAN COLOR IMAGER (OCI)

An Ocean Color Imager (OCI) is one of the three instruments identified by the Joint Oceanographic Institutions Inc. as essential for the major oceanographic studies planned over the next decade. In particular, the Global Ocean Flux Study (GOFS) outlined at a recent National Academy of Sciences Workshop requires an OCI.

The OCI also has many commerical applications for fisheries, offshore oil drilling and shipping. NASA is supporting NOAA in its effort to work with industry to build and fly a commercial OCI. NASA's role would be to develop a global data processing system and archive in support of GOFS and other science programs.

ALASKAN SAR FACILITY (ASF)

Three SAR-equipped satellites are planned for launch in the early 1990's. These are the European Space Agency's First Remote Sensing Satellite (ERS-1), Japan's Earth Resources Satellite (ERS-1), and Canada's RADARSAT. There is no provision for recording SAR data aboard ESA's ERS-1. Thus, as data are received by the satellite, they must be transmitted in real-time to ground receiving stations within view of the satellite.

In anticipation of needs on the part of the U.S. research community, NASA--in concert with NOAA and NSF--has considered various, general locations for a research facility, whose functions would be to receive SAR data, to process these data into images, to derive geophysical products from these images, to manage an archive for appropriate products and to serve as the focal point for a program utilizing SAR for both basic and applications research. From the collective agency perspective, research in the Arctic appears to offer the greatest potential benefit through the utilization of such SAR technology.

Several factors were considered in selecting a site for the facility. The consensus opinion of the agencies was that the facility should be placed in the hands of an organization primarily interested in the application of SAR technology to solving basic and applied research problems in the Arctic. Combining this requirement with the need to maximize reach over the arctic ocean, a site on the West Ridge of the University of Alaska-Fairbanks campus was considered an optimal site.

Funds to begin design and implementation of the facility have been authorized in the FY 86 budget and continue through FY 89. The highlight of the facility will be a new SAR processor currently under development at JPL. The processor will be capable of handling data from all three satellites, processing the raw data into images in about 1/10th real time. The entire facility is planned to be operational by January 1990, coincident with the launch of ESA's ERS-1.

PILOT OCEAN DATA SYSTEM (PODS)

The necessity of adequate and appropriate data archival and management systems to assimilate data from past, present, and proposed satellite sensors has become more pressing as we see our proposals for New Starts approved. The Pilot Ocean Data System at JPL, funded in conjunction with NASA's Information Systems Office (Code EI), continues to prepare for a transition from its present role as a developer of satellite ocean data systems technology to an ocean science support facility. This mission transition also entails a funding transition from Codes EI to EEC (the Oceanic Processes Program). The goal is the development of a distributed NASA Ocean Data System (NODS). PODS is envisioned as the prototype data archive and will become the JPL node of the NODS distributed system.

PODS has supported the Sea Surface Temperature Workshops with preparation of comparative data sets and analyses from Nimbus-7 SMMR, NOAA AVHRR & HIRS/MSU, and GOES VAS. An ocean color/temperature analysis capability has been developed, utilizing the University of Miami Display System Programs. The first year (1979) of the West Coast Color Temperature Time Series has been processed by Mark Abbott and Phil Zion using this software with support from the PODS staff and facilities. Development of plans to process DMSP SSM/I data for archival and research purposes is being developed in collaboration with NOAA's World Data Center-A in Boulder, CO. Work continues on improvement of data links connecting PODS to outside users. A prototype network should be completed in 1986.

Plans to develop a processing and archival system for SSM/I are being completed and results from the Third Sea Surface Temperature Workshop have been published. Development of remote work stations linked to PODS for working with large archived data sets efficiently will continue. Optical digital disk storage techniques are being implemented on an exploratory basis. These systems are expected to be a key part of future archive systems designed to handle the huge amount of satellite data anticipated in the 1990's.

As noted below under National and International Coordination, NASA--in concert with NSF, NOAA, and Navy--has established the Satellite Ocean Data System Science Working Group (SODSSWG). One of the objectives of this group is to advise on how best NASA, working through PODS/NODS, can best expedite the utilization of satellite data by the oceanographic community.

NATIONAL AND INTERNATIONAL COORDINATION

In the area of interagency coordination, aspects of the Oceanic Processes Program have been addressed during this past year by numerous groups within the National Academy of Sciences (NAS). Most notably, we at NASA participated in the interagency oceanography reviews recently conducted by the Ocean Studies Board (OSB).

We are also participating in the preparation of a long-range plan for Federal ocean research, an endeavor suggested at a meeting of the Ocean Principals Group, OPG (the group of heads of agencies which have involvement in oceanography, including representatives of NASA, Defense, State, and Interior). OPG sponsorship for preparing the draft plan offers the flexibility and the informality that is essential to developing a truly comprehensive and cohesive plan. The NSF has agreed to take the lead in working with other Federal agencies to prepare this plan. Following policy-level approval of the long-range plan, the NSF will arrange for its publication and distribution, in consultation with other interested agencies and the NAS/OSB. A review and updating of the plan, convening annually, will be presented to the Ocean Principals Group for their review each year.

We have also been working with the Joint Oceanographic Institutions Inc. (JOI) completing an overall strategy for the decade in order to meet the needs for spaceborne ocean observations. JOI, a non-profit consortium representing the ten academic oceanographic institutions which operate deep-sea-going ships, operates the Deep Sea Drilling Program under contract to the National Science Foundation. The second part of the two-part report, "Oceanography from Space, A Research Strategy for the Decade 1985-1995," has been published. Under the aegis of NASA sponsorship, the JOI Satellite Ocean Data System Science Working Group (SODSSWG) was established in 1985, including agency liaison representatives, with an overall objective to provide guidance and advice on how best the satellite and associated in situ data needs of research oceanographers and allied earth scientists can be met. (See page II-25 for SODSSWG specific terms of reference.) In pursuit of the committee's objectives, the SODSSWG has convened two meetings since November, 1985 and formed four panels for consideration of the following topics at issue: NODS, Networking, Archiving, and Non-NASA Flight Projects.

In the area of international coordination, we continue to work 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 (WCRP). Organizationally, JSC falls under the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU), while CCCO falls under the Intergovernmental Oceanographic Commission (IOC) and the Scientific Committee on Oceanic Research (SCOR) of ICSU. Principal components of the WCRP upon which we have centered our attention are the World Ocean Circulation Experiment (WOCE) and the Tropical Ocean/Global Atmosphere program (TOGA). Our potential contribution to WOCE and TOGA would involve the utilization of satellite techniques (such as altimetry and scatterometry, discussed in Section II) 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 addition, we are exploring potential contributions which satellite techniques might make to the Global Ocean Flux Study (GOFS) and the Program for International Polar Ocean Research (PIPOR). For GOFS, the use of an Ocean Color Imager (OCI) could assist in improving our estimation of global primary productivity. For PIPOR, the use of microwave radiometry and synthetic aperture radar could assist in improving our understanding of polar ice cover and its growth and movement.

Table 2 (see page I-13) outlines national and international ocean-related spacecraft activities for the next decade, which are at various levels of planning and development. (In addition to the acronyms and definitions accompanying Table 2, we have included a brief paragraph describing each of the spacecraft listed and commenting on their present status.) We are exploring potential areas of mutual interest with sponsors of these spacecraft, being particularly interested in determining the extent to which we might pursue cooperative work and provide mutual access to appropriate spaceborne data. We would like to note that we have recently concluded an agreement with the European Space Agency (ESA) including direct access to ERS-1 SAR data by the Alaskan SAR Facility, located at the University of Alaska at Fairbanks. Briefly, the agreement provides a basis for direct readout of SAR data within coverage of the ASF, as well as the exchange of data sets such as from the NASA Scatterometer aboard N-ROSS, the ESA Scatterometer aboard ERS-1, and NASA's Shuttle Imaging Radar.

TABLE 1

RECENT NASA SCIENCE WORKING GROUPS

SCIENCE WORKING GROUP	CHAIRMAN	ESTABLISHED	REPORT
Satellite Ocean Data System Science Working Group	D. James Baker, JOI	Nov. 1985	
Ice Sheet Science Working Group	Robert Thomas, RAE	Apr. 1984	Nov. 1985
Ocean Surface Energy Fluxes Science Working Group	Peter Niiler, SIO	Mar. 1984	Aug. 1985
West Coast Chlorophyll Temperature Time Series Science Working Group	Mark Abbott, SIO/JPL	Jun. 1984	Jun. 1985
SSM/I Sea Ice Research Science Working Group	Norbert Untersteiner, Univ. of Washington	Dec. 1982	Jun. 1984
In-Situ Science Working Group	Russ Davis, SIO	Sept. 1981	Mar. 1984
ERS-1/SAR Sea Ice Study Team	Gunter Weller, Univ. of Alaska	Apr. 1982	Dec. 1983
Satellite Ocean Color Science Working Group	John Walsh, BNL/Stonybrook	Oct. 1981	Dec. 1982
Satellite Surface Stress Team (S-Cubed)	James F. O'Brien, FSU	July 1981	July 1982
Topex Science Working Group	Carl Wunsch, MIT	Feb. 1980	Mar. 1981

TABLE 2

OCEAN RELATED SPACECRAFT: NEXT DECADE

SATELLITE	SPONSOR	OCEAN-RELATED SENSORS/COMMENTS	LAUNCH	STATUS
GEOSAT	USN	ALT	Mar. 1985	Operational
DMSP	USAF NASA	MR MR Data Receiving/ Processing Facility	Jan. 1987	Approved Approved
MOS-1	JAPAN	CS, IR, MR	Jan. 1987	Approved
ERS-1	ESA NASA	ALT, SAR, SCAT, IR Alaskan SAR Facility	Dec. 1989	Approved Approved
N-ROSS	USN NASA	ALT, MR Contribute SCAT	Sept. 1990	Approved Approved
NOAA K, L, M	NOAA NOAA/NASA	AVHRR OCI	1990	Approved Proposed
ERS-1	JAPAN NASA	SAR Utilize Alaskan SAR Facility	1991	Approved Proposed
TOPEX/POSEIDON	NASA/CNES	ALT	1991	Proposed
RADARSAT	CANADA NASA NOAA UK	SAR Contr. Launch, Develop SCAT Contribute SCAT Contribute BUS	1992	Proposed Proposed Proposed Proposed
GRM	NASA	Satellite-to-Satellite Tracking	1992	Proposed

GEOSAT

This is a U.S. Navy sponsored mission to provide the Defense Mapping Agency with a larger quantity of altimeter data of Seasat quality. The primary, eighteen month mission to map the marine geoid should be completed in late summer or early fall 1986. Following this, there will be an eighteen month oceanographic mission (known as the Exact Repeat Mission) having a 20 day repeat cycle and a 150 km equatorial track spacing. In general, the mean sea surface data from the initial eighteen-month geodetic mission will be classified, with the residuals from this surface being unclassified. Although not yet formally promulgated, data from the second eighteen-month mission are planned to be unclassified.

DMSP

This is a series of U.S. Air Force operational meteorological satellites in sun-synchronous orbits. For those satellites planned for launch between 1986 and 1991, there will be a microwave radiometer (the Special Sensor Microwave Imager, or SSM/I) aboard having four frequencies over the range from 19 to 85 GHz. As SSM/I data are useful in characterizing sea ice, snow cover, surface winds, and atmospheric water, NASA plans to acquire these data for research purposes.

MOS-1

The purpose of this mission is to establish Japanese technology for Earth observations and to carry out practical observations of the Earth, primarily focused on the oceans. MOS-1 is all passive, has a two-year design life, and will be in a sun-synchronous orbit.

ESA's ERS-1

The European Space Agency's First Remote Sensing Satellite is a marine science and applications mission whose purpose is to establish, develop and exploit ocean and ice applications of remote sensing data. On board the spacecraft, planned for sun-synchronous orbit, will be a C-band SAR (for obtaining high resolution maps and, in a low power mode, for use as a wave scatterometer), a radar altimeter and an along-track scanning radiometer. The satellite is planned for launch in December 1989. Acquisition and exchange of ERS-1 data between ESA and NASA is the subject of a Memorandum of Understanding (MOU) signed in January 1986.

N-ROSS

This is a U.S. Navy mission with NASA, Air Force and NOAA participation. The NASA (provision of a scatterometer) and Navy components were approved in the FY 85 budget. This mission is viewed as an applications demonstration of how well spaceborne ocean observations can meet operational Navy needs. The spacecraft will be in a sun-synchronous orbit, have a three-year design life, and may be operated as an element of the overall DMSP program. In addition to the SSM/I for estimating sea ice coverage, etc., it will carry a lower-frequency microwave radiometer for estimating sea surface temperature and an altimeter for mesoscale feature detection and monitoring. Data from the NASA scatterometer will be used to complement TOPEX data in addressing the general circulation of the oceans.

OCI

The Ocean Color Imager (OCI) is an improved version of the Coastal Zone Color Scanner presently deployed aboard NIMBUS-7. It is currently being considered by NOAA as a candidate for development by the commercial sector. An opportunity for the flight of an OCI is aboard one of the NOAA series of polar-orbiting, operational meteorological satellites.

Japan's ERS-1

This is a Japanese spacecraft with the same acronym as ESA's ERS-1. Its objective is to establish SAR technology for Earth observations and to carry out observations of the Earth, primarily focused on terrestrial applications. It will be in a sun-synchronous orbit and will have an L-band SAR with a two-year design life. Preliminary design and definition studies are underway. Discussions with the Japanese government regarding the possibility of direct read-out of SAR data from this satellite at NASA's Alaskan SAR Facility have been initiated.

TOPEX/POSEIDON

This is a dedicated altimeter mission whose data--when combined with data from NASA's Scatterometer on N-ROSS--will be utilized to advance our understanding of the general circulation of the oceans. TOPEX/POSEIDON is a joint mission between NASA and CNES. Joint implementation studies have been completed whereby NASA will provide the satellite and TOPEX sensors and CNES will provide an Ariane launch and the POSEIDON sensors. The orbital characteristics are: inclination of 63 degrees, altitude of 1300 km, equatorial track spacing of 300 km, and track repeat of 10 days. Primary tracking will be provided by DMA's Tranet system. Satellite design studies have been completed, and according to present schedules, TOPEX could be launched in time to provide a significant overlap with the N-ROSS mission.

RADARSAT

This is a mission employing a C-Band SAR to monitor sea ice characteristics in the Arctic Ocean and marginal seas. Measurements would be used to support shipping and petroleum exploration operations principally in the Beaufort and Labrador Seas by providing forecasts of sea ice conditions. Although the Canadian government has approved funding to support design studies both for RADARSAT and its ground segment (which will also be used with ESA's ERS-1), current efforts are underway to explore prospects for reducing cost, whether via greater commercial and/or international participation or through a descoping of the mission.

GRM

This is a mission designed to improve our understanding of the Earth's gravity and magnetic fields; it is planned to extend our knowledge of these fields down to horizontal scales on the order of 100 km. GRM is planned as a two-satellite system flying at a 160 km altitude.

ACRONYMS

ALT	Altimeter
ASF	Alaskan SAR Facility
CNES	France's National Center for Space Studies
CS	Color Scanner
DMSP	Defense Meteorological Satellite Program
ERS-1	ESA's First Remote Sensing Satellite #1 and Japan's Earth Resources Satellite #1
ESA	European Space Agency
GEOSAT	Geodetic Satellite
GRM	Geopotential Research Mission
IR	Infrared Radiometer
MOS-1	Marine Observational Satellite #1
MR	Mircrowave Radiometer
N-ROSS	U. S. Navy Remote Ocean Sensing System
NSCAT	NASA Scatterometer
SAR	Synthetic Aperture Radar
SCAT	Scatterometer
SEASAT	Sea Satellite
SSM/I	Special Sensor Microwave Imager
TOPEX	Ocean Topography Experiment

SPACEBORNE OCEAN-SENSING TECHNIQUES

Altimeter -	a pencil beam microwave radar that measures the distance between the spacecraft and the Earth. Measurements yield the topography and roughness of the sea surface from which the surface current and average wave height can be estimated.
Color Scanner -	a radiometer that measures the intensity of radiation reflected from within the sea in the visible and near-infrared bands in a broad swath beneath the spacecraft. Measurements yield ocean color, from which chlorophyll pigment concentration, and diffuse attenuation coefficient, and other bio-optical properties can be estimated.
Infrared Radiometer -	a radiometer that measures the intensity of radiation emitted from the sea in the infrared band in a broad swath beneath the spacecraft. Meaurements yield estimates of sea surface temperature.
Microwave Radiometer -	a radiometer that measures the intensity of radiation emitted from the sea surface in the microwave band in a broad swath beneath the spacecraft. Measurements yield microwave brightness temperatures, from which wind speed, water vapor, rain rate, sea surface temperature, and ice cover can be estimated.
Scatterometer -	a microwave radar that measures the roughness of the sea surface in a broad swath on either side of the spacecraft with a spatial resolution of 50 kilometers. Measurements yield the amplitude of short surface waves that are approximately in equilibrium with the local wind and from which the surface wind velocity can be estimated.
Synthetic Aperture Radar -	a microwave imaging radar that electronically synthesizes the equivalent of an antenna large enough to achieve a spatial resolution of 25 meters. Measurements yield information on features (swell, internal waves, rain, current boundaries, and so on) that modulate the amplitude of the short surface waves; they also yield information on the position and character of sea ice from which, with successive views, the velocity of sea ice floes can be estimated.

SECTION II - PROJECT AND STUDY SUMMARIES

PROJECT/STUDY NAME	AUTHOR	PAGE
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• TIROS-N/NOAA	Joel Susskind, GSFC	II-6
• NASA Scatterometer (NSCAT)	Michael H. Freilich, JPL Benn D. Martin, JPL	II-8
• SSM/I Sea Ice Archive	Roger Barry, CIRES, U. of Colo.	II-10
• Alaskan SAR Facility (ASF)	Frank D. Carsey, JPL Young H. Park, JPL	II-12
• NASA Ocean Data System (NODS)	J. Charles Klose, JPL V. Zlotnicki, JPL	II-14
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NIMBUS-7 OBSERVATORY

Dr. Edward J. Hurley, Nimbus Manager, GSFC,
Code 636, Greenbelt, MD 20771, 301-344-9414

The Nimbus-7 Satellite, in operation since 1978 is currently the most significant source of experimental data from Earth orbit relating to atmospheric and oceanic processes. Two of its eight experiments are primarily involved in observations of the oceans. The Coastal Zone Color Scanner (CZCS) instrument, which has experienced an increasing frequency of start-up failures during the last year, is still collecting observations of ocean color parameters. Due to the increasing start-up problems, the CZCS is not expected to operate beyond 1986. The Scanning Multichannel Microwave Radiometer (SMMR), operating without the 21 GHz channel which was turned off permanently in March 1985 due to spacecraft power limitations, is still returning data on sea surface temperature, sea surface wind, total column water vapor, and sea ice. The development of data sets from these experiments is discussed below.

COASTAL ZONE COLOR SCANNER (CZCS)

E. F. Szajna, GSFC, Code 636, 301-344-9427

Seven and one-half years of observations from the Nimbus-7 Coastal Zone Color Scanner (CZCS) have been collected, but only a small portion have been analyzed to produce chlorophyll concentration, surface temperature (first year only), diffuse attenuation coefficient, and water radiances for selected regions of the world's oceans and waterways. Observations have been collected since launch subject to the constraints of available spacecraft power and experimenter requests for coverage. Most of the requests for coverage have been in a limited number of coastal areas, however, and it is in these areas where most CZCS observations have been made and the data processed. Some open ocean data have also been collected, although because of a lack of requests, much of this data has not been completely reduced. Most of the processed and archived data from the CZCS consists of partially calibrated radiances (level 1). Today, derivation of level 2 and level 3 parameters is mostly done by individual scientific users of the data.

Nimbus Project personnel, working with GSFC ocean scientists, have defined a new open ocean chlorophyll product which will be much more widely useful to the ocean science community. The Nimbus Project is developing a processing system with the capacity and efficiency to process the large quantities of CZCS observations that will be required to produce a global scale data set, while possessing the image processing capability to allow scientific analysts to validate the data by applying calibration and atmospheric corrections, and comparing results with in situ observations.

The software portion of this system has been installed and tested on a GSFC VAX 11-780 computer system. Pilot production has begun using the existing image processing system. Delivery of several hardware components (summer 1986), including a sophisticated image processing work station, will complete system development.

SCANNING MULTICHANNEL MICROWAVE RADIOMETER (SMMR)

Dr.Paul H. Hwang, GSFC, Code 636, 301-344-9848

The original primary objectives of the Scanning Multichannel Microwave Radiometer (SMMR) are to obtain sea surface temperature and near-surface wind speed, two very important parameters required by oceanographers for developing and testing global ocean circulation models and other aspects of ocean dynamics. Other geophysical parameters are also extracted from the SMMR data. These include: sea ice parameters and total atmospheric water vapor over open ocean.

Six years of data have been validated and archived at the NSSDC. The archived data are: (a) TCT: calibrated brightness temperature for each channel in its original pixel resolution, (b) TCT $1/2^{o}$ map: TCT data mapped into a $1/2^{o}$ x $1/2^{o}$ (55 km resolution) grid system, (c) TCT $1/4^{o}$ map: 37 GHz data from TCT, mapped into a $1/4^{o}$ x $1/4^{o}$ grid system, (d) CELL data tape: calibrated brightness temperature data arranged by orbit and binned into cells ranging in size from 30 km x 30 km to 150 km x 150 km, (e) PARM tape: extracted geophysical parameters, i.e., sea surface temperature, sea ice concentration, multi-year ice fraction, total atmospheric water vapor and near surface wind speed in the same format as the corresponding level 1 CELL data and (f) MAP tape: PARM tape data mapped into mercator and polar stereo projections. Beginning with

the sixth year of data, MAP products are being replaced by a new product called PARMAP. Each PARMAP tape contains individual geophysical parameters mapped with a $1/2^{0}$ x $1/2^{0}$ spatial resolution Earth grid. This change in format was adopted to facilitate scientific uses of the data that involve combining and/or comparing SMMR data with weather satellite and surface observations. PARMAP will also be produced for data years 1 through 5 and beyond. All data are in the form of computer compatible tapes. In addition to the tape specification for each of the aforementioned data tapes, three user's guides are available: (a) CELL Data User's Guide, (b) PARM Tape User's Guide and (c) MAP Tape User's Guide. All documentation may be obtained from the NSSDC or from the Nimbus-7 Project at the GSFC.

TIROS-N/NOAA Series

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(301) 344-7210 or FTS 344-7210

Project Objectives:

1) To provide spectral radiometric information for accurate sea and land temperature mapping, determination of global atmospheric temperature humidity profiles, day-night cloud cover information, and monitoring of total ozone burden and outgoing longwave and shortwave radiation.

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-8 and 5-channel on NOAA-7, NOAA-9) 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. Future satellites will carry the 5-channel AVHRR.

2) TIROS Operation Vertical Sounder (TOVS)
This sounder consists of three instruments: a High Resolution Infrared Radiation Sounder (HIRS/2), a Stratospheric Sounding Unit (SSU), and a Microwave Sounding Unit (MSU). These instruments provide better temperature and humidity soundings than previous sounders especially in the presence of clouds. In addition, other parameters such as sea/land surface temperature, sea ice extent, and cloud cover can be determined from these sounders.

3) ARGOS/Data Collection System (ARGOS/DCS)
This system, provided by France, is designed to locate, 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.

5) Search and Rescue (SAR)
SAR was launched on NOAA-8 and is also on NOAA-9 and all future satellites. Its purpose is to receive and locate distress signals from ships and planes.

6) Solar Backscatter Ultra Violet Spectrometer (SBUV/2).
This nadir viewing radiometer measures vertical ozone distribution and total ozone. Its main purpose is to determine the long term trends in global total ozone burden. Soundings are produced only during the day on the afternoon satellites.

7) Earth Radiation Budget Experiment (ERBE)
This is a NASA experiment, flying on NOAA-9 and scheduled to fly on NOAA-G, to collect global data on the radiation processes of the Earth's Surface and Atmosphere.

Current Status:

The current system is a two satellite system with a morning satellite in a 0730 LST descending orbit and an afternoon satellite in a 1430 LST ascending orbit at the equator. Both are in sun synchronous orbits at an average altitude of approximately 830 km with orbital periods of 102 minutes. Each satellite provides essentially global coverage twice daily. NOAA-9, launched in December 1984, is the current afternoon satellite, replacing NOAA-7 launched in 1981, and TIROS-N launched in 1979. NOAA-9 contains the 5 channel AVHRR and is the first satellite containing SBUV and ERBE. NOAA-8, launched in 1984 to replace NOAA-6, launched in 1979, failed shortly after launch. It is scheduled to be replaced by NOAA-G in June 1986. NOAA-G will contain the 5 channel AVHRR and ERBE but will not contain SBUV2 because it is a morning satellite.

Data Availability:

Data from the AVHRR are 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-NESDIS at Suitland, MD, and 4) readout of onboard recording selected highest resolution (LAC) data. AVHRR and TOVS data are archived at NOAA/SDSD, World Weather Building, Camp Springs, MD. The data are available in two forms: level Ib calibrated radiance data, and level II retrieval products data, from February 1979 to present. Both tapes and picture imagery are available on request. SBUV and ERBE products are not yet available.

NASA SCATTEROMETER (NSCAT)

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The NASA Scatterometer instrument is one of several sensors to be flown on the U.S. Navy Remote Ocean Sensing System (N-ROSS) mission. NSCAT will provide frequent measurements of oceanic near-surface vector winds (both speed and direction) with high spatial resolution and global coverage. The data will be used operationally by the Navy, and in NASA-sponsored research studies by the oceanographic and meteorological science communities.

The N-ROSS mission will provide measurements of near-surface winds, ocean topography, wave height, sea-surface temperature, and atmosheric water content over the global oceans. In addition to NSCAT, N-ROSS will carry a microwave altimeter, a four-frequency microwave radiometer (SSM/I), and a low-frequency (5.2 and 10.4 GHz) scanning radiometer (LFMR). Present plans are for a late 1990 launch into a sun-synchronous orbit at an altitude of 820 km and a 98.7 degree inclination angle. The mission is designed for a minimum operational period of three years. Both N-ROSS and NASA's contribution, NSCAT, received Congressional approval as new starts in Fiscal Year 1985.

The NSCAT instrument is an active microwave radar similar to but significantly improved over that flown on SEASAT in 1978. Six fan-beam antennas (two more than SEASAT) will allow measurements of radar back-scatter cross-section to be obtained at three azimuth angles within two 600 km swaths separated by a sub-satellite gap of 350 km. The inherent resoluton of the instrument will be 25 km, using an on-board digital doppler filter; SEASAT achieved 50 km with analog doppler filters. The NSCAT system is designed to yield winds with an accuracy of 2 m/s (rms) and 20 degrees (rms) over the range 3-30 m/s, and to map 90% of the global ice-free oceans every two days.

The NSCAT Project includes a dedicated ground data processing and distribution system. The system will process NSCAT raw telemetry, N-ROSS orbit and attitude, and SSM/I data types, and produce earth-located, rain-flagged, vector winds and averaged wind field maps. The "six-stick" antenna design will enable the data system to select unique wind directions using an objective ambiguity-removal algorithm. The NASA science investigators will be able to selectively access subsets of several levels of processed data by means of an on-line archival and distribution system such as the NASA Ocean Data System (NODS). NSCAT data will also be made available to NOAA/NESDIS for broader distribution.

Significant progress was achieved in all aspects of the NSCAT Project during FY 85. The instrument and data systems designs were refined and preparations were made for formal

Preliminary Design Reviews in early FY 86. Contracts were placed for the instrument traveling-wave tubes (TWT's) and antennas, and a VAX 11/785 computer was purchased to support systems design analyses and data processing algorithm development efforts. As the N-ROSS Project efforts accelerated, key spacecraft and data-flow interfaces with the Navy became more active.

In March the Navy announced that the N-ROSS launch date would be delayed from June 1989 until September 1990. The NSCAT Project accomplished a replanning effort designed to minimize the cost increase due to the lengthened schedule.

An Announcement of Opportunity soliciting proposals for scientific research utilizing the NSCAT data was released in January 1985, as was a companion Science Opportunities Document (Freilich, 1985). Sixty-five proposals covering a broad range of oceanographic and meteorological research topics were received. After completing the review process, the following investigators were selected:

Principal Investigator	Submitting Institution
Dr. Robert Atlas	Goddard Space Flight Center, NASA
Dr. R. C. Beardsley	Woods Hole Oceanographic Institution
Dr. Robert A. Brown	University of Washington
Dr. Mark A. Cane	Lamont-Doherty Geological Observatory, Columbia University
Dr. Dudley B. Chelton	Oregon State University
Dr. Peter Cornillon	University of Rhode Island
Dr. M. Crepon	Laboratoire d'Oceanographie Physique du Museum, France
Dr. Mark A. Donelan	Canada Centre for Inland Waters, Canada
Dr. Lee-Lueng Fu	Jet Propulsion Laboratory, NASA
Dr. Ross N. Hoffman	Atmospheric and Environmental Research, Inc.
Dr. William R. Holland	National Center for Atmospheric Research
Dr. W. Timothy Liu	Jet Propulsion Laboratory, NASA
Dr. James J. O'Brien	Florida State University
Dr. James G. Richman	Oregon State University

Cryospheric Data Management System for Special Sensor Microwave Imager (SSM/I) Data

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Program Science Objectives:

In 1986 the Defense Meteorological Satellite Program will launch a polar orbiter which will for the first time, provide near-real time microwave data on sea ice, atmospheric moisture and precipitation, soil moisture, and ocean parameters from the Special Sensor Microwave/Imager (SSM/I). This project will establish a long-term, secure archive and distribution center for data products over the polar oceans derived from the SSM/I. The project will accomplish this goal by implementing a mini-computer based data management and retrieval system using the Pilot Ocean Data System software.

National Snow and Ice Data Center (NSIDC) will develop a computer based Cryospheric Data Management System (CDMS) to extract the cryospheric data and make them readily available to the non-operational user community. The proposed management system is designed to provide a multi-disciplinary research data set comprising both cryospheric and atmospheric data, improve the ease of information transfer, and anticipate new data needs and requirements.

- Extract SSM/I cryospheric data from the orbital input data stream.
- Create mapped data sets.
- Distribute data to the user community (foreign and domestic.)
- Provide an interactive data catalog.
- Implement revised microwave algorithms.

Current Status:

During the second year of this three year project, the routine operation of the VAX 11/750 computer was initiated and transfer of the Pilot Ocean Data System (PODS) software to NSIDC started. Initial tests of the PODS-SSM/I software have been started with good results.

The GOLD catalog has also been successfully located on the CDMS computer, although further testing and revision of the software is required. The telephone line for the SPAN network has been installed and completion of the SPAN connection is expected in the next two months.

Associated Work:

NSIDC will re-grid SMMR (and possibly ESMR) data into the SSM/I grid format over the next several months. It is our intention to provide a long-term passive microwave data set in the same grid format. This work is being done in collaboration with the Ocean and Ice Branch at Goddard.

Data Distribution Plan:

Exact dates for data distribution are indefinite because the SSM/I launch date has not yet been precisely determined. It is expected that limited data distribution will commence within 4-8 months after SSM/I launch, now expected in the last three months of 1986.

ALASKAN SAR FACILITY (ASF)

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The Alaskan SAR Facility (ASF) Project has approval to place a receiving station and data processing system at a suitable site in Alaska in order to receive and process a total of up to 35 minutes per day of SAR data from the ERS-1 satellite of the European Space Agency, the ERS-1 satellite of the Ministry of International Trade and Industry of Japan, and the RADARSAT satellite of the Division of Energy, Mines and Resources of Canada, all of which are scheduled to fly in the early 1990s. The objective of the program is to support geophysical investigations with the SAR data from these satellites. Current planning calls for the station site to be on the University of Alaska campus on the edge of Fairbanks. The approximate scope of the project is known but the specific requirements are not at present fully defined for each element. Substantial portions of the project are well defined at this time, however, and work will begin on these in the current fiscal year.

The total project is understood to consist of project management, the receiving station itself, a SAR processor, a science support system, and a Science Team to conduct research with the data. Of these the first two elements are fully defined and budgeted, and final design work will begin on them in FY 1986. The receiving station will receive and record SAR data from the 3 satellites, the SAR Data Processing System will process the signal data into images of 3 basic sorts: a 1-look highest resolution complex phase image, a 4-look 30m resolution image, and a 64 or 128-look browse image. The output of the Data Processing System will go to the science support system in tape form. The science support system cannot be defined until the Science Team is chosen. The process of its selection started in FY 86 and may be completed by the end of the year. In general terms the science support system will generate some or all of the geophysical products of the program and will also archive the SAR images and the geophysical products of the system in support of the investigations of the Science Team. The total project has been

divided into a pre-launch and a post-launch component, and the task as currently defined and being worked on includes only the activity prior to launch; the operation of the station, the distribution of data products from the station, and the support of science investigations during the flight phase of the program are to be defined and appproved later.

In the period prior to approval a Science Working Group published a review of the benefits of an Alaska receiving station for SAR data, and concluded that the major applications would be in the area of sea ice geophysics with other applications in glaciology, geology, vegetation, and oceanography. These findings are in Science Program for an Imaging Radar Receiving Station in Alaska, by G. Weller, F. Carsey, B. Holt, D. Rothrock and W. Weeks, JPL 400-207, Jet Propulsion Laboratory, Pasadena, CA 91109, 45p, 1983, and in A Programme for International Polar Oceans Research (PIPOR) by the PIPOR Group ,B. Battrick, ed., ESA SP-1074, Paris, 42p, 1985. Other documents are now in process including Science Opportunities for The Alaska SAR Facility, "Alaska SAR Facility Science Requirements: SAR Processor", and "Alaska SAR Facility Science Requirements: Receiving Station". The science preparation for the ASF also includes preparation and submission of proposals to the flight agencies to secure access to the flight-instrument data itself in support of the Science Team investigations. The generation of these proposals, at least one for the polar oceans research and one for earth-surface sciences research is now underway; they are to be submitted in fall, 1986.

NASA Ocean Data System (NODS)

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Data sets from past, present, and future ocean observing satellites represent a non-renewable national resource that must be preserved. The need for an information system that effectively curates and distributes these data sets has been identified by national and international scientific committees as an essential element in the flow of information from the satellites to the end user. It is recognized that common use of satellite data sets will not become reality until effective access to these data set can be provided. In response to this need, the NASA Ocean Data System is being developed at the Jet Propulsion Laboratory.

PROGRAM OBJECTIVES: The objective of the NASA Ocean Data System (NODS) is to archive and distribute data sets from spaceborne ocean viewing sensors and, to a limited extent, data sets from in-situ measurement systems. NODS will provide: a catalog of data sets relevant to ocean science; abstracts of documents relevant to catalogued and archived data sets; data at processing level 0, 1, and 2 (swath-oriented), level 3 and 4 (gridded); browse files -- small data subsets designed for quick, interactive browsing; the ability to select much of the NODS holdings by time, region, project, sensor, data level, and measurement type, as appropriate; the ability to display graphics or tabular data subsets at the user's terminal; the ability to transfer graphics or tabular data subsets to the user, either electronically to the user's computer or shipped as hardcopies, tapes or optical disks. Catalog, bibliography, data selection request, and browse file displays will all be available interactively.

APPROACH: The NASA Ocean Data System will evolve from the Pilot Ocean Data System (PODS). Science requirements from the JOI sponsored Satellite Ocean Data System Science Working Group (SODSSWG), flight project requirements from NSCAT and Topex, and lessons learned during the PODS pilot phase are being incorporated into a new design, which when implemented, will result in an operational system capable of dealing with the data management and distribution requirements of oceanic flight projects of the 1990's. NODS is being developed by extending the existing pilot system to meet NODS requirements. The NODS design will be tested and tuned using data from DMSP SSM/I, Geosat, and the West Coast Satellite Time Series. NODS will be implemented as a network of distributed archives. The JPL node is considered to be the prototype for the other nodes in the NODS network. Newly created nodes will be provided with the JPL developed software, thus ensuring cost efficiency and as much uniformity as possible within the network. The National Snow and Ice Data Center at the University of Colorado is

expected to become the second full functional node in the Spring of 1987. In the next year nodes having data set cataloging capability will be established at the University of Rhode Island, the University of Miami, the University of Colorado, the University of Delaware, and the National Ocean Data Center.

CURRENT STATUS: NODS/PODS responded to 977 request for Seasat and GEOS-3 data and shipped 1577 products to the oceans research community. We also distributed subsets of the level one Seasat Alt,' SMMR, and SASS data to the European Space Agency (ESA) for their use in preparing algorithms for ERS-1 (the entire level 1.0 and 2.0 Seasat ALT, SASS, and SMMR data sets are being delivered to ESA in 1986). NODS is housing, and will eventually distribute (probably in 1987), over 4000 west coast passes of AVHRR and CZCS data taken by the Scripps Satellite Facility. We continued to make good progress towards the development of a system to process, archive and distribute SSM/I data in support of NASA's polar and ocean research programs (SSM/I is expected to be launched in the last quarter of 1986); in the last year we: 1) continued to develop the necessary data processing and data management capabilities, 2) drafted SSM/I operations plan with the National Snow and Ice Data Center at the University of Colorado, 3) made arrangements with Naval Space Surveillance for the acquisition of DMSP SSM/I orbital elements, and 4) initiated the purchase of a 200 Gigabyte digital optical disk data storage system that will house the SSM/I data base. In 1985 a 15 node oceanography computer communication network was designed which incorporated facilities provided by the NASA Program Support Communication Network (PSCN) and the Space Physic Analysis Network (SPAN); the network is expected to become operational in mid 1986. Also during 1985 software to implement a prototype for a distributed catalog for oceanographic data was completed and partially tested; by 4/86 the fully tested prototype will be delivered to the University of Rhode Island, the University of Miami, the University of Delaware, the National Snow and Ice Data Center, and NOAA/NODC.

Processing and Archival of Data from the DMSP SSM/I

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During the latter half of 1986, it is anticipated that a Defense Meteorological Satellite Program (DMSP) satellite will be launched into a polar orbit carrying the first Special Sensor Microwave Imager (SSM/I), a new passive microwave radiometer. Information relating to atmospheric water vapor, precipitation, wind speed, soil moisture, and ice conditions can be derived by processing the SSM/I data.

The SSM/I data will be processed by the Fleet Numerical Oceanography Center (FNOC) on a real-time basis for operational use by the Navy. It is expected that FNOC will produce Temperature Data Records (TDRs), Sensor Data Records (SDRs), and Environmental Data Records (EDRs). The TDRs consist of earth-located antenna temperatures that have been surface-type tagged and calibrated. The SDRs are brightness temperatures computed from the antenna temperatures by applying an antenna pattern correction. The EDRs contain the geophysical parameters computed from the SDRs, such as, ice parameters, precipitation, and wind speed.

Existing agreements require that data from DOD satellites be sent to NOAA's Satellite Data Services Division (SDSD) of the National Environmental Satellite, Data, and Information Service (NESDIS) for distribution to research and commercial users. Initially, the SSM/I data sets will be transmitted to NESDIS via magnetic tape. However, starting in late 1987 these data sets will be broadcast to NESDIS via an RCA satellite link.

The NASA Ocean Data System (NODS) will receive TDR tapes from NESDIS on a regular basis after the DMSP satellite is launched. The TDR files were chosen over the SDR files because FNOC has stated that both types of data may not be sent due to time constraints and the TDR data would have priority. The TDR data will be received from NESDIS within about two or three weeks after the observations are made. NESDIS data delivery times should improve once the satellite link between the Navy and NESDIS is established.

Once received at NODS, the global, swath TDR antenna temperatures will be converted to brightness temperatures (SDRs) using an antenna pattern correction scheme equivalent to that used by the Navy. These brightness temperatures or SDR data will be stored in the "SDR Rapid Access Archive" designed to allow rapid,

selective access to subsets of the data. The Rapid Access Archive will be stored on optical platters. It is this Rapid Access Archive which will be used to create the higher level products.

Gridded (Level 3) products will be produced from swath brightness temperatures by temporally and spatially averaging the data onto regular Earth-fixed grids covering the polar regions. The data from the 85-GHz channels will be presented on daily, 12.5 kilometer (km) grids. Data from the 19, 22, and 37 GHz channels will be given on 25 km grids. Using these gridded average brightness temperatures as input, first year, multi-year, and total sea ice concentration will be calculated using an algorithm provided by the NASA Sea Ice Algorithm Working Group. The ice concentrations will be presented on 3 day, 50 km grids. Daily, high resolution (12.5 km) ice edge maps will eventually be produced from the 85 GHz brightness temperatures; algorithms for this product are under development.

Once produced, the gridded products will be loaded on the NODS archive system for distribution to the research community. Swath and gridded SSM/I data products will be available both on-line via terminal access, and off-line via mail. Users will be able to interactively search a catalog of SSM/I data products, display images of gridded SSM/I brightness temperature and ice concentration products, display listings and plots of SSM/I swath data on their own terminal, and order data subsets. Delivery of large amounts of data will be via magnetic tape or optical platter. For users who are connected to NODS via a computer network it will be possible to transfer small (less than 2 megabytes) data subsets using electronic file transfer procedures.

After approximately 6 months of SSM/I operations at JPL there will be a gradual shift in operational responsibility to the National Snow and Ice Data Center (NSIDC) at the University of Colorado at Boulder. NSIDC will be provided with the SSM/I data processing, archival and distribution software developed at JPL. They will augment this software to produce and manage snow products, in addition to the ice products already discussed. Eighteen months after SSM/I launch NSIDC will assume complete responsibility for the production, archival and distribution of all SSM/I ice and snow products.

GEOSAT

The following summary by Ernest T. Young, JOI, was compiled from materials provided by the Office of the Oceanographer of the Navy. It represents our best attempt at reflecting the Navy information but does not itself have Navy concurrence. The Navy point of contact is CDR. William L. Shutt, telephone 202/653-1616.

GEOSAT was successfully launched on 12 March 1985 into a near-circular orbit with an altitude of 800 km. It is projected to operate continuously for at least 48 months which should satisfy both the primary and secondary missions. The primary mission of GEOSAT is to provide a homogeneous, high density, intermediate and long wavelength gravity data base over the world ocean areas for required improvements in the Navy's earth gravitational models. The primary mission is planned for a total of 18 months.

Along with determining the gravity field, GEOSAT data can also be used to enhance naval warfare capability by improving the maps of the ocean bottom. For this reason, the geoid data and the raw altimeter data from the primary mission is classified. Oceanographers realize however that some insight into ocean variability can be gained by using residual sea height information obtained by removing the geoid. Navy is planning to release some of this data on a special request case-by-case basis. The Navy also plans to release GEOSAT's waveform, significant wave height, and wind speed information and corrections it applies to the data for water vapor attenuation, ionospheric variations, tides and other sources of environmental error.

After completing the primary misison period, the project plans to shift to an "Exact Repeat Misison (ERM)", which will complement the SEASAT 17-day, near-repeat ground tracks and should continue until satellite failure. Both oceanographic and geodetic data will be collected during the ERM.

Data release for the ERM is subject to negotiations with the Navy.

NAVY REMOTE OCEAN SENSING SYSTEM (N-ROSS)

The following summary by Ernest T. Young, JOI, was compiled from materials provided by the Office of the Oceanographer of the Navy. It represents our best attempt at reflecting the Navy information but does not itself have Navy concurrence. The Navy point of contact is CDR. William L. Shutt, telephone 202/653-1616.

The Navy Remote Ocean Sensing System (N-ROSS) is a satellite system which will provide oceanographic measurements on a continuous, all weather, global basis. The N-ROSS mission is designed to acquire ocean data for operational and research use by both the military and civil sectors.

Sensors to be flown include the NASA Scatterometer (NSCAT) for winds, a two-frequency, large antenna microwave radiometer for sea surface temperature, a four-frequency microwave radiometer (the Special Sensor Microwave/Imager, SSM/I) for imaging ice properties and the sea-ice edge, and a GEOSAT-type altimeter for wave height and front and eddy location. A detailed breakdown of the sensor capabilities is provided in the table below.

The satellite is currently scheduled for a three-year mission starting in late 1990, still TBD, pending outcome of an RFP and will be placed into a near-polar, sun-synchronous orbit with an inclination of 98.7 degrees, a height of 820 km, and an 0600 ascending local equatorial crossing time. With this orbit, 90% of the ocean will be observed every two days.

Three of the sensors, the altimeter, the SSM/I, and NSCAT, are under contract. An RFP will be issued in early summer 1986 to compete the spacecraft, system integration, and the remaining sensor, the LFMR. The contract award is expected before January 1987.

The availability of data for research and the method of distribution is in the preliminary discussion phase. The altimeter data is expected to be classified.

N-ROSS Sensor Capabilities and Heritage

Sensor	Parameter	Capability	Heritage
Scatterometer	Wind Speed Wind Direction	2.0 m/s (Range 3-30 m/s) 20º	Modified from Seasat. Improved Wind Direction.
Altimeter	Altitude Significant Wave Height Wind Speed	8 cm (when H1/3<5m) 0.5 m or 10% whichever is larger 2 m/s (1-18 m/s range)	Same as Geosat Altimeter.
Microwave Imager (SSM/I)	Surface Wind Speed Ice Edge Precipitation	+/- 2 m/s (25 km Resolution) +/- 12.5 km (25 km Resoultion) +/- 5 mm/hr (25 km Resolution)	DMSP Instrument; High frequency for ice edge better than Seasat SMMR.
Low Frequency Microwave Radiometer (LFMR)	Sea Surface Temperature	1.0ºC 25 km Resolution	New Device with Higher Resolution than SMMR.

ERS-1 : THE FIRST EUROPEAN REMOTE SENSING SATELLITE

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Status : The development and manufacture phase of ERS-1 started in January 1985, conducted by an industrial consortium of European and Canadian companies; the programme has been approved by 13 countries with the objective of a **launch by mid-1989** by the Ariane launcher from Kourou, French Guiana, into a sun-synchronous circular orbit at 780 km altitude, with a mean local time (descending node) of 10.30. The expected lifetime of ERS-1 is 2 to 3 years; it is anticipated that ERS-1 will be the forerunner of a series of European remote sensing satellites to become operational in the mid-1990's.

The ERS-1 **mission objectives** are of both a scientific and application nature and aim to :

- Increase the scientific understanding of coastal zones and global ocean processes which, together with the monitoring of polar ice regions, will provide a major contribution to the World Climate Research Programme.

- Establish, develop and exploit the coastal, ocean and ice applications of remote sensing data (offshore petroleum activities, ship routing and fishing activities).

- Stimulate and develop scientific research and application demonstration activities using all-weather high resolution data from the imaging radar (Synthetic Aperture Radar).

Priority in the **payload** has been given to a comprehensive set of radar instruments designed to observe the surface wind and wave structure over the oceans. These instruments consist of a **C-band wind scatterometer** designed to measure wind speed and direction; a **Ku-band radar altimeter** to measure significant wave height and wind speed at nadir and provide measurements over ice and major ocean currents; and a **C-band synthetic aperture radar (SAR)** to take all-weather high resolution images over polar caps, coastal zones, and land areas. The latter will also be operated in a sampled mode over oceans as a **wave scatterometer** with the aim of measuring the wave spectrum.

In addition to these radar instruments, the following elements are included : **laser retroreflectors** for accurate tracking of the satellite and radar altimeter calibration; the **Along-Track Scanning Radiometer** completed with a two-frequency **Microwave Nadir Sounder (ATSR-M)** to measure sea surface temperature and to provide information for the "wet-atmosphere" correction for the radar altimeter; and the **Precise-Range and Range Rate Equipment (PRARE)** to provide high-accuracy tracking information in support of the radar altimetry for ocean circulation studies.

The ground segment concept which has been selected will provide the following functions :

- Spacecraft and payload control and mission management
- Provision of **SAR regional service,** SAR operating time being limited to a maximum of 10 minutes per orbit (i.e. duty cycle of 10%).
- Provision of **low bit rate (LBR)** global service thanks to the on-board tape recorder with a capacity allowing one complete orbit period (i.e. 100 minutes) of LBR data (i.e. data other than from the SAR sensor) to be stored.
- Generation and delivery within 3 hours from observation of a number of selected products called **fast-delivery (FD)** products, including SAR "Fast Delivery" images, wind speed and direction, wind speed at nadir, wave height at nadir and wave image spectra.
- Archiving and generation off-line of **precision and thematic products** using national facilities provided to the Agency by some of its Member States (France, Germany, Italy and UK).

To further promote and expand the utilization of ERS-1 data, ESA will issue worldwide an Announcement of Opportunity for scientific investigations, application demonstration experiments and contributions to the geophysical data validation, with the aim of selecting Principal Investigators by the end of 1986.

MARINE OBSERVATION SATELLITE - 1 (MOS-1)

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Program Objectives: The main mission objectives are: (1) to establish the fundamental technologies of earth observation satellites; (2) to carry out experimental observation of the state of sea and atmosphere using three different sensors--a multi-spectrum electronic self-scanning radiometer (MESSR), a visible and thermal infrared radiometer (VTIR), and a microwave scanning radiometer (MSR)--and to verify the performance of these onboard sensors; and, (3) to perform basic experiments for a data collection system.

The design mission lifetime is two years.

Mission Hardware: Three kinds of sensors and a data collection transponder will be flown on board. MESSR is an electronic scanning type radiometer using charge-coupled devices (CCD) having 2048 elements, which will provide approximately 50-meter spatial resolution over 100 km swath width in three visible bands and a near infrared band. Two sets of MESSR hardware including the signal processor and 8 GHz data transmitter are installed, and the viewing direction of telescopes are canted slightly (2.7 deg) to each other. The swath width then becomes 200 km in the case of parallel operations. Data from MESSR will be used for surveying sea surface colors which relate to vegetal plankton, land usage and crop inventories. VTIR is a mechancial scanning radiometer with a Ritchey-Chretien type telescope, which will provide approximately 900-meter spatial resolution in the visible band and 2700-meter in the infrared band over 1500 km swath width. VTIR has one visible and three infrared channels, and will permit the measurement of sea surface temperature and atmospheric vapor. MSR is composed of two Dicke type radiometers in frequencies of 23 GHz and 31 GHz. Scanning is performed by rotating an offset parabolic reflector. MSR will provide approximately 32 km spatial resolution in the 23 GHz band and 23 km in the 31 GHz band over 320 km swath width, and will permit the measurement of the water content of the atmosphere, sea ice and snowpack on land. In addition to the remote sensors, DCST (Data Collection System Transponder) will be flown on board. This will collect the data transmitted at 400 MHz band from DCP (Data Collection Platform) floating on the sea surface and send the information to the ground station at 1700 MHz band through the onboard repeater.

Orbit: MOS-1 will be placed into sun-synchronous and near-recurrent orbit with altitude of approximately 909 km and inclination of approximately 99 deg. Recurrent period is 17 days and a local time at descending node is from 10:00 to 11:00 a.m.

Planned Launch Date: MOS-1 is planned to be launched in early 1987 by N-II launch vehicle from the Tanegashima Space Center.

Current Status: Preliminary design of MOS-1 started in 1979 based on Japanese technologies. Qualification test (QT) of prototype model (PM) was completed in 1985. At present, MOS-1 is on the final stage of development phase, and the acceptance test (AT) of flight model (FM) is in progress. AT will be accomplished by April 1986.

Data acquisition station for MOS-1 is located at Hatoyama, about 50 km northwest of Tokyo. Hatoyama Earth Observation Center (EOC) is responsible for mission management, in particular for scheduling of data acquisition and processing in accordance with request of domestic and foreign users.

EARTH RESOURCES SATELLITE - 1 (ERS-1)

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Program Objectives: The main objectives are: (1) to establish the technologies of active microwave sensor, synthetic aperture radar (SAR); and, (2) to examine the terrestrial resources and environment, primarily focused on the geological and topographic survey and other applications such as scientific understanding of snow cover, sea-ice and vegetation distribution and monitoring of coastal and offshore activities and environmental pollution on a global basis.

The mission lifetime will be two years.

Sensors on Board: Three kinds of sensors will be flown on board: (1) An L-band synthetic aperture radar (SAR) is a main mission equipment for establishment of the technology of an active sensing satellite. SAR will provide approximately 18-meter spatial resolution over 75 km swath width. Data from SAR will be used for study of geological features, sea-ice behavior and oceanic dynamics. (2) A visible and near infrared radiometer (VNR) will provide approximately 18-meter spatial resolution over 75 km swath width and capability of stereographic imaging. Data from VNR will be used for understanding of vegetation distribution and discrimination, etc. (3) A short wavelength infrared radiometer (SWIR) will provide approximately 18-meter spatial resolution over 75 km swath width. Data from SWIR will be used for geological survey.

Orbit: Orbit altitude of approximately 568 km and inclination of approximately 98º (circular, sun-synchronous) with repeat cycle of 44 days and mean local time at descending node of 10:30 +/- 30 min. have been selected as baseline.

Planned Launch Date: ERS-1 is planned to be launched in early 1991.

Current Status: Study of ERS-1 was undertaken by NASDA in 1980, and since 1985 the Ministry of International Trade and Industry (MITI) has been responsible for development of mission equipments (SAR, VNR, SWIR, Mission Data Recorder, and Mission Data Transmitter) and NASDA for development of bus equipments, integration of the mission and bus equipments into a satellite system, tests of the system, launch and tracking and control of the satellite.

Data acquisition station and processing sytem is under study by MITI and NASDA.

Preliminary design of ERS-1 was completed in 1985. Critical design will start in 1986 after basic design.

SATELLITE OCEAN DATA SYSTEM SCIENCE WORKING GROUP (SODSSWG)

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Objective and Scope:

The overall objective of the Science Working Group is to provide guidance and advice on how best the satellite and associated in situ data needs of research oceanographers and allied earth scientists can be met. The specific terms of reference are to provide:

1) the conceptual design of a distributed data system to couple flight projects (e.g., TOPEX, N-ROSS/NSCAT, NOAA/AVHRR & OCI, DMSP/SSMI, ERS-1/SAR) with local/regional/national processing and analysis centers (e.g., at oceanographic institutions, universities and/or government facilities), and national archives (both U.S. and foreign),

2) recommendations concerning how this system will couple to the data management systems of large ocean research programs such as WOCE, TOGA, GOFS, and PIPOR,

3) recommendations concerning how this system will couple to present and planned systems for operational use of satellite data,

4) recommendations concerning how such a system can serve as the oceanographic component of and be compatible with similar data systems for multi-disciplinary programs such as the Earth Observing System,

5) an identification of present and potential agency roles in the implementations of such a system, and

6) recommendations concerning how NASA might best fulfill its role in the development of such a system, including as elements the Pilot Ocean Data System at JPL and appropriate facilities at GSFC.

Anticipated Benefits:

The overall strategy for ocean research using satellite data has been defined in two recent documents: "Oceanography from Space: A Research Strategy for the Decade 1985-1995," Part I "Executive Summary" and Part 2 "Proposed Measurements and Missions." This strategy is built upon the proposed sequence of space missions due to be launched circa 1990. These missions will produce an enormous and rapid increase in ocean data.

The long term goal of the subsequent SODSSWG studies is to have in place and operating by 1990, a distributed, linked, system of data management units that can process, distribute, analyze and archive ocean satellite data and associated in situ data for research. Implementing this will involve actions by NASA, other agencies, and the oceanographic research community.

Three major types of data management units are key elements to meeting the computation and data management challenges; archival data centers, data repositories for recent, mission

specific data; and, active data sites involved in intensive research. There are candidate centers for each of these three classes and several networks already in place or planned for related needs (e.g., SPAN, UNIDATA, NSFNet). There is not, however, a strategy defined to develop a data system for oceanographic research, to review the capabilities of existing candidate units, or, to identify serious gaps. The SODSSWG effort will develop this strategy.

Status:

SODSSWG was established in 1985 as a committee of about 12 members with associated agency liaison representatives. Broad community representation has been achieved through membership on panels of SODSSWG.

At the first meeting of SODSSWG at JPL on November 14-15, 1985, the group considered the management of existing or near-term satellite ocean data systems, existing data management elements including in particular the SPAN network and its applicability to oceanography, and the status of the NASA Ocean Data System, NODS. These case studies identified requirements for successful future operations. Four subpanels were established to address specific issues relating to: NODS; Archiving; Networking; and Non-NASA flight projects. The minutes of this meeting are available from JOI.

Subsequently, SODSSWG reviewed the potential of the SPAN network, (based on DECNET protocols) to serve oceanographers' needs. The group concluded that it was advisable to take the opportunity presented by the existence of SPAN and the new NASA Program Support Communications Network (PSCN) for the near term while techniques of internetwork connection developed. Fourteen oceanographic centers will be in operation on this network by summer 1986.

SODSSWG met for the second time at Goddard Space Flight Center on April 17-18, 1986 together with the WOCE/TOGA Data Management Working Group-IV. In addition to the full group, the panels held initial meetings to develop their agendas and reporting schedules. The full group reviewed progress on the SPAN and PSC networks, the Pilot Climate Data System, progress in the distributed implementation of the NODS GOLD Catalog and considered NOAA plans for satellite data management. Minutes of the meeting, including the panel meetings, are available from JOI.

ICE SHEET ALTIMETRY

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In view of the planned launch of several instruments which might provide information that could be applied to ice sheet investigations, NASA asked a Science Working Group (SWG) to assess these potential research applications. The report of the SWG* published in 1985, indicated that first priority should be given to acquisition and analysis of all over-ice data from future radar altimeters.

Radar Altimeters are well proven instruments for conducting glaciological research from space. Data from GEOS-3 and SEASAT have been used to improve significantly the surface-elevation maps of both Greenland and Antarctica. Such information has several important applications:

- Measurements of surface slope are needed to determine the driving force for ice motion.
- Accurate measurements of surface elevation delineate individual ice streams and their drainage basins, the grounding line separating ice sheet from floating ice shelf, and grounded ice rises within the ice shelves.
- Sequential altimetry surveys should reveal areas where the ice sheet is thickening or thinning.

In addition to the altimeter currently operating aboard the U.S. Navy's GEOSAT, similar instruments will be included on ESA's ERS-1, N-ROSS, and TOPEX. Although TOPEX will not overfly the polar regions, the highly accurate data from this mission will be used to "calibrate" and improve the accuracy of measurements from the other missions. Existing data from SEASAT is currently being used at GSFC to compile accurate surface-topography maps of Greenland and Antarctica within the latitude band 72° N to 72° S. In addition, positions of the ice-cliff margins of Antarctica that were traversed by Seasat are being mapped to an accuracy of a few hundred meters--a considerable improvement over existing maps. The resulting maps of topography and ice-cliff margins provide a set of "baseline" information appropriate to the lifetime of SEASAT (1978). Comparison with data from subsequent altimetry missions should reveal those areas where the ice-cliff margin has advanced or retreated, and areas where surface elevation has changed. In keeping with the recommendations of the SWG, NASA has requested release of the over-ice data from GEOSAT for such a comparison, and we are optimistic that the request will be approved.

The SWG also supported development of a satellite laser altimeter which, because of its smaller footprint, could provide a more accurate measurement of ice-surface elevations. In particular, thickening or thinning of the ice sheets would be more readily detected by laser altimetry. Early detection of such changes is becoming increasingly important, since ice-sheet thinning could have a significant effect on world sea level following the much predicted "greenhouse" warming.

*Satellite remote sensing for ice sheet research. NASA Technical Memorandum 86233, 1985.

SAR MAPPING OF ANTARCTICA

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Antarctica remains as one of the least explored and most poorly understood regions of the earth. Remote and inhospitable conditions have limited scientific investigations conducted on the surface and frequent cloud cover and the polar night severely restrict visible observations from aircraft or from space. Now, predictions of global warming due to increasing concentrations of atmospheric CO2 are leading to a heightened awareness of both polar regions and the impact that gradually retreating ice sheets could have on sea level. This concern, coupled with new initiatives to evaluate the mineral wealth of Antarctica is resulting in increasing levels of scientific investigation on the continent. These multinational programs have been very successful at piecing together important elements of the geologic and glaciologic puzzle but rarely have individual investigations been integrated into a broader portrait of the dynamics of the southern continent. This synthesis is not occurring because there are no continent-wide observations into which discreet, detailed observations can be incorporated.

In September 1985, a meeting was convened at JPL to address these issues by exploring the potential for imaging the continent with synthetic aperture radar (SAR) to be flown aboard the space shuttle. Discussions by this interdisciplinary and international group were focused first on the characteristics of the radar and the possible imaging modes capable from the shuttle. The scattering properties of the snow and ice comprising the ice sheet were also discussed in order to estimate what glaciological parameters could be deduced from radar images. Finally, the group considered the scientific problems that could be addressed with SAR, including, for example: 1) providing benchmark measurements of the spatial extent of the ice sheet and ice shelves; 2) identification of present and past flow features; 3) location and configuration of ice rises; and, 4) the location of blue ice zones. The consensus opinion of the group was that continent wide imaging to study problems such as those listed would constitute a valuable and practical program with a strong likelihood for success.

In addition to the more general goals, a need was recognized by several of the participants to establish accurately located points on the surface of the ice sheet that would be recorded on the radar image. The points would be used primarily for three purposes: to provide accurate benchmarks for compiling composite maps; to provide surface velocity measurements from repeated observations; and, to provide data for correcting determinations of the shuttle orbit. Large corner reflectors precisely located on the surface seemed to be the best way to satisfy this requirement and several test reflectors were deployed in Antarctica during the 1985-1986 season. A reflector at the South Pole is presently being observed by station personnel year round to record the effects of wind and snow on the structure.

The first opportunities for attempting a radar imaging program of Antarctica will be in 1990 when the European Space Agency is planning to launch a C-band radar aboard ERS-1. NASA's shuttle imaging radar program is currently planned to continue in 1990 with the flight in polar orbit of SIR-C, a multifrequency, multipolarization system. The capabilities of these two programs complement each other very well with ERS-1 providing repeated observations during its expected three-year lifetime and the SIR-C experiment providing important details on the physics of scattering from polar snow and ice. In anticipation of the opportunities

offered by ERS-1, the polar ice sheet community has organized to prepare a response to the ESA Announcement of Opportunity for ERS-1. The proposal is in a draft stage and will be circulated throughout the community by NASA Headquarters; all interested scientists are encouraged to contribute.

MODERATE-RESOLUTION IMAGING SPECTROMETER INSTRUMENT DEFINITION PANEL

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The Moderate-resolution Imaging Spectrometer (MODIS) Instrument Panel was formed in March 1984 to formulate the instrument requirements for the visible and infrared sensor which will provide global observations for terrestial, oceanic, and atmospheric Earth System research as part of the Earth Observation System (EOS). The EOS is planned to occupy one or more polar orbiting space platforms in conjunction with the Space Station. EOS is composed of a large suite of instruments and a data system to support global, decadal scale studies in the mid 1990's. The MODIS is a key EOS instrument, providing global coverage at about 1 kilometer resolution every two days, with complete spectral information. The science driving this stems from work with the AVHRR, CZCS, HIRS-2, and the Landsats. MODIS is complemented by the High Resolution Imaging Spectrometer (HIRIS) with 20-30 meter resolution in 128 bands over a 150 km swath.

The panel was composed of 20 scientists representing all discipline and technology concerns. The panel attempted to define the required visible and IR observations and operations required to support each major discipline, and to reconcile conflicts to provide design criteria for MODIS. The scales of interest ranged from days to decades, and from hundreds of meters to tens of kilometers over the globe. A major requirement was that a single and consistent data set emerge which would be useful for monitoring global change as well as permit research and development in earth sciences to proceed. That is, especially in the spectral domain, the panel members argued strongly against including only specific spectral bands for which proven algorithms exist.

The observational requirements for ocean imaging at 1 km were based on the MAREX and OCI on SPOT-3 studies. These were extended to obtain a complete spectrum at 10 nm resolution, ability to observe solar stimulated chlorophyll fluorescence, bioluminescence, and improved atmospheric correction studies using polarization techniques. For terrestial studies, requirements derived chiefly from the need to apply Thematic Mapper spectral information to global scale studies of vegetation performed now with two AVHRR bands, improved land surface temperature, and bidirectional reflectance (BDRF) measurements across the spectrum. There was no clear concensus on required spatial resolution for such global scale studies, and 500 meters was adopted pending further study. Most requirements for snow, ice, and atmospheric applications were superceded by land or oceans require-

ments, with notable exceptions in resolving oxygen a bands for cloud studies, and the need for atmospheric sounding to improve temperature measurements.

In many areas the requirements were very complementary among the scientific disciplines, and some conflicts were resolved in system design concepts. Thus two optical components were recommended. A tilting component (MODIS-T), having a 1500 km swath, 64' spectral bands covering the region from 0.4 to 1.04 microns at 10 nm resolution, with a minimum of 17 to be collected routinely if data transmission is limited, satisfies many of the ocean and land BDRF requirements. MODIS-T tilts up to 60 degrees for and aft. A nadir-looking component (MODIS-N) having 1500 km swath, 35 bands from 0.4 to 15 microns, 500 meter resolution for land (TM) visible bands, and 1000 meter resolution for the remaining bands is recommended as the complement. The instruments may share a common data system. This approach has the advantage of optimizing MODIS-T for a true spectrometer useful to both land and oceans, avoids most conflicts over coastlines (for ocean color needs the sensor must be tilted away from the sun to avoid specular reflections), while allowing those channels requiring high sensitivity and/or cooling and essential land and oceans data to be collected continually at nadir. Since the components are coupled, this breakout also serves to constrain calibration of each component as well as algorithms for derived properties.

Conflicts in determining an optimal equatorial crossing time were more difficult to resolve. Short of recommending several sensors at various times of day, the panel recommended 1 - 1:30 pm as the better choice over a morning crossing.

Other areas of discussed in the report are on-board and on orbit calibration requirements, on-board commandable processing and compaction, sensor dynamic ranges required for ocean, land, and cloud climatology studies, data system and data product requirements, archiving and distribution, validation procedures, management and scientific team concepts, and unique scientific opportunities given simultaneous MODIS and HIRIS observations.

The MODIS Instrument Panel Report will be released as a NASA Document in June, 1986. The MODIS will be a NASA Facility, to be developed and managed by GSFC. Both MODIS components are undergoing a more detailed Phase B study. An Announcement of Opportunity for the entire EOS, including requests for proposals utilizing MODIS observations, is scheduled to be issued by NASA Headquarters Office of Space Science and Applications (Code E) in October 1986. Proposals in response to this AO will be used to select members of the MODIS Science Team, which will serve as the scientific advisory group during instrument development and operation. Dr. Vincent Salomonson is the Goddard Science Team Leader, and Dr. William Barnes is the Sensor Scientist. Copies of the Panel Report may be obtained from either NASA HQ, Code EEC; or from GSFC, Code 671.

OCEAN TOPOGRAPHY EXPERIMENT (TOPEX)

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Program Science Goals: Topex/Poseidon is an international satellite mission resulting from the merger of NASA's Topex with the French Centre National d'Etudes Spatiales' (CNES) Poseidon experiment. The goal of the mission is to increase substantially our understanding of global ocean dynamics by making precise, accurate, and global observations of sea level for several years. The observations will then be used by NASA and CNES Principal Investigators selected through an Announcement of Opportunity and by the wider oceanographic community working with large international programs for observing the Earth, on studies leading to an improved understanding of ocean dynamics and the interaction of the ocean with global processes influencing life on Earth. The specific goals are to: (1) measure sea level of the global oceans for a period of at least three years with an accuracy and precision sufficient for determining the ocean's general circulation, tides, and mesoscale variability; (2) process and verify the data and distribute them in a timely manner to science investigators; and (3) lay the foundation for a continuing program for providing long-term observations of the ocean's circulation and its variability.

Instrumentation: The Topex/Poseidon mission will measure sea level using NASA and CNES altimeters on a well tracked satellite. The NASA altimeter is derived from similar instruments flown on Skylab, Geos-3, Seasat, and Geosat, except it will operate at two radio frequencies to measure the height of the satellite above the sea, and to correct the height measurement for the influence of free electrons in the ionosphere. The CNES altimeter is the first of a new solid-state design, and it will be used to test the design for use on future satellites. An advanced technology model of the NASA altimeter has been developed at the Applied Physics Laboratory of the Johns Hopkins University under the direction of the Wallops Flight Center of the Goddard Space Flight Center (GSFC); and its performance is now being evaluated. In addition, the Topex/Poseidon satellite will carry a three-channel microwave radiometer to gather data necessary for correcting the altimeters' height measurement for the influence of water vapor in the troposphere.

The orbit of the satellite will be calculated from tracking data obtained from the Defense Mapping Agency's Tranet system, and from a CNES Doris system. A third tracking system, which will be carried as an engineering demonstration, will track the position of the satellite using differences in the signals from the Global Positioning Satellites (GPS) received by Topex and by ground stations. Because the accuracy of the orbit calculated from the Tranet data depends significantly on knowledge of Earth's gravity field at the satellite's height, an improved gravity field is now being developed by the GSFC and the University of Texas, with participation from the University of Colorado. Verification of the satellite's height and orbit will be made using laser tracking of a retroreflector carried on the satellite.

Current Status: Topex/Poseidon was included in the President's budget submission and is awaiting Congressional approval. The proposed mission is based on work carried out from 1980 through 1985 including conceptual and definition studies by NASA and CNES, a one-year study by both agencies of the feasibility of a joint mission, and studies by three contractors of the feasibility of using existing satellite deigns for the mission. The three contractors were Fairchild, RCA, and Rockwell International. Each proposed a satellite complete with major subsystems that could be used with minor modifications. One of the three designs will be chosen based on proposals submitted by the contractors.

The proposed mission includes a launch of the Topex/Poseidon satellite by Ariane in 1991, a satellite designed to last three years with sufficient expendables for an additional two years, and a system to process and distribute data. The satellite will operate in an orbit with an altitude of 1334 km and an inclination of 63.4°. The orbit minimizes the influence of tidal aliases on the measurements of sea level; it repeats exactly every ten days to minimize the influence of geoidal undulations on measurements of the temporal variability of sea level; and it passes directly over two planned calibration sites, one at Bermuda to be operated by NASA, and one near Dakar to be operated by CNES pending approval by the government of Senegal. Because the NASA and CNES altimeters will share a common antenna, the two agencies have agreed that the CNES altimeter will operate for one day out of twenty (for 5% of the time) while the NASA altimeter is turned off.

Data Availability: NASA and CNES will each process data from their own instruments and tracking systems, and will then exchange processed data in the form of Geophysical Data Records. Geophysical data processed with verified algorithms will be available about six months after launch and continuously thereafter. Interim data records from the NASA instruments will be available within five days to provide information for scheduling the mission and for verifying algorithms. In addition, wind and wave observations from the NASA altimeter will be provided in near real time to the U.S. Navy's Fleet Numerical Oceanography Center within hours of aquisition of data from the satellite.

OCEAN COLOR INSTRUMENT (OCI)

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The OCI mission objectives are governed by the scientific requirements established by the NASA Ocean Color Science Working Group in the MAREX Report by the Joint U.S./French Science Team and by experience with the Coastal Zone Color Scanner.

OCI mission objectives may be summarized as follows:

Mapping world-wide chlorophyll distribution means in correlation with sea surface temperature, and spatial and temporal variance.

Determining important aspects of the role of biological physical coupling in phytoplankton dynamics in an oceanic system.

Verifying laboratory derived models for determining the instantaneous rate of marine primary production.

Enabling plankton biology to be studied within a Lagrangian reference frame.

The Marex Report recommended that NASA develop and fly an OCI mission, and it also furnished baseline scientific performance specifications. Goddard then completed a Phase A Study for the flight of such a mission on one of the NOAA H, I, J Series. Since that mission was not possible, NASA and the French Space Agency investigated the feasibility of an OCI flight on a French SPOT spacecraft. This task studied and scoped an OCI/SPOT mission in cooperation with CNES. A Phase A Report was issued in 1985 on the feasibility and ROM cost of that mission. In addition, it updated the option of a NOAA flight possibility on NOAA K, L, M series.

Status to date, efforts to obtain funding for an OCI have been unsuccessful. The one remaining flight option is on NOAA K, L, M Series. NOAA has decided that the OCI should be a commercial venture. They are looking for a commercial firm willing to build the instrument and sell the data for commercial and scientific uses. NASA supports this effort and would be active in making the data available to the research community should it come to pass.

Support of science working groups and science definition will continue. Design studies are underway for MODIS, the next generation of instrument beyond the OCI, which is planned as part of the Earth Observing System on the Polar Platform of the Space Station scheduled for launch in the mid-1990's.

Earth Observing System

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The new emphasis in Earth science is to think in quantitative terms about how the atmosphere, oceans and land surfaces function together as a global system. The Earth Observing System (Eos) is a multidisciplinary mission being planned for the 1990s to provide the observational capabilities and a data and information system needed to understand how the Earth works as a system, with emphasis on those global processes that operate at or near the Earth's surface. The concepts for Eos were developed by an Eos Science and Mission Requirements Working Group (SMRWG) that was chartered to consider the broad Earth Science objectives that could be addressed from a low-earth orbital perspective in the 1990s, including the specific observations and instruments that would be needed to meet the science objectives (Butler et al., 1984). After the SMRWG completed its work in the summer of 1984, an Eos Science Steering Committee (SSC) was formed to develop an implementation strategy for Eos while preserving the concepts set forth by the SMRWG. As part of the SSC's effort, six Eos instrument panels and an Eos data panel were formed to refine the concepts established by the SMRWG.

The concept that was developed diverges somewhat from past practices in that Eos is considered as an Earth science information system, where mission operations, Eos data bases and information about other relevant data sets are tied together by an information network (Butler et al. 1984, Arvidson et al. 1985, Hartle and Tuyahov, 1986). The network would link users with mission data repositories, with Eos and non-Eos data archives and with subsets of Eos and related data maintained as active research data bases.

The strategy of the SSC assumes that the Eos instruments are to fly on polar platforms developed as part of the Space Station complex. Since some of the instruments of research interest to Eos are considered operational instruments, it is assumed by the SSC that NOAA will develop, fly and produce data from those instruments designated as operational within the Eos payload. Thus, the aggregate payload of NASA and NOAA provided instruments are expected to achieve the requirements implied by the Eos science goals and objectives through flight on platforms in sun-synchronous orbits. Three platforms are presently planned to be launched by the Space Shuttle during the Space Station Project's Initial Operating Configuration (IOC). Two of the platforms will be provided by the United States and one by the European Space

Agency. Some Shuttle launches will be used for servicing the platforms and instruments, including repair and replacement of instruments as well as the addition of new instruments. This capability will make it possible for the mission life to be greater than ten years, a time interval required for study of some of the long term processes. A preliminary instrument manifest and deployment plan for the IOC time frame is shown in the table below (instrument acronyms are defined in Donohoe and Vane, 1986). Two of the platforms will orbit at an altitude of 824 km in the morning and afternoon and one at 542 km in the afternoon. To complete the Eos science requirements, the following instruments will be flown post IOC: AMSR, TIMS, NCIS, LFMR, LASA-B, CIS, IR-RAD, SUB-MM, F/P-INT, MLS, VIS/UV, DOPLID and ESTAR.

The key research problems to be addressed by Eos imply the need for international scientific cooperation. Implementation of a program aimed at understanding the Earth as a globally interacting system will require considerable attention be given to organizing and coordinating an effort to link multi-national projects with a more focused Earth observing project. Thus, the overall needs of Earth sciences requires approaching Eos as more than space platforms with instruments, but as an Earth science information system. Orbiting remote sensing instruments, in-situ measurement devices, and a data and information system must be fused into a highly capable research tool.

NASA-Eos/NOAA BASELINE SCENARIO

824 KM/PM		542 KM/PM		824 KM/AM	
*ADCLS	*CR	*MAG	*MPD	*SCM	*SUSIM
*F/P-INT	*GLRS	*SAR			
*HIRIS	*LASA-A				
*MODIS	*PMR				
AMSU(2)	ARGOS			AMSU(2)	ARGOS
AVHRR(2)	ERBI			AVHRR(2)	HIRS(2)
HIRS(2)	LFMR			LFMR	MLA
S&R	SEM			S&R	SEM
SSMI	DB			SSMI	DB
ALT	ATSR			ALT	ATSR
GOMR	OCI			ERBI	SCATT
SCATT				SEASAR	

* NASA PROVIDED (2) REDUNTANT INSTRUMENTS
MLA COMMERCIAL PLACE HOLDER

SECTION III - INDIVIDUAL RESEARCH SUMMARIES

Individual research activities supported in full or in part by the NASA Oceanic Processes Program in Fiscal Year 1985 are summarized in the following pages. The activities are listed alphabetically by senior principal investigator.

STUDIES OF OCEAN PRODUCTIVITY

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and

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Long-Term Interests: To understand the spatial and temporal variability of the amount and production rate of phytoplankton biomass and the relationship of such variability to physical forcing.

Specific Objectives: To understand the coupling of physical and biological processes responsible for the temporal and spatial variability observed in Coastal Zone Color Scanner (CZCS) and thermal imagery. I am particularly interested in mesoscale and large-scale variability.

Approach: Satellite imagery from the continental shelf off Vancouver Island, B.C. (with Dr. K. L. Denman) are being studied. Also, CZCS imagery from the Coastal Ocean Dynamics Experiment (CODE) off northern California have been analyzed and compared to the detailed physical measurements. Complete images of the California Current System are being produced. Eventually, this time series will cover the life of the CZCS and will include both AVHRR and CZCS data. Analysis of this time series is focusing on the seasonal variation of the observed patterns and on the dynamics of large filaments that transport large amounts of coastal water offshore.

Current Status: Analysis of CZCS imagery from Vancouver Island has concentrated on estimating decorrelation times as a function of length scale. Initial results show large differences between coastal and open ocean waters. A manuscript detailing the large-scale pigment patterns during CODE-1 has been submitted for publication. Temporal and spatial patterns of pigment were shown to be largely driven by the local wind field. All CZCS data from 1981 and 1982 covering the California Current has been processed, and analysis of these patterns is continuing. Comparisons of a set of CZCS images with a CalCOFI cruise in 1981 are being analyzed. This work was partially supported by ONR.

Scatterometer Applications to Ocean Surface Analysis and Numerical Weather Prediction

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Long term interest: To utilize scatterometer wind data to improve analyses over the ocean and numerical weather prediction and to increase our understanding of processes at the air-sea interface.

Objectives of this specific task: To (a) produce global fields of surface wind and surface fluxes using the complete 96-day Seasat scatterometer (SASS) data set; (b) Evaluate objectively dealiased winds and the impact of these winds on global gridded analyses; (c) develop techniques to increase the beneficial impact of scatterometer data.

Approach: a) Use a 4-dimensional Seasat analysis/forecast system to dealias and assimilate SASS winds and generate surface fluxes; b) Evaluate dealiasing schemes; c) Compare analyses with and without SASS data; d) Utilize data generated from a simulated "nature" model to assess future scatterometer data.

Status: The complete 96-days of Seasat scatterometer data has been objectively dealiased. This data has been assimilated using the GLA analysis/forecast system to produce global gridded fields of surface wind, wind stress and sensible and latent heat fluxes at 6 hour intervals from 0000 GMT 7 July to 0000 GMT 10 October 1978. Both the dealiased winds and the gridded fields have been made available to the oceanographic community and are currently being used by investigators in the United States, Canada and Europe.

A detailed evaluation of dealiased SASS winds was performed in order to assess the uncertainty in the selected wind directions. To this end, 266,769 comparisons were made between subjectively dealiased winds and the GLA objectively dealiased winds. Of these, the chosen directions agreed in 73% of the cases. A regional breakdown of the agreement between these fields showed little difference between the Atlantic, Indian and Pacific Oceans. However, significant variations between different latitude bands were observed. The best agreements were found in the Southern Hemisphere tropics. The lowest agreement occurred in high latitudes of the Southern Hemisphere. The global results were also evaluated in terms of speed and directional differences. 13% of the subjective and GLA objective winds were found to differ by more than 60°. But the vast majority of these were at relatively low wind speeds. Only 3% of the winds differed by more than 60° and had speeds greater than 10 m sec^{-1}.

Time-averages of the global gridded fields are currently being compared with existing climatologies. The effect of SASS data on the gridded analyses is also being assessed.

EXTRACTION OF GLOBAL WIND, WAVE, AND CURRENT FIELDS FROM SPACEBORNE SYNTHETIC APERTURE RADAR

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Long-Term Interests: Application of spaceborne microwave sensors to problems in physical oceanography, with emphasis on the energy exchange mechanisms at the air-sea boundary, i.e., the partitioning of surface stress into waves, turbulence, and drift currents.

Objectives: Determine the potential of SAR for measuring the directional wavenumber spectrum of both the surface wind and the surface wave field. Investigate the relationship of each to the other via development of wind-wave generation models and the use of coincident satellite and aircraft estimates.

Approach: Using digitally processed SIR-B (SAR) wave imagery collected coincidentally with NASA P-3 wave measurements, assess the potential of SAR for estimating the global ocean wave directional energy spectrum. Apply the results to refine models of hurricane development and infer variability of the global current field. Extract statistical properties of extreme waves, and determine the influence of strong currents on their generation.

Status: Analysis and interpretation of the SIR-B Extreme Waves Experiment conducted off the coast of Chile is proceeding. We have five days of simultaneous aircraft and spacecraft estimates of the surface wave field, with sea states ranging from 1.5 to 5 m, and waves in various stages of development. Analysis is concentrating on comparisons of directional spectra measured or predicted by way of four independent methods. We are finding subtle differences in the transfer function of each technique, but, in general, good agreement in sea states above 2 m. However, the global wave model estimates exhibit a systematic angular bias of about 30°.

Upon completion of the spectral comparisons, we will attempt to reconcile the inferred wave sources with major events shown on the meteorological analyses and on NOAA-7 and GOES imagery.

STUDY OF THE MESOSCALE STRUCTURE OF FRONTS OVER THE OCEAN USING THE SEASAT A SATELLITE SCATTEROMETER

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Long Term Interests: Our long term interests are in obtaining satellite derived geophysical parameters such as stress, wind, and temperature fields on meso- to synoptic scales. We will then use this data to produce basic fields for surface winds, geostrophic winds, surface pressure and temperature. These fundamental data will be used in our ongoing research into the nature of air-sea interaction (heat and momentum flux) on the mesoscale and larger.

Objectives: This project is an investigation of the mesoscale structure of midlatitude fronts using the Seasat A Satellite Scatterometer (SASS) data. We are analysing North Pacific fronts viewed by Seasat, collecting all ancillary data. Since we are involved in the Storm Transfer and Response Experiment (STREX) and interacting with groups using SMMR results, these relevant data are being used in our study. The understanding of the dynamics of fronts will enable the improvement of parameterizations in the large areas around fronts where traditional models often fail and fluxes can be very large. We will be able to evaluate SASS performance in the rare cases of very high winds.

Approach: Our approach is to develop an appropriate semi-objective analysis scheme that uses SASS as well as all other available information. The results will be checked against known flow patterns around fronts and cyclones from STREX and other such data to evaluate wind algorithms in regions of high winds and strong variation in boundary layer stratification. The results are simultaneously incorporated in a PBL model so that the value in forecasting capability and large scale flux parameterizations is evaluated.

Current Status: The semi-objective analysis scheme has been completed and was presented in a paper by G. Levy at the AMS Air-Sea conference in Miami, Jan. 1986. It will appear in JGR this year. Comparisons with SMMR data revealed mesoscale details. The PBL model was used to produce surface pressure fields comparable to NWS fields. This was also presented in Miami by Brown and will appear in MWR. Our present investigation is centered on vorticity and divergence behavior across a front.

ANALYSES OF THE WIND-DRIVEN RESPONSE OF TROPICAL OCEANS

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Long-Term Interests: The long-term interest of this research task is to study the upper-ocean response to surface wind stress estimates from tropical oceans. Modelling studies are used to identify regions of important variability in the wind field, analyze the associated oceanic response, and demonstrate the applicability of remotely sensed vector wind stress data.

Objectives: The primary objectives to the present research are to study the wind-driven variability of the tropical Pacific and Atlantic Oceans. Major thrusts include determining how the interannual solution relates to the seasonal response, investigating current capabilities to model the variability of the subsurface thermal structure given reasonable estimates of the surface wind stress, and assessing the impact of NSCAT winds on tropical ocean modelling.

Approach: A combination of ocean models, various surface wind analyses, and in-situ ocean data are invoked to carry out this research. The incorporation of several contemporaneous wind products helps to identify the range of error in present data used as forcing functions. The in-situ data serve to establish the observed scales of variability. Quantitative estimates of agreement between similar data/model parameters are performed. In regions of significant agreement the model results are used to infer and diagnose the observed scales of variability.

Status: Among the efforts of the past year, a multi-mode linear model of the tropical Pacific has been forced by ship-board estimates of the surface wind field for 1979-1983. Subsequent computations will be driven by estimates of the surface wind field derived from cloud motion vectors for the same period. In conjunction with this modelling effort XBT profiles from the Noumea-Scripps Ship of Opportunity Program are being processed at the ORSTOM center in Noumea. Both model and observational depictions of the upper ocean thermal field are being analyzed along the major ship tracks in the western, central, and eastern tropical Pacific.

ROLE OF SATELLITE MEASUREMENTS IN THE ESTIMATION OF PRIMARY PRODUCTION IN THE OCEANS

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Long-term interests of the investigator. Development of algorithms for estimating phytoplankton biomass and primary production on regional, basin or global oceanic scales, and for studying processes that govern biological systems in the oceans. Implicit is the need for a variety of platforms to address processes in widely varying time and space domains.

Objective of this specific research task. To characterize the undersampling error involved in estimates of areal annual primary production derived from ship measurements, and to consider whether that error may be reduced using satellite imagery.

Approach utilized for this task. Three questions are being addressed: (1) What is the variance/covariance in integral primary productivity over space and time? (2) What fraction of that variance can be accounted for/modeled using surface chlorophyll, and other information available to the remote-sensing data analyst? (3) How can algorithms minimize bias resulting from non-random sampling of space and time? In collaboration with Jay O'Reilly of the National Marine Fisheries Service, we are attempting to answer these questions for the Northwest Atlantic Continental Shelf using the MARMAP/Ocean Pulse data.

Status and progress. Taken as a whole, the MARMAP integral productivity data appear approximately uniformly distributed over time and space, and are lognormally distributed with mean of 0.91 $gC\ m^{-2}\ d^{-1}$ and a standard deviation of 0.67 $gC\ m^{-2}\ d^{-1}$. Surface chlorophyll and integral productivity are uncorrelated. However, the ratios of integral productivity to surface chlorophyll show a seasonal pattern with the highest values occurring in the summer. This suggests that photosynthetically available radiation must also be included in any model relating productivity to biomass abundance. A paper is being written based on results presented at the AGU/ASLO Ocean Sciences Meeting in January, 1986 (EOS 66(51):1267).

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Long-Term Interests relevant to this project are: (i) to develop the ability to calculate the wind-driven circulation of the upper layers of the tropical oceans; (ii) to understand the interaction of the tropical oceans and atmosphere.

Objectives of this Research Task. (1) To understand how errors in the specified wind stress propagate through model calculations into errors in oceanographic quantities such as sea level. (2) To construct a relatively simple coupled ocean-atmosphere model capable of simulating the El Nino-Southern Oscillation (ENSO) cycle, while specifying as little as possible.

Approach. We use a mix of analytic procedures and numerical models. The ENSO model is a perturbation model, with a specified mean state.

Current Status. In the wind error study we have completed the mathematical analysis needed to obtain the transfer functions from wind to sea level errors in the context of linear adiabatic physics. The analysis uses the results of Cane and Sarachik (1981) together with ray tracing techniques. Estimates of wind errors based on differences of products from FSU, NMC, and FNOC were then used to estimate errors in calculated sea level.

In the ENSO study, we have augmented the linear shallow water model of Cane and Patton (1984) with a simple mixed layer to allow explicit prediction of sea surface temperature (SST). The resulting model has been successful in reproducing the observed SST anomalies of the 1982/1983 event and those of the Rasmusson and Carpenter (1982) composite event. The model results show that horizontal advection is often important so that modeling SST as a simple function of local thermocline displacement is inadequate. In the next stage of this work the ocean model was coupled with an improved version of the atmospheric response model of Zebiak (1982). The coupled model has successfully simulated the major features of the ENSO cycle. Results suggest that interannual variability of the ENSO cycle is created and maintained by deterministic interactions in the tropical Pacific region. Mean conditions, including the annual cycle, largely determine the spatial pattern and temporal evolution of ENSO events.

Most recently the same model has been used to forecast ENSO events. Initial conditions are created by running the model forced by historical winds as analyzed at FSU. Forecasts made retrospectively from all the non-El Nino years since 1970 show that the model is generally able to predict both El Nino events and non-events 1 and 2 years ahead.

DEVELOPMENT OF IN-SITU SENSORS TO COMPLEMENT OCEAN COLOR REMOTE SENSING

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Long Term Interests: We are developing ocean color constituent algorithms and micro processor-controlled in situ optical instrumentation for deployment on buoys in order to improve the interpretation of satellite-derived ocean color signals.

Objectives: The objective of our current research is to develop a high spectral resolution solid-state instrument to measure radiance reflectance, beam transmission, chlorophyll fluorescence and near-forward/back scattering. Algorithms to deduce chlorophyll pigments, gelbstoff, and detritus concentrations from these data are also being developed.

Approach: We are developing a solid-state in situ prototype spectral transmissometer, upwelling radiometer and downwelling irradiometer for buoy deployment. A field-portable, 256-channel spectral radiometer is being used aboard ships and low-flying helicopters to develop a remote sensing reflectance model for deriving the concentrations of ocean color constituents and to help with interpreting "in situ" spectral radiometry data.

Current Status: The optical and electronic components of the spectral transmissometer and spectral upwelling radiometer have been successfully integrated, and the downwelling irradiometer integration is under way. A machine-language, CMOS micro-processor (80C85) has been programmed and integrated to control the operation and data storage and retrieval aspects of the instrument. A magnetic bubble memory data storage module is now being installed, and initial field sampling will start early this summer in the Gulf of Mexico.

A remote sensing reflectance model for Case I and Case II waters has been developed and tested in the Gulf of Mexico, Tampa Bay, the Georgia Bight, and the Straits of Juan de Fuca. It simulated the optical effects of chlorophyll-like pigments, gelbstoff, detritus, and a colloidal ferric precipitate indigenous to the Puget Sound/Straits of Juan de Fuca region. Fluorescence quantum efficiencies have been calculated from field reflectance data which appear to detect phytoplankton populations stressed due to nutrient limitation/photo-inhibition.

Bibliography: See attached

IMAGING RADAR STUDIES OF SEA ICE

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Long-Term Interests: Benjamin Holt, John Crawford and I are interested in developing applications of active microwave remote sensing to conduct research on science and operational problems of the polar oceans.

Objective of this Task: The objective of this task is to improve the interpretation of active microwave remote sensing data, especially imaging radar, for sea ice. The focus is on the observation of ice motion and type, the geophysical interpretation of the results and the development of methods of rapid analysis, preparing for data from future spaceborne imaging radars.

Approach: The approach is to examine the Seasat data set and data from SIR-B, Landsat, other satellites, instrumented airacraft and other platforms, notably buoys. The types of analysis in use are:

1) Tracking of ice floe features on sequential images to determine fine-scale ice motion. 2) Examination of ice motion data for divergence and vorticity with emphasis on the motion of ice generally near the ice edge to develop suitable means of describing the motion field. 3) Development of means of automatically extracting the ice motion from pairs of radar images using optimized image-analysis techniques. 4) Comparison with surface data and aircraft data sets as available, principally from field work such as from Freezeup or the Swedish Bothnian Ice Study.

Current Status: This new task, the successor to "Active-Passive Microwave Analysis of the Seasonal Cycle of the Polar Oceans", is devoted to preparation for the flight of SIR-C and of imaging radar satellites including those to be flown by ESA, Japan and canada in the early 1990s and whose data will be received and processed at Fairbanks, Alaska.

ARCTIC SEA ICE STUDIES WITH PASSIVE MICROWAVE SATELLITE OBSERVATIONS

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Long-Term Interests: The long range goals are to improve the capability for making large-scale sea ice measurements from passive microwave space observations and to utilize these measurements in oceanic processes studies.

Objectives: The focus of this research is on the study of new ice production and the associated air-sea-ice interactions in the Arctic using passive microwave satellite observations. Two primary objectives are (1) to refine existing sea ice algorithms for the purpose of mapping regions of new ice production in the central Arctic and in seasonal sea ice zones, and (2) to study the role of Arctic polynyas in sea ice and dense water production along the Alaskan and Siberian continental shelf regions.

Approach: Coordinated surface, aircraft and satellite passive microwave observations made during the Bering Sea Marginal Ice Zone Experiment (MIZEX-WEST) will be utilized to develop a capability to map regions of new ice production. In particular, microwave polarization at 18 and 37 GHz from the Nimbus SMMR and at 85 GHz from the upcoming DMSP SSMI will be utilized to discriminate between open water and new ice. In the study of Arctic polynyas, sea ice data from the SMMR as well as weather station data will be used to calculate heat and salt fluxes and ice production rates for the winter months of 1978 through 1982.

Status: A comparative analysis of SMMR data with aircraft and surface observations made during the Bering Sea experiment confirms that the polarization at 37 GHz maps the large-scale distribution of open water and thin ice. Work is continuing on the quantitative determination of a thin ice distribution in the Bering Sea. Monthly SMMR 37 GHz polarization variance maps for the entire Arctic region during the four winter periods analyzed are used to identify sites of persistent coastal polynyas.

RELAYS: Real-Time Link and Acquisition Yare System

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Our interests include obtaining a more complete understanding of meso- to large-scale low frequency ocean circulation; technologically they include exploiting existing state-of-the-art technology to create the necessary tools to do so. These developmental activities are consistent with and form an integral part of an oceanic observing system concept which we have been pursuing for several years.

The objectives are to obtain statistically reliable maps of various physical properties of the ocean. The requisite data should provide a new first-order kinematical description from which we expect to derive a more complete dynamical understanding of the linkages between small and large scales as well as the frequency dependence of temporally-averaged current fields.

Our approach to obtaining the desired subsurface horizontal sections relies upon developing a relatively low cost, general purpose relay system capable of reaching into the interior of the ocean and telemetering data from various depths, via a satellite-based data collection and location system (DCLS), to shoreside facilities. This new system permits data acquisition over a much broader depth range, with more diversified sensors, and with a nominal one-year lifetime. Major innovations include providing measurements from two underwater observational systems, extending a total systems communicator protocol, and transmission of all underwater systems data via satellite. Our initial configuration acquires temperature, pressure, and velocity fields, the current velocity being obtained from acoustic signaling float observations and differential location of the relay system with satellite Doppler DCLS records. Although we had planned to implement on-board current sensors, supplying relative current velocities for field calibrating the Lagrangian response of the drifter, funding limitations have prevented us from carrying the designs beyond the prototype stage.

Presently we have completed both the systems and detailed engineering designs; construction and field testing of prototype systems, each consisting of decoupled surface float (with controller, DCLS transmitter, and power supply), subsurface electromechanical cable, and acoustic receiver, has been completed. The three-buoy prototype RELAYS system is currently being used in the NSF-sponsored Pre-Subduction Experiment (J. Price, Principal Investigator).

FACILITIES FOR OCEANOGRAPHIC REMOTE SENSING APPLICATION

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Many questions relating to meso- and large-scale ocean circulation might better be addressed with an observing system, closely akin to that which is available to the meteorological community. A long term interest includes developing a complete ocean observing system (utilizing remote sensing, Eulerian, and Lagrangian measurements) which could be used to gain a more complete description and understanding of large-scale, low-frequency ocean dynamics.

Facilities provided under this contract form an integral component of an observing system. They consist of an appropriate selection of hardware and software capable of reducing both satellite and in situ data, integrating the data into a four dimensional display of the recovered fields, and providing a convenient and powerful interactive tool for the joint analyses of these data.

Our approach involves selecting a relatively low cost, general purpose, image processing and computational system which provides the greatest flexibility for the individual researcher, for integration of software developed at other institutions, as well as for future growth. Specialized software are created for specific oceanographic experiments in which these facilities are used for analysis of both in situ and remote sensing data.

This project was initiated in September 1982. The hardware/software system was selected (the ESL, Inc. VAX/IDIMS), installed, and the Oceanographic specific software from Scripps Institution of Oceanography has been implemented. The system is now being used to support analyses of data from the California Current, Agulhas Current, East China Sea and several smaller experiments. Numerical modelling and tomographic inversions are also being run on the system.

This work is jointly sponsored by the Office of Naval Research and the National Aeronautics and Space Administration.

TEMPORAL AND SPATIAL VARIABILITY OF SEA SURFACE WINDS

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Long-Term Interests: To utilize satellite measurements for the study of large-scale low frequency variability of the ocean through statistical and numerical models. Primary emphasis is on winds and sea level. However, sea surface temperature (SST), water vapor and atmospheric liquid water are also of interest.

Objectives: One of the objectives is to evaluate the usefulness of passive microwave measurements from the NIMBUS-7 SMMR and, after correcting calibration drifts and biases, use measurements during 1982 and 1983 to study the development of El Niño in the tropical Pacific. The second objective is to utilize Seasat scatterometer data to study the wind field over the global ocean.

Approach: The approach for determining the usefulness of the SMMR data has been to examine the brightness temperatures measured as a function of frequency, incidence angle and time and identify calibration drifts and cross-scan biases. These problems have been removed to develop internally consistent data sets which can now be used to construct monthly average fields of SST, wind speed, water vapor and atmospheric liquid water. The approach for analysis of scatterometer data is to generate spatial and temporal averaged wind fields from the vector winds and compute wavenumber spectra and space and time lagged correlations and EOFs.

Current Status: The SMMR brightness temperatures have been examined and several calibration and bias problems have been identified and corrected. We are now investigating several algorithms for retrieval of geophysical signals from the brightness temperatures. During this fiscal year, monthly average maps of SST, wind speed, water vapor and liquid water will be generated for the 1982-3 El Niño period.

In the scatterometer study, global monthly average fields of a number of wind parameters have been generated. These global fields are being analyzed to identify features poorly resolved in conventional wind data. Present efforts are also devoted to a detailed examination of the spatial and temporal variability of the near surface wind field over the Southern Ocean.

ANALYSIS OF AVHRR, CZCS AND HISTORICAL IN SITU CHLOROPHYLL DATA OFF THE OREGON COAST

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Long-Term Interests: Use of satellite data to investigate variability in coastal ocean and eastern boundary current systems, and to explore the causes of this variability. This study concentrates on relations between fields of sea surface temperature (SST), phytoplankton pigment concentration and wind stress off the northwest coast of the U.S.A., on seasonal and interannual time scales.

Objectives: 1) To characterize the seasonal cycles and interannual variability in SST and pigment concentration off the coast of Oregon by forming monthly composite fields from individual images obtained from the NOAA-AVHRR AND NIMBUS-7 CZCS sensors; 2) to explore the statistical relationships between these fields and fields of surface wind stress.

Approach: Satellite data from the West Coast Satellite Time Series (WCSTS) project at JPL will be used to explore methods of compositing the individual partial images into monthly mean fields, attempting to minimize the influence of daily cloud contamination and inaccuracies in the atmospheric correction algorithms. Historical *in situ* pigment concentration and temperature data from this region will be used to help interpret the composite images in terms of biological and geophysical variables. Seasonal cycles formed from monthly mean fields for the period 1979-1985 will be subtracted from the fields to form monthly anomaly fields. Using statistical correlations, wavenumber spectra and cospectra, and EOF analysis, the seasonal cycles and anomalies of SST and pigment concentration will be compared to the seasonal cycles and anomalies of meteorological forcing, available current and sea level data. An attempt will be made to identify dynamical processes responsible for the patterns revealed in the analysis.

Current Status: The project is new and the analysis has just begun. Historical surface pigment concentration and temperature data from this geographic region have been obtained for spring-summer, 1980-85, and are being examined. Other ancillary data sets are being obtained. Analysis of satellite imagery is expected to commence in July 1986, when the image processing system becomes operational.

SPECTRAL STUDIES OF MARINE PHYTOPLANKTON

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Long-Term Interests: The long-term goal of this program is the use of remote sensing for the determination of the productivity of the oceans, and to understand the relationships between the physics and the biology of the upper mixed layer. Included in the study are the relationships between chlorophyll abundances, the distribution of sea-surface temperature and phytoplankton productivity.

Objectives: The objective of this research is to develop techniques for the remote assessment of the productivity of the ocean. This research includes spectral studies of the fluorescence, absorption and scattering of marine phytoplankton, including investigations of taxonomic and photoadaptation effects and primary production required to interpret remotely sensed data obtained from the phytoplankton community in the ocean.

Approach: The approach is a continuation of work by Kiefer and Mitchell (1983) to explore simple mathematical relationships between the near-surface concentration of chlorophyll a and other pigments and the primary productivity of the upper mixed layer. These relationships will be used for the prediction of phytoplankton productivity through the remote sensing of the visible and infrared spectra of the ocean. These algorithms will include the description of the photoadaptive state and of the taxonomic composition of the phytoplankton population through the relationships between photosynthesis and the spectral characteristics of the phytoplankton. We will test the ability of these algorithms to predict primary production through the use of remote sensing and field samples.

Status: A collaborative effort with D. Kiefer and J. SooHoo to examine the relationship between photosynthesis and the spectral characteristics of phytoplankton cultures has led to the identification of photoadaptive characteristics of marine phytoplankton. An algorithm is under development for the assessment of the productivity of the ocean using visible wavelength data from the Coastal Zone Color Scanner (CZCS) and sea-surface temperature data from the Advanced Very High Resolution Radiometer (AVHRR).

MULTISPECTRAL MICROWAVE SIGNATURES OF SEA ICE AND ICE/OCEAN PROCESSES STUDIES

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Long-term Interest: An optimal utilization of satellite multichannel microwave data in the characterization of the sea ice cover and an improved understanding of ice/ocean/atmosphere processes.

Objectives: (1) To develop or improve techniques for deriving sea ice parameters from multispectral microwave radiances, (2) to create daily/weekly ice cover data set from 8-years of SMMR data, and (3) to analyze and evaluate seasonal and interannual variabilities of the ice cover and understand how ice interacts with the oceans and the atmosphere.

Approach: Orbital brightness temperatures from each SMMR channel are mapped to a common polar grid for comparison and evaluation of the utility of each of the channels in deriving geophysical parameters. Physical temperatures derived from THIR are also mapped to the same grid and used in combination with SMMR radiances to study spatial and temporal variabilities of ice emissivities. Statistical and cluster analysis of multichannel emissivities are implemented and results are interpreted with the aid of in-situ measurements and radiative transfer model results. Ice algorithms are developed using bootstrap techniques and consistency checks involving known spatial and temporal characteristics of the ice cover. Gridded ice data are derived, compiled, and analyzed to study leads and polynyas, the marginal ice zone, and growth and decay characteristics of the ice cover.

Status: A comprehensive study of the spatial variability of winter ice emissivities has been completed and a new technique for deriving sea ice concentration has been developed. An ice algorithm for the southern hemiphere has also been developed in conjunction with in-situ data and in collaboration with Neal Sullivan. Also, the microwave radiative characteristics of first year sea ice grown from a tank have been studied at 10, 18, 37, and 90 GHz in collaboration with Tom Grenfell. A paper on offshore polynyas and oceanographic effects, with H.J. Zwally, and A.L. Gordon, has been published, while another paper with A.L. Gordon on deep ocean polynyas over the Maud Rise and the Cosmonaut Sea is in preparation. About four years of daily SMMR polar maps have been generated and analysis of the long term ice data has been initiated.

OBJECTIVE EDGE DETECTION IN SST FIELDS AND A SURVEY OF OPEN OCEAN PAIRED VORTICES

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Long-Term Interests are a better understanding of physical oceanographic phenomena at the mesoscale through the use of satellite-derived data. The particular phenomena of interest are: large scale currents, eddy dynamics and air-sea interaction.

Objectives: (a) the development of a better edge detection algorithm for the location of fronts in sea surface temperature (SST) data. (b) a survey of large-scale open ocean vortex pairs to answer questions related to their size, motion, relative strength, origin, etc.

Approach: (a) the applicability of algorithms based on the detection of reflection horizons in seismology to the detection of SST fronts will be investigated. This technique, based on the Kalman filter, is attractive because it applies to time-varying or time-invariant front models, and to nonstationary or stationary noise processes. Furthermore, by using each scan line in the satellite data as a single channel of a multi-channel series, a multi-channel version of the Kalman filter frontal detector would use statistically relevant data across as well as along a front. (b) All available AVHRR data for 1982 through 1985 will be scanned at low resolution for the existence of paired vortices. Identified pairs will then be studied in detail with full resolution AVHRR data as well as in situ data where available.

Status: The project began on March 1, 1985; hence, little progress has been made to date. Work has begun on single channel versions of the Kalman filter edge detector and the low resolution AVHRR data is being remapped to a projection convenient for the survey seeking paired vortices.

Development of a Self-Contained Acoustic Current Profiler

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Long-Term Interests: The investigator's long-term interests are development of tools for understanding upper-ocean dynamics, particularly aspects involving atmospheric forcing. Present areas of focus are mixed layer response to wind forcing, upwelling, and upper ocean fronts.

Objectives: The program objective is to develop a self-contained current profiler using the Doppler shift of acoustic scattering to measure velocity. The technical challenges are (1) producing acoustic beams which are narrow enough that the profiler can be used from moorings, (2) reducing system power, making long-term deployments feasible, and (3) recording the data volume obtained by measuring at many depths.

Approach: System development is subcontracted to RD Instruments which has experience in bottom-mounted and shipboard acoustic profilers. RDI has reduced the acoustic transducer slidelobes by optimizing the impedance loading around the perimeter of the solid disk transducer to achieve shading of the amplitude in the radial direction and to suppress radial mode vibrations of thee transducer. Software has been developed to correct data for pitch and roll caused by mooring motion. A low power tape recorder has been incorporated which allows up to 60 megabytes of data to be recorded from a 50 watt-hour battery pack. The prototype instrument has been deployed in a mooring with 8 conventional vector-measuring current meters. This data is presently being analyzed.

Status: Ken Prada of Woods Hole Oceanographic Institution is persuing further development of a low-powered, high capacity data storage system. The ultimate goal is a system which appears to the data souorce as an IBM personal computer, thereby utilizing a defacto industry standard for data storage. This development effort is apparently yet in its infancy.

COMPARISON OF SATELLITE AND AIRCRAFT OBSERVATIONS

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Long-term Interests: The application of remote sensing tools to oceanographic research in the areas of ocean dynamics, productivity, and global biogeochemical cycles.

Objectives: To undertake a comprehensive comparison of Coastal Zone Color Scanner (CZCS) parameters with Airborne Oceanographic Lidar (AOL) parameters, specifically CZCS pigment and water radiances with AOL chlorophyll fluorescence and water Raman spectra. The comparison should determine if AOL data can contribute to CZCS algorithm development, especially in Case 2 waters.

Approach: CZCS scenes for days on which AOL data is available and which are cloud-free over the flight track are processed to level 2, applying Rayleigh and aerosol corrections to three radiance channels and determining pigment concentrations. The CZCS parameters are then extracted from under the AOL flight track and compared to the AOL data using various statistics, in collaboration with F. Hoge and R. Swift of Wallops Flight Facility.

Status: This is a new task beginning in fiscal year 1986. The CZCS data has been assembled and some of the AOL data is available. The processing to level 2 and initial comparisons have commenced with data from 1981 and 1982.

ASSESSING OCEAN PRODUCTIVITY FROM SATELLITE MEASUREMENTS

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Long-Term Interests. Plankton production in the oceans, the physiology of phytoplankton, nutrient consumption and recycling, relations between plankton production in the upper layer of the ocean and the sinking flux of biogenic material to deep water, the nitrogen economy of phytoplankton.

Specific Task Objectives. Since phytoplankton chlorophyll can be assessed using the Coastal Zone Color Scanner (CZCS) with useful precision we then ask whether primary production in the ocean can be estimated from the CZCS chlorophyll data. This is the objective of this research.

Approach. Using existing data on ocean primary production, collected in the past by ships, we compare depth-integrated primary production (mg C m^{-2} day^{-1}) with near-surface chlorophyll-like pigments (mg m^{-3}), determining the proportionality between the two. Two different ocean regions were examined: the Southern California Bight and the equatorial eastern Pacific. Climatological data, phytoplankton species and pigment group information are used as ancillary information to define and minimize error in the primary production estimates within regions.

Current status. We find that global ocean primary productivity can be better estimated using regional mean values of the proportionality between production and chlorophyll than a global mean value. Data for the Southern California Bight indicate that within a region, the proportionality between production and chlorophyll is related to climatological data, reducing the error in estimating production by about one-half. In the eastern tropical Pacific, variation in the production-chlorophyll relation depends upon the photo-adaptive state of the phytoplankton. Information on turbulence and mixing of the upper layer will be needed in order to best estimate productivity from chlorophyll data. Collaborators are Dr. Mark Abbott (JPL and SIO), and Dr. Robert Owen, Southwest Fisheries Laboratory, NMFS, NOAA.

DEVELOPMENT OF A DELAYED DOUBLE FLASH FLUOROMETER TO SIMULTANEOUSLY ESTIMATE PRIMARY PRODUCTIVITY AND CHLOROPHYLL IN AQUATIC SYSTEMS

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This investigator's long-term objective is to develop an understanding of the processes regulating photosynthesis and the distribution of primary producers over continental shelves. This research is integrated into the overall research effort at BNL to quantify the contribution of oceanic biota in the biogeochemical cycling of materials and energy across the edge of the continental shelf. To help achieve these objectives, we have developed moored xenon flash fluorometers to measure in vivo fluorescence of chlorophyll a in marine algae, thereby providing a basis for estimating biomass. These fluorometers were successfully deployed and recovered in the Mid-Atlantic Bight during 1984 as part of a DOE-funded program (SEEP).

This specific research task explores the feasibility of developing a xenon flash fluorometer which would simultaneously estimate ongoing photosynthetic rates as well as phytoplankton biomass in the ocean. In pursuing this objective, basic experiments were designed to test general principles which describe the functional relationship between photosynthesis and fluorescence.

The project is based upon a "pump and probe" technique, where the change in the fluorescence yield of a weak probe flash, following a saturating excitation flash, reflects the electron flow around photosystem II. The technique is potentially applicable to moored fluorometers or to airborne fluorosensors.

We have designed and constructed a microprocessor controlled pump and probe fluorometer. The prototype fluorometer is a bench top version which is used for laboratory experiments. In FY 1987 we plan to construct a submersible instrument which will be compatible with a CTD data acquisition system for use at sea. The submersible version will be field tested in spring 1987 and used in the second SEEP field program in 1988.

APPLICATIONS OF OCEAN COLOR IMAGERY IN THE STUDY OF OCEANIC PROCESSES AND THEIR BIOLOGICAL RESPONSE

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Long Term Interests: To demonstrate how satellite ocean color observations can be used to better understand the relationship between the physical and biological processes in the ocean.

Specific Objective: To use satellite ocean color data to quantify the large-scale variability in phytoplankton distribution, abundance and productivity in the equatorial Pacific Ocean and to relate this variability to the patterns of circulation and large-scale energy exchange of the region.

Approach: Satellite ocean color and sea surface temperature data will be combined with surface observations (physical, chemical, biological, meteorological) to address a number of specific topics including:

1- Expand the existing eastern equatorial Pacific data set to better quantify the interannual variability of the region and to document the effects of the 1982-83 El Nino.
2- For the highly productive regions along the western coast of South America, interannual variability in regional productivity appears to be driven primarily by changes in the size of the productive area rather than by the intensity of production within the area itself.
   a) what processes regulate the size of the productive habitat?
   b) how can we best use satellite ocean color data to refine our estimates of regional primary productivity?
3- Use ocean color imagery to understand and quantify the influence of islands and island groups on oceanic productivity.
   In particular, can the distributions and abundances of phytoplankton around the Galapagos Islands be used as an indicator of equatorial circulation patterns?
4- Use ocean color data to improve our understanding of the structure and the dynamics of the Equatorial Front.

In addition to the research program described above, I am directly involved in the production of the Global Ocean Basin Chlorophyll Data Set at Goddard Space Flight Center.

SCATTEROMETRY STUDIES

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Long-Term Interests: To develop dynamically-based models relating backscatter cross-section as measured by microwave scatterometers to geophysical quantities such as near-surface wind velocity and wind stress. To use satellite scatterometer data to study wind forcing of the ocean on small and medium scales.

Specific Objectives: (1) Model the interactions between centimetric ocean waves and both the wind and the long wave field (collaboration with G.T. Csanady of Woods Hole). (2) Calculation of the 2-d wavenumber spectrum of surface winds on scales from 200-2200 km, using the SASS unambiguous vector wind data sets (collaboration with D. B. Chelton of Oregon State). (3) Examination of sampling errors inherent in satellite scatterometer data (with Chelton).

Approach: (1) A realistic model for direct momentum and energy input from winds to short waves is being developed (Csanady) based on recent laboratory measurements of vorticity and water velocity under growing and decaying wind waves. Specific emphasis is placed on the detailed water motion in the boundary layer near the crests of steep wavelets. (2) The study of wavenumber spectra of winds was extended to ten regions, covering portions of all of the global oceans. 1-d spectral shapes were similar to those calculated earlier for the Pacific alone. (3) Simulations, using realistic scatterometer orbits, measurement swaths, and time-varying winds, were used to determine the magnitudes of random errors in spatial/temporal averaged winds as a function of geographical locations, averaging areas and times, and scatterometer individual measurement errors.

Status: (1) A paper on (water) separation bubble characteristics under the influence of wind shear spikes has been submitted for publication (Csanady). (2) A paper describing the wavenumber results in the Pacific will appear in the 4/86 issue of JPO. Global results are being prepared for publication. (3) An extensive simulation study shows substantial errors due to sampling for temporal averages of less than ten days. These errors are not significantly increased by addition of even spatially correlated scatterometer errors. Ambiguity removal skill plays an important role, however.

MASS, HEAT, AND FRESHWATER FLUXES IN THE OCEAN

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Long-Term Interests: The long-term objectives of this project are to estimate the fluxes of mass, heat, freshwater and other water properties in the ocean through synthesis of a variety of observations. These fluxes bear important relationships to the global climatic, hydrological, and biological cycles.

Objectives: Near-term objective is to estimate the meridional mass, heat, and freshwater fluxes in the South Indian Ocean using existing hydrographic sections.

Approach: The general approach is inverse modeling based on requirements of property conservation and the knowledge of wind forcing.

Status: The results of the study have been described in Fu (1986). A brief summary is given here. In the interior of the South Indian Ocean, the geostrophic flow is generally northward. At 18°S, the northward interior mass flux is balanced by the southward Ekman mass flux at the surface, whereas at 32°S the northward interior mass flux is balanced by the southward mass flux of the Agulhas Current. The Indian Ocean is exporting heat to the rest of the world's oceans at a rate of 0.7×10^{15}W at 18°S and 0.3×10^{15}W at 32°S. This heat flux is dominated by its barotropic component. There is a convergence of freshwater flux in the area between 18°S and 32°S, but the magnitudes of the flux are much less than existing hydrological estimates.

OCEAN CIRCULATION FROM SATELLITE ALTIMETRY

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Long-Term Interests: My long-term interests with this project are to explore the utility of satellite altimetry for studies of the general circulation and variability of the oceans. The rapid and global coverage of satellite altimetry makes it possible to study basin-wide circulation patterns which cannot be adequately observed by conventional techniques.

Objectives: Near-term objectives are (1) to study the temporal variabilities of ocean current using data from Seasat, Geos-3, and possibly Geosat, and (2) to investigate the nature of errors of altimetric measurement and to develop methods to correct them.

Approach: (1) Altimetric crossover differences (differences between measurements made at the ground track intersections) are used to construct spatial arrays of time series of sea level variations. The procedure involves least-squares optimization for both error reduction and time series estimation. (2) Orbit errors, the dominant errors in altimetric measurement, are modeled in terms of Fourier series with its coefficients determined by a least-squares method.

Status: (1) The 3.5 years of nearly continuous altimeter data from the Geos-3 mission have been used to study the seasonal and interannual variabilities of the Gulf Stream. The results indicate a dominant seasonal variability with the strongest surface current in late winter and the weakest surface current in late fall, consistent with limited in-situ measurements. (2) The system of equations for the Fourier coefficients of the modeled orbit error has been shown to be singular. The characteristics of the singularities and the treatment for them are discussed in a paper by Tai and Fu (1986). The developed procedure will be applied to the newly reprocessed Seasat Geophysical Data Records to make global corrections for orbit errors.

A Multi-Sensor Remote Sensing Approach for Measuring Primary Production from Space

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The long-term interest is the development of methods to assess primary production for the global ocean. The Coastal Zone Color Scanner images which have been processed to date demonstrate a real potential for obtaining truly global information on phytoplankton biomass in the future with the proposed Ocean Color Imager. In order to improve our understanding of global primary production, robust algorithms must be developed for determining primary production from ocean color.

We propose to develop a multi-sensor remote sensing approach for computing primary production from space. This approach is based on our existing capability to measure—from space—the prime environmental factors that regulate photosynthesis. The factors are the instantaneous shortwave radiation, the radiation experienced by the phytoplankton in the recent past and nitrogen availability. Shortwave radiation is obtained from VISSR sensors on the GOES satellites for major portions of the globe. Nitrate concentrations can be determined in many parts of the ocean from sea-surface temperature and nitrate regressions; sea-surface temperature is measured by AVHRR. We will begin with an empirical, multi-variate, correlational approach, and then progress to a semi-empirical approach, based on measuring phytoplankton biomass, shortwave radiation and sea-surface temperature.

The proposed multi-sensor approach should improve our estimates of primary production and its variability in response to climatic changes. It is a very important step toward a truly global assessment of primary production.

This work is in collaboration with Dr. M.J. Perry (University of Washington).

This project has only recently begun.

A Summer Ice/Ocean Microwave Remote Sensing and Mesoscale Modeling Experiment for Mizex/East'84
RTOP #161 40 01

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Long-Term Interests: To utilize microwave radiometric and radar data obtained from spacecraft and airborne instruments for studying the role of air-sea-ice interactions in hemispheric weather and climate, for detailed studies of polar lows, and to develop the potential of enhanced weather maps with the use of Nimbus-7 SMMR microwave radiances.

Objectives: 1) Analyze multispectral microwave radiance data acquired by airborne radiometers in combination with simultaneous and similar data acquired from spacecraft and surface observations to understand better the physical ocean/ice/atmosphere interactions occurring in the marginal ice zone (MIZ). 2) Improve the algorithm for obtaining sea ice concentration and age from such data.

Approach: Proceed with the analysis of the data set acquired during MIZEX'84.

Current Status: The past year has been spent preparing the NASA CV-990 and Nimbus-7 SMMR data sets into formats suitable for detailed data analysis. To this end, a Flight Report has been issued which lists detailed flight information on each of the seven microwave mosaic flights during MIZEX'84. Color-scale images have been generated for both the 19.35 GHz (A/C ESMR) and the 92 GHz (AMMS) imagers; these were designed for use in several papers that are currently being written by various MIZEX sub-groups, e.g. the 'eddy papers', the 'morphology papers', and the 'ice physics papers'. There are at present eight papers actively being assembled for the special JGR issue on MIZEX. Strong differences in the signatures of the multiyear sea ice (during freezing conditions) were noted when comparing the AMMS and ESMR mosaics. In fact, in the AMMS images, it was not possible to distinguish multiyear ice from open water. The 18 and 37 GHz airborne microwave (AMMR) data have been processed using the SMMR sea ice algorithm to produce strip charts of total and multiyear sea ice concentrations along the aircraft tracks. Both freezing and melting conditions were encountered.

AN INVESTIGATION OF THE UTILITY OF OCEAN COLOR IMAGERY FOR DELINEATION OF OCEANIC PROCESSES IN THE WESTERN NORTH ATLANTIC

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Long Term Interest: To understand the color of the ocean and its variability (in space and time) as observed by the Nimbus-7 Coastal Zone Color Scanner (CZCS), in relation to physical and biological processes.

Specific Investigation Objectives: (a) study the seasonal variability of the phytoplankton pigment concentration; (b) attempt to compute the net sources of phytoplankton pigments from observations of color and thermal imagery on successive days; and (c) derive a time series of high resolution thermal maps.

Approach: The test area chosen to carry out the study is the Middle Atlantic Bight, a region of intense study in 1982 and 1985 by virtue of the Warm Core Rings Experiment (WCRE) and the BIOWATT experiment. WCRE and BIOWATT investigations yield the ancillary surface data (surface current, surface pigments, thermal structure, etc.) needed for comparison with CZCS imagery. These data will be useful in testing the satellite-based techniques, which can then be extended to other time periods and locations.

Status: To assemble seasonal time series, several problems have had to be overcome. These include development of a good sensor calibration history, incorporation of more complex physics in the atmospheric correction procedures, and of course, acquisition of the data in question. Sufficient progress has been made on these problems to produce a time series of temperature and phytoplankton for the WCRE study area covering the period 14 April to 8 May 1982. This series clearly delineates the seasonal warming and the "spring bloom," revealing comparable flowering in the Shelf and Slope waters. Attempts to generalize this short time series to a longer interval are underway. A thermal time series has been produced which permits seasonal studies of slowly varying phenomena, e.g., western boundary current separation latitude, El Nino, seasonal warming, etc. This time series was the basis of the SST sequences used in the "Planet Earth" television series.

RADAR SCATTERING FROM THE OCEAN SURFACE: A VARIATIONAL APPROACH

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Long Term Interests: To utilize recently developed variational methods for obtaining a greater understanding of radar scattering from the ocean surface and for improving the determination of oceanographic parameters from radar measurements from satellites. The results of this program will eventually lead to an improved method for determining the characteristics of the ocean wave field and of the ocean surface wind field through radar scatterometry.

Specific Objectives: (1) To use the variational method for finding the scattering of an electromagnetic plane wave by a sinusoidal surface. (2) By employing stochastic concepts to a spectrum of such sinusoids, the results of these calculations will be applied to the scattering from the actual ocean surface. (3) To interpret data of radar scattering from satellites utilizing these methods.

Approach: The approach to all these calculations is by way of a stochastic variational method previously developed at APL and tested on a variety of scattering problems. In this method, a trial function is chosen as a first approximation to the scattered field where a judicious choice for the trial function is important.

Current Status: A paper entitled "Wave Scattering by a Sinusoidal Surface: A Variational Approach" by E.P. Gray and J.F. Bird has been accepted for presentation at the URSI Symposium Commission B in Philadelphia, Pennsylvania, June 9-13, 1986. A paper entitled "A Variational Approach to Scattering from the Ocean Surface: A Sinusoidal Model" by E.P. Gray and J.F. Bird has been accepted for presentation at the URSI Commission F Open Symposium in Durham, New Hampshire, July 28-August 1, 1986. A paper entitled "Variational Solution for Wave Scattering by a Sinusoidal Reflection Grating" by J.F. Bird and E.P. Gray is in preparation and will be submitted for publication shortly. These papers document our variational solution for scattering from a sinusoidal surface. We are currently attempting to extend these solutions to the case of several sinusoids. In addition, one paper by J.F. Bird (supported in part by grant #NAGW-574) has been published in JOSA A, and another such paper has been accepted by JOSA A.

MICROWAVE EMISSION FROM POLAR SURFACES

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Long Term Interests: To determine how multifrequency microwave remote sensing imagery can be used most effectively to investigate the large scale structure of sea ice and its environment. Important parameters amenable to this method are sea ice extent, concentration, ice type distribution, and weather effects which influence the surface structure of the ice pack.

Objectives: To determine the relationships between microwave emission from ice and snow surfaces and the controlling physical properties in order to determine how well passive microwave imagery can distinguish among sea ice types and surface conditions throughout the year in different parts of the Arctic Basin.

Approach: We make surface based measurements of emissivity at frequencies from 6.7 to 90 GHz together with concurrent determinations of the important physical properties of the upper layers of the ice and snow. Recently derived theoretical models are used to calculate emissivities for comparison with our observations. These efforts are being combined with concurrent radar observations to see how well multisensor comparisons can enhance the information retrieval.

Current Status: Our principal experimental activity during the past year was the second stage of the CRREL ice tank experiment from January to March 1985. We studied in detail the growth cycle of sea ice from formation, to thick cold ice, through to warmup and the transition to multiyear ice. We also observed a simulated pressure ridge whose signature was intermediate between cold first-year and multiyear ice. Preliminary results were presented at the IGARSS symposium in October.

Since mid-1984, we have been working closely with the MIZEX remote sensing group in order to define the passive microwave signatures of spring and summer ice and to compare and correlate our results with radar data. We have found, for example, that the emissivities may reveal significant information about local weather conditions via the properties of the surface layers of the ice or snow. In cooperation with European coworkers, we proposed and are developing an all season 90 GHz algorithm for ice concentration based on polarization which will exploit the high spatial resolution of the highest frequency channel of the DMSP SSM/I. This work is sponsored jointly with the Office of Naval Research under the contract N00014-81-K-0460.

Ocean Modeling and Data Analysis Studies

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Long term interests center around understanding the physical processes that dtermine the low frequency ocean general circulation and its coupling with the atmosphere, and in learning how to model the behavior of the ocean and the atmosphere on these scales. Knowing the boundary conditions at the air-sea interface is essential, and a secondary interest is in improving our knowledge of these surface fluxes of momentum and energy through the use of conventional data, remotely sensed data and models.

Specific objectives of recent work and approach used have included: (i) developing and using ocean models appropriate for studying both how the ocean and atmosphere jointly determine sea surface temperature changes in the tropics, and how strong current systems like the Gulf Stream create recirculation zones; (ii) evaluation of wind stress, wind stress curl and surface wind convergence feilds over the ocean from conventional and remotely stressed data. (iii) examination of the wind variability in the tropical Pacific from long time series of island observations.

Current status of work is that: (i) one paper, on the relationship between the monthly mean wind variability, has appeared in Monthly Weather Review (ii) another paper, on factors affecting our ability to model the deep general circulation of the ocean with simple models has appeared in the Journal of Geophysical Research (iii) another ms, on the vertical and horizontal structure of monthly mean wind variability in the tropical Indian and Pacific oceans has been submitted for publication (iv) three mss on the variablilty of tropical Pacific island winds are in preparation. (v) modeling studies of SST evolution during the 1982-83 El Nino event, using different imposed wind stress fields to force the model, are underway.

Other support is received from the National Science Foundation and the National Ocean and Atmospheric Administration.

SEASAT ALTIMETER REPROCESSING TASK

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Long-Term Interests: To provide geophysical data to researchers for the study of oceanic phenomena. To engage in the development of geophysical data from satellite-borne sensors by developing systematic techniques for updating high demand data sets.

Objectives: The primary objective of this task is to reprocess the Seasat Altimeter (ALT) data. Implementation of advanced geophysical algorithms will result in a more accurate data set. Algorithms implemented in this task were inherited from the Seasat project and provided by scientists conducting pertinent research.

Approach: The ALT data are being reprocessed to produce a new, updated geophysical data record (GDR86). The principle goal is to use a more accurate ephemeris developed at Goddard Space Flight Center(GSFC) to improve the radial height and sea surface elevation. This new ephemeris incorporates Seasat ALT data and Doppler tracking data and replaces the Code 900 ephemeris used for the production of the original GDR. Deficiencies in the backscatter coefficient can be eliminated by inverting the GDR backscatter values and processing the resultant AGC through a linear backscatter retrieval algorithm. In addition, a new model function will more accurately portray wind speed. Furthermore, better temporal distribution of the SMMR wet troposhere correction will be achieved.

Current Status: The GSFC ephemeris spanning the entire Seasat mission has been acquired and processed to produce a validation data set. The new wind speed model function has been implemented as have corrections to the backscatter coefficient and ionosphere pathlength correction. A validation data set has been produced for analysis. Upon completion GDR86 will be distributed on magnetic tape and made accessible by the NASA Ocean Data System.

OCEANIC REMOTE SENSING LIBRARY

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Long-Term Interests: To provide a special collection of books, periodicals, and atlases dedicated to oceanography and ocean remote sensing. Specifically, internal reports, the so-called "gray literature," form the core collection. To enable investigators to locate and receive documents related to their research interests by providing a reliable and consistent source.

Objectives: To collect current publications and provide access to relevant documents through a physical collection and electronic search system. To enhance the information collection by adding pertinent literature requested by library patrons.

Approach: To provide access to oceanic remote sensing documents the ORSL librarian acquires, organizes, and distributes major scientific journals. In addition, DMSP, TOPEX, NSCAT, and PODS reports have been a focus of document acquisition. The ORSL uses the Library of Congress classification system. Material distribution requests are received by mail, telephone, and the NODS on-line bibliography. This interactive system provides abstract search, extract, review, and order capabilities for JPL researchers and others working at large distances from JPL. Reference citations can be reviewed on a computer terminal and ordered from the ORSL collection. The librarian compiles the bibliography entries.

Current Status: The collection of books, atlases, and periodicals was expanded in FY85 to meet researchers' requests and to provide an up-to-date collection. The percentage increase over the FY84 collection size was: Books, 7%; Atlases, 5%; Periodicals, 9%. Moreover, the bibliography was expanded by 19%, and more than 600 documents were distributed to researchers. Electronic computer-to-computer information transfer was initiated, reducing in-house development time.

THE USE OF SATELLITE-DERIVED CHLOROPHYLL FIELDS IN MODELING CARBON FLUX ON THE SOUTHEASTERN U.S. CONTINENTAL SHELF

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Long-Term Interests relevant to this study are: 1) to develop techniques for embedding pigment fields obtained from the Coastal Zone Color Scanner (CZCS) in numerical models of physical-biological interactions, 2) to use CZCS data in conjunction with numerical models of physical-biological interactions to investigate carbon flux on continental shelves.

Objectives: 1) Use CZCS data as initial conditions, updates and validation for a Lagrangian particle model and a physical-biological model of the lower trophic level dynamics on the outer southeastern U.S. continental shelf. 2) Use CZCS data in conjunction with phytoplankton fields obtained from the lower trophic level dynamics model to understand the influence of physical and biological factors on the across-shelf flux of carbon resulting from wind- and Gulf Stream-induced upwelling on the outer southeastern U.S. continental shelf.

Approach: To investigate the effect of the Gulf Stream and its associated upwelling on biological production along the outer and mid-shelf region of the southeastern U.S. continental shelf, two numerical models have been developed: a Lagrangian particle model, and a ten component coupled physical-biological model of the lower trophic level dynamics. These models are based upon data obtained during the GABEX I (February - June 1980) and GABEX II (June - October 1981) field programs. The pigment fields derived from the CZCS will provide initial conditions and subsequent verification for these models. Initially, the CZCS data will be interfaced with the Lagrangian particle model, which is the simpler of the two models. Numerical experiments performed with this model will aid in determing the validity of the physical model. Differences in the simulated and actual pigment fields will also indicate the importance of biological processes.

Current Status: The available CZCS images for the southeastern U.S. continental shelf from the GABEX I and II time periods have been identified, processed and received at Texas A&M University. Present effort is focused on interfacing these data with the Lagrangian particle model. This work is being done by Mr. J. Ishizaka, a graduate student at Texas A&M University, for his Ph.D dissertation research.

APPLICATIONS OF LASER TECHNOLOGY

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Long Term Interests: To demonstrate that existing airborne laser technology and electronic systems can provide valuable, quantitative, physical, chemical, and biological oceanographic data over wide areas. This technology will be directed toward enhancing the scientific understanding of the ocean surface as well as the subsurface water column. Interests include using laser systems (separately and in combination with passive ocean color systems) to advance the development and calibration of satellite color scanners and altimeters.

Objectives: (1) To develop accurate airborne lidar methods of measuring oceanic water column constituents including chlorophyll *a* and other phytoplanktonic photopigments such as phycoerythrin. (2) To combine the airborne laser-induced and water-Raman-normalized pigment fluorescence with simultaneously recorded passive ocean color data to identify optimum spectral regions (and in-water algorithms) for advanced spaceborne ocean color scanner development. (3) To develop airborne lidar methods for measurement of oceanic optical and bio-optical parameters.

Approach: The NASA Airborne Oceanographic Lidar will be flown in cooperative, multi-institutional, oceanographic field investigations such as the National Science Foundation's Warm Core Rings, the Department of Energy's Shelf Edge Exchange Processes and Spring Recovery Experiment field efforts, and the Office of Naval Research's optical variability and bioluminescence studies (BIOWATT). These past (and some ongoing) field programs involve numerous universities and oceanographic institutions.

Status: Airborne laser-induced chlorophyll *a* and phycoerythrin fluorescence data have been obtained, analyzed, and supplied to the cooperating institutions. Corroboration with participating scientists in the analysis of the data and publication of important findings is an ongoing activity. Comparing airborne laser derived chlorophyll *a* measurements with moored fluorometer, shipboard, and Coastal Zone Color Scanner data is considered high priority for understanding phytoplankton dynamics and estimating primary productivity. During the past several years, numerous papers have been published on oceanic lidar applications to airborne measurement of chlorophyll, phycoerythrin, tracer dye concentration, oil film thickness and identification, monomolecular films, front mapping, water depth, and sea surface backscatter characteristics. Several papers have been recently published on active-passive (laser-solar) airborne ocean color methods for phytoplankton pigment concentration measurement, and several chlorophyll color algorithm studies show promise for eventual publication.

MICROSCALE OCEAN SURFACE DYNAMICS

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Long Term Interests: The exchanges of momentum, energy, mass, and heat across the air-sea interface all occur at microscale; spatial and temporal integrations give us the global weather and climate. A consequence of the air-sea interaction at the microscale is the generation of surface waves, which can also be used as a indicator of the dynamic processes. Our long term interests are to study the microscale ocean surface dynamics to provide the base for understanding the global scale air-sea interaction problem, and also to provide the foundation for proper interpretation of microwave remote sensing data.

Objectives: (1) To study the detailed statistical characteristics of the ocean surface, (2) to study the evolution of wind wave spectra under the actions of winds and ambient currents, and (3) to study the wave breaking processes and the source of turbulence at the upper ocean layer.

Approach: The approach adopted here is to conduct a selected number of carefully controlled experiments at the wind-wave and current interaction facility at Wallops Flight Facility. Theoretical investigation will be conducted at the same time. Comparisons with the field data will be emphasized, and acutal comparisons will be made whenever field data are availble. Our aim is to understand the basic physics of the microscale ocean dynamic processes; therefore, our approach is analytical and physical rather than emperical.

Status: Our study is a continuous effort within the air-se interaction program. The most recent results are: (1) We found that the wind can suppress the long term weak nonlinear wave-wave interaction processes, (2) we have established the influence of the sea state on the determination of the drag coefficient, and (3) we have established an analytical model of the oceanic whitecap coverage percentage as a function of the sea state and wind condition. Further investigation of the wave current, and turbulence interaction phenomena is planned for the coming years.

MICROWAVE RADAR OCEANOGRAPHIC INVESTIGATIONS

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Long term interests: Remote sensing of ocean surface waves and surface conditions; electromagnetic interactions; wave dynamics.

Task objective: To develop a viable spaceborne microwave observing system for ocean wind and wave spectrum measurements. A simple and accurate approach to the global wave spectrum measurement problem has already been demonstrated in the ROWS (Radar Ocean Wave Spectrometer) technique. This technique utilizes short pulse radars in a conical scan mode near vertical incidence to map the directional slope spectrum in wave number and azimuth and can be implemented at low cost by simply modifying existing satellite altimeters. Specific task objectives include a) defining a Shuttle experiment to demonstrate the technique, b) further refining and validating the technique, principally through joint flights with the Surface Contour Radar (SCR), and c) utilizing the already proven capability of the aircraft ROWS to conduct basic wave physics investigations.

Current Status: No effort has been made this year to define a Shuttle experiment; however, some analysis work has been carried out in connection with R. Beal's Spectrasat concept. This indicates that "azimuth walk" may limit the integration time to ca. 0.05 s. Signal to noise, however, is still adequate. The Norwegian Sea hindcast study is being prepared for publication. Work on this study had taken a back seat to the MASEX mean square slope analysis, which is now complete and submitted for publication. The MASEX fetch-limited data set is essentially analyzed. However, publication is being delayed on account of an what appears to be anomalous signal and noise levels. Also, we are waiting for the final SCR spectra for the final comparison tests. Most critical will be how accurately the ROWS estimates the relative weights and directions for the bidirectional wave systems. On completing these comparison tests, the ROWS data will be analyzed for growth and spreading characteristics as a function of fetch and the bidirectional wave systems will be modeled. All the SIR-B underflight data have been analyzed and communicated to the Applied Physics Laboratory where three-way sensor intercomparisons (ROWS, SCR, and SIR-B) will be made in common formats. The comparisons made so far show remarkably good agreement between the three sensors for a variety of sea conditions (see papers in IGARSS'85 Digest; Beal et al., 1986). The ROWS particpated successfully in the FASINEX experiment in February, 1986, obtaining good wave directional spectra data for the five flights as well as cross section data during the low-level runs with the SCR. A new A/D and data system for the ROWS is being procured which should be ready for the proposed EM bias experiment next year.

AIR-SEA INTERACTION STUDIES

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Long-Term Interests: Our aim is to determine the intrinsic properties of short gravity-capillary waves and their relation to wind stress and long waves. Implications of the results for air-sea interaction and microwave remote sensing will be investigated.

Objectives of this specific research: Our objectives were to extend our previous findings on wavenumber spectra of short waves to higher wind speeds and various atmospheric stability cases.

Approach: Surface roughness can best be described by the wavenumber spectrum of short waves. Therefore, we measured wave heights and calculated the frequency spectra which were then converted to wavenumber spectra by correcting for Doppler shift caused by long wave orbital velocities and surface currents. Surface roughness, obtained from wavenumber spectra averaged over time, can be correlated with measured friction velocity to investigate its dependence on wind stress. The breaking waves also contribute to surface roughness. However, due to their turbulent nature, breaking waves can not be studied with the above approach and were excluded from these analyses by using a technique we developed earlier.

Current status: With the techniques we developed, several data sets were analyzed. For wavelengths 1.4 to 5 cm (commonly used in scatterometers) the spectral amplitudes were found to grow by a factor of 10 as the wind increased from 2.7 to 6.1 m/s. A publication on this work is almost ready for submission. Collection of wave data at higher wind speeds is in progress in Lake Washington. In addition we participated in a joint experiment on platform FPN in the North Sea in December 1985. For winds up to 32 m/s we directly measured the wind stress. Radar backscatter at C and Ku bands were simultaneously obtained by W. C. Keller of the Naval Research Laboratory and W. Alpers of the University of Bremen. This latter data set will serve to test the implications of the results from the Lake Washington wave study for microwave remote sensing of winds by scatterometers.

OCEAN CIRCULATION STUDIES WITH SATELLITE ALTIMETRY

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Long-Term Interests:

I am interested in studying ocean circulation variability on time scales of weeks to years with an emphasis on understanding the wind forced circulation.

Objectives:

The objectives of this study are to understand the physical processes that cause sea level variability as measured with satellite altimeters.

Approach:

Quantitative descriptions of sea level variability are derived from satellite altimeter data. In situ data and models are used to understand the physical processes that cause the observed sea height fluctuations.

Status:

Mesoscale Studies:

An extensive analysis of wind fields and current measurements in the North Pacific has been undertaken to understand wind forced mesoscale circulation. A first paper on this work has appeared (Niiler and Koblinsky, 1985) and a second is now in preparation.

Basin Scale Studies:

Work is in progress to study large scale variability in the Northwest Atlantic using GEOS-3 and SEASAT data. Interannual fluctuations have been found with an rms of 10cm and are being compared with in situ data and models.

A global estimate of the long wavelength mean sea level relative to the PGSS4 geoid has been computed and the results are similar to those found by others. Further calculations are now in progress with new orbits and geoids computed from the latest TOPEX gravity model.

A NASA graduate student fellow, Dan Steinberg, has implemented the NOAA/GFDL Ocean General Circulation Model on the CYBER 205.

OCEAN SURFACE WIND STRESS MEASUREMENTS IN SUPPORT OF SCATTEROMETRY STUDIES

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Long–Term Interests: The application of remotely sensed vector wind stress measurements to large scale air–sea interaction problems.

Objectives: To establish an empirical correlation between the magnitude of the ocean surface wind stress, τ_o, and coincident microwave backscatter as given by the normalized radar cross–section (NRCS). To investigate differences between this correlation and correlations between wind speed.

Approach: Ignoring the wind direction for the present, the approach is to obtain coincident measurements of τ_0, and NRCS over a wide range of conditions (sea state, sea surface temperature, atmospheric stability, and wind speed, then investigate the empirical relationships that emerge. The results should place useful constraints on theoretical studies. No presumption is made that NRCS is more closely related to wind stress than to other quantities, only that since wind stress is the parameter of most interest at the sea surface, an attempt should be made to directly relate it to measureable quantities such as NRCS. Airborne scatterometry is to provide the NRCS data, thus relieving the severe sampling constraints of a satellite system while maintaining the mobility to sample different geographical regimes. The surface wind stress is measured from either surface ships or buoys via the inertial dissipation technique and also from boundary–layer turbulence aircraft.

Status: An instrument has been developed for routine τ_o measurements from surface ships and buoys. During the intensive phase (10 February–10 March 1986) of the Frontal Air–Sea Interaction Experiment (FASINEX) it operated continuously on board R/V Endeavor. Analyses are now underway to verify that stress was measured correctly. In addition, hot film probes from the Naval Postgraduate School were operating on both R/V Endeavor and R/V Oceanus, and turbulence aircraft overflew the ships. Thus a complete set of wind stress data is available from FASINEX. Meanwhile wind velocity was being measured over a 50km array of five surface moorings. During FASINEX the NASA Ames C130B aircraft flew 11 missions (>20 hours of radar data) with other aircraft over the ships and buoys. As hoped, the FASINEX conditions included a well developed ocean surface temperature front with as much as a 2.0°C change in 5km and wind speeds from calm to 18 m/s.

Instrumentation For The Field Measurements of Dielectric Constant at 18, 35 and 94 GHz

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Long Term Interest: To assist in the development of methods for interpretation of multi-spectral microwave images of snow-ice and other scenes. In particular, to utilize parameters derived from physical and electrical in situ measurements of the scene (obtained coincident with the collection of radar data) in research to develop models for interpretation of SAR imagery and to extend the in situ measurements capability to support other microwave and millimeter remote sensing systems.

During the past 12 years or so advantage has been taken of a number of data gathering flights with the X-C-L synthetic aperture radar system. Ground measurements taken during the SAR data collection periods have included (1) measurement of dielectric constant, surface roughness and other parameters and (2) establishing calibration references for the absolute calibration of the SAR system.

Instrumentation has been developed for the in situ measurement of complex dielectric constant of snow, ice and soil. These instruments operate at the frequencies of the SAR, 1.2 GHz, 5 GHz, and 9.5 GHz, and at 100 MHz and 500 MHz. Also, a method to achieve absolute calibration on a SAR system has been developed.

Specific Objectives: To verify scattering models using data obtained from calibrated microwave instruments and the parameters that describe the scene conditions as derived from surface measurements. Develop and utilize instrumentation for in situ measurements to characterize scattering areas such as dielectric constant, surface roughness and other related parameters for use with microwave and millimeter remote sensing systems.

Approach: Design and fabricate instrumentation for the in situ measurement of critical parameters adequate to describe the scattering surface areas. The construction of instrumentation for the in situ measurement of dielectric constant at frequencies of 94 GHz, 35 GHz and 18 GHz and the field testing of these instruments will be accomplished on this program. Support for construction of additional instruments for dielectric constant measurements at 10 GHz, 6 GHz, 1.2 GHz, 500 MHz and 100 MHz have been provided from other sources.

Current Status: During the past year instrumentation for the in situ measurements of dielectric constant at 94, 35 and 18 GHz has been designed and construction is under way. Measurements are being made using available instrumentation at 10 GHz to obtain data from which to derive the dielectric constant of surfaces. The values of dielectric constant are being derived to demonstrate procedures and models that will be utilized in deriving dielectric constant from the 94, 35 and 18 GHZ data. Instrumentation is scheduled to be completed and initial testing accomplished during the summer months of 1986.

OCEAN SCATTEROMETRY RESEARCH

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Long-Term Interests: To develop physical models relating radar backscatter from the ocean to various geophysical quantities, such as near surface winds, and to explore active microwave techniques to retrieve such geophysical quantities.

Objectives: Improve the present scatterometer geophysical model function by comparing the radar backscatter at Ku band to ocean wind and wind stress, and to other auxiliary geophysical variables such as sea state, sea surface temperature and tension, etc.

Approach: We will collect a comprehensive data set of σ_0 and surface measurements under a range of atmospheric and oceanographic conditions and use this data set to guide the development of a model function relating σ_0 to ocean winds. In FY85 and FY86, we prepared for and participated in the Frontal Air-Sea Interaction Experiment (FASINEX) with the Airborne Microwave Scatterometer (AMSCAT). FASINEX was conducted around an ocean surface temperature front near Bermuda. Several ships, buoys, and airplanes participated in surface measurements and AMSCAT was used on the Ames C-130 to collect σ_0 measurements at 14.6 GHz. About 22 hours of σ_0 data were obtained on the experiment site in 10 flights. A wind speed range of $\sim$2 to $\sim$12 m/s was observed. The incidence angle used ranged from 0° to 60°. In three of the flights, the data were collected in formation flight with the NCAR Electra, the NRL P-3, and the NASA Wallops P-3, which were measuring wind stress, atmospheric, and wave conditions. In the other flights, data were obtained in conjunction with the NRL P-3 over the ships and buoys. This data set from FASINEX will be used to assess the relationship between σ_0 and wind stress, the dependence of σ_0 on sea surface temperature and detailed dependence of σ_0 vs azimuth angles.

Status: The FASINEX data are being reduced to σ_0. A meeting to initiate the intercomparison of the σ_0s with the surface measurements is being planned for the fall of 1986.

REMOTE SENSING OF AIR-SEA EXCHANGES IN HEAT AND MOMENTUM

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Long-Term Interest: Using space-borne sensors to study the interactive processes of atmosphere-ocean exchanges in momentum and energy.

Specific Ojectives: Developing a technique to estimate monthly averaged ocean surface latent heat flux (evaporation) with satellite observations and applying the technique to study the month to month variation of sea surface temperature in tropical Pacific.

Approach: (1) Using radiosonde reports from ocean stations, to seek a global relation between precipitable water measured by spaceborne sensors and the surface-level humidity required to compute ocean evaporation. (2) Using this relation and Seasat/SMMR measurements - wind speed, sea surface temperature, and precipitable water, to demonstrate the capability of spaceborne microwave radiometers in measuring large-scale month-to-month variation of latent heat flux. (3) to evaluate similar measurements by Nimbus/SMMR, to apply them in studying the 1982-83 warming event in equatorial Pacific. (4) to combine different measurements from various existing spaceborne sensors for computing the net ocean-atmosphere heat exchange in tropical oceans for the Tropic Heat and TOGA experiments. (5) Using Nimbus-SMMR observations and ship data, to study the possibility of computing latent heat flux from brightness temperatures using statistical model.

Current Status: Steps (1) and (2) described above have been completed. Step (3) is in progress. For step (4), an interagency-supported experimental program called the TOGA Heat Exchange Project (THEP) has been established at the beginning of FY '86 with P. Niiler, C. Gautier, R. Bernstein, and F. Wentz.

Analysis of Satellite-Tracked Drifting Buoys in the North Pacific

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Long-Term Interests: Dynamics of ocean fluctuations on time scales of 1 hour to 1 year. In this arena, satellite-tracked drift buoys have been under-utilized with respect to robust high frequency oscillations like inertial waves, despite the good position accuracy, short sampling intervals and large geographic coverage of the drifter datasets.

Objectives: Extraction (and subsequent interpretation) of the following information from drifting buoy trajectories that were collected during 1976-1981 in the North Pacific:
1) the kinematic properties of near-surface inertial oscillations (peak periods between 18 hours and 5 days) as a function of space and time;
2) the kinematics (period, wavelength, meridional structure, etc.) of the meandering of the North Equatorial Counter-Current; and
3) the spatial and temporal (seasonal and interannual) variability of the mean currents and the mesoscale eddy field (periods between 5 and 100 days) in the North Pacific.
Furthermore, we are attempting to determine the optimum spectral (including robust) estimation procedure from irregularly-sampled data, which irregularity is a common feature of many satellite-derived datasets.

Approach: Traditional statistical analyses are employed, as well as a novel spectral analysis technique to quantify the characteristics of the inertial oscillations. The latter employs a normalization of the drift tracks with respect to the variation of the planetary vorticity with latitude, yielding a time series in which the inertial oscillations have the same period as a function of time despite the latitudinal excursions of the drifters.

Status: In fiscal year 1985, during which this project began, we accomplished the following:
1) tabulated the mean period and kinetic energy of the near-surface inertial oscillations as a function of latitude from 4 °N to 18 °N; large frequency shifts of the inertial peak are observed, some of which are due to the vorticity contribution of mean shears, while the remainder may be atmospherically-generated; the meridional distribution of kinetic energy in the inertial peak appears to be closely related to surface wind kinetic energy;
2) compared the drifter data with moored measurements, which indicates that, aside from the non-linear advection evident in the inertial oscillation characteristics, no other non-linear behavior is detectable;
3) tabulated the mean and eddy kinetic energies of the near-surface flow for a 40 ° square area of the mid-latitude Pacific and a wide band of the tropical Pacific as a function of season; and
4) modified auto-regressive and inverse techniques for spectral estimation directly from the irregularly-spaced drifter track data, after testing a variety of interpolators (non-data-adaptive) that proved unsatisfactory except for the crudest applications.
Manuscripts are in preparation.

ANALYSIS OF SIR-B OCEANOGRAPHIC DATA

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Long-Term Interests: To understand the SAR imaging mechanisms for ocean waves and to develop and evaluate additional SAR techniques for oceanographic remote sensing.

Objectives: To compare SIR-B wave images from the Southern Oceans Experiment with theoretical calculations, and to attempt to extract additional types of oceanographic information from SIR-B data.

Approach: A SAR image simulation model has been developed and is being operated using wave spectrum measurements made by the NASA ROWS and SCR instruments. The results of these model predictions are compared with actual SIR-B images. Additional SIR-B data sets are being processed in an attempt to extract winds and currents. Laboratory measurements will also be made to investigate the mechanisms underlying these information extraction techniques.

Status: Initial wave image comparisons have been made for two SIR-B data takes. Two additional data sets are currently being analyzed. We are awaiting the raw data for the wind and current investigations, and are setting up to begin the laboratory measurements.

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 topograpy and to apply this knowledge to relevant problems in ocean circulation. Satellite radar altimeter data are being analyzed for the determination of the sea surface geometry and the development of analytical and interpretative techniques for determining the contributions of the ocean geoid, mesoscale circulation phenomena, tides and dynamic topography. Analyses concerned with orbit computation accuracy improvement to the decimeter level are being studied.

Specific Investigation

The objectives of the work are to compute global as well as regional maps of mean sea surface topography from a combination of satellite altimeter data and precision orbit information and to use these data in conjunction with models of ocean circulation, independent in situ observations and the geoid to derive information on dynamic ocean processes.

Approach

Refined techniques for the computation of regional and global mean sea surfaces have been developed. Improved orbit accuracies are being achieved through the use of results from NASA Geodynamics investiations in the areas of the earth's gravity model and other geodetic parameters.

Status

The total sets of SEASAT and GEOS-3 satellite altimeter data have been analyzed for the computation of a new global mean sea surface on a 1/8° grid. A global illuminated map of the mean sea surface has been produced using image processing techniques.

The most recent global bathymetric/topographic 1/12° data set produced by Washington University has been image processed on the same scale and format for detailed comparison purposes.

Improved orbit accuracies have been achieved for SEASAT through the use of improved geodetic parameters resulting from the TOPEX gravity model development work.

A Satellite Study of Polynyas on the Siberian and Alaskan Continental Shelf Using the Nimbus-7 SMMR Data Set

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Long Term Interests: Our interests are in the use of satellite and related surface data sets to study the formation and persistence of polynyas in the polar oceans. We plan to use these data sets to compute the ocean-to-atmosphere heat flux, the related ice production rate, and the brine flux into the water column. We then will relate these fluxes to deep and bottom water formation, and to the transfer into the deep ocean of oxygen, carbon dioxide, and radionuclides.

Objectives: The large heat flux from polynyas means that they are also regions of large ice and brine production. The brine flux creates a dense salty water, which flows into the polar ocean deep waters, and renews deep water oxygen content. This downwelling water may also transfer into the deep water, carbon dioxide from the atmosphere, and radionuclides from the surface mixed layer. Our purpose in these studies is to understand the interannual variability of the fluxes between the ocean and atmosphere, and the fluxes between the ocean surface mixed layer and the ocean interior.

Approach: Our present work employs two data sets, the Nimbus-7 SMMR, and the NCAR 6 hour weather station data, to study polynya formation over the four winters November-March 1979-1983. This is a joint project with Dr. Donald Cavalieri of NASA/Goddard; he is taking responsibility for the SMMR data set, and I am working on the weather and oceanographic data. The SMMR data shows us the location and persistence of the various polynyas; the weather data gives us the rates of ice and dense water production.

Status: We have completed a preliminary study of the polynyas which form along the Antarctic Wilkes Land coast. Our present study of the behavior of Arctic Ocean polynyas between 1979-1983 is underway. We hope to continue this work using the SSMI with the addition of the SAR to study ice formation details within the polynyas. In a related study, we are working with the active radar group at JPL on radar observations of frazil ice.

INVESTIGATIONS OF MESOSCALE PHYSICAL AND BIOLOGICAL OCEANIC PROCESSES

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LONG TERM INTERESTS: The variability of phytoplankton populations on time and space scales resolvable by the CZCS is, to a large extent, driven by physical processes. Significant changes in physical forcing usually produce measurable changes in phytoplankton abundance and distribution. It is often possible to differenciate the effects of various forcing mechanisms by the pigment patterns produced. Studies that quantify the coupling between physical and biological fields can lead to improved insight into both physical and biological processes.

OBJECTIVES: The primary objectives of this program are to (1) document the response of phytoplankton to changes in physical environment in a variety oceanic systems, (2) explain the temporal and spatial variability in terms of conceptual models and (3) quantify the magnitude of those changes using various statistical analyses.

APPROACH: In order to study a number of oceanic systems, collaborations with on-going multidisciplinary field programs have been initiated and arrangements for several university collaborators to work at GSFC have been made. These include studies in the South Atlantic Bight of the eastern U.S. continental shelf, the Gulf of Mexico, N.W. Spain*, the eastern equatorial Pacific Ocean, the Adriatic Sea, the Arabian Sea, the Bering Sea, and the Caribbean Sea. Whenever possible, CZCS and AVHRR data are collected during cruises in order to tie the imagery to high quality *in situ* measurements for interpretation. In order to understand variability on seasonal and interannual time scales, time series of images are processed and composited into seasonal mean and variance fields.

CURRENT STATUS: Published studies partially supported by this program include investigations of Gulf Stream, Loop Current and Kuro-Kuroshio frontal upwellings, of El Nino and interannual variability in the eastern equatorial Pacific Ocean, and of wind-driven upwelling off N.W. Spain. Studies of seasonal variability in the South Atlantic Bight and of interannual variability in the Adriatic and Arabian Seas have been completed. Studies in the Bering and Caribbean Seas are underway.

*Partially supported by the Department of State.

DEVELOPMENT OF ISLAND STATIONS FOR SATELLITE READ-OUT OF IN-SITU SENSING OF ENVIRONMENTAL PROPERTIES
NAGW 318

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Long Term Interests of the P.I.: Study the basic global processes operating now and in the past to form and alter the planets. Develop and apply technology for the study of the Earth and the other planets and satellites from space. Apply this new knowledge and technology to provide new data on scientific questions and for practical benefit.

Objectives of this Specific Research Project: Develop a system of Island Stations in the Pacific Basin for the purpose of sensing environmental properties and transmitting them via satellite (GOES-West Data Collection System) to the Honolulu laboratory. Make specific measurements of global terrestrial processes, make the systems available to other users, and aid other investigators in similar projects. Support space remote sensing missions such as TOPEX by providing ground truth.

Approach Used: Identify important environmental parameters to be measured in support of major scientific investigations such as the long-range sea level monitoring project by Professor Klaus Wyrtki; work with satellite communication equipment and sensor manufacturers to develop and supply appropriate devices; develop equipment and techniques in-house; test systems in the lab and at Honolulu harbor; install systems on remote islands, link with the GOES-West D.C.S., and monitor their operation; automate data receipt and station monitoring to provide other users with data.

Status: Eight island stations are installed and operating: Christmas, Ponape, Tarawa, Majuro, Nauru, Honiara, Rabaul, and a test system in Honolulu. Sea level, temperature and system parameters are monitored. Hardware and software was developed (in-house and in conjunction with manufacturers) to sense and encode the data, up-link to satellite, access and record the returned data and distribute it to users. Data acquisition, processing, and distribution are fully automated and operating routinely. Techniques, personnel, and procedures were developed for installing and maintaining these stations at remote island sites. Maintenance procedures were developed with service trips made to insure continuity in data return. An FM link has been developed, field tested and is now ready to take measurements at sensing sub-stations and telemeter them to a central up-link. Dr. Wyrtki's tide gauges have been interfaced at each site, providing data routinely.

The Pacific Tsunami Warning Center is currently receiving data from two stations in a combined effort. With the advance of the technology and the level of concern over tsunami danger to Pacific Rim countries this combined effort should continue to expand. The Pacific Marine Environmental Laboratory has contracted to utilize our capabilities in a joint effort to more effectively maintain systems operating at common locations.

THE MAPPING OF OCEAN SURFACE CURRENTS USING MULTI-FREQUENCY MICROWAVE RADARS

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The Microwave Remote Sensing Laboratory (MIRSL) at the University of Massachusetts is studying the feasibility of measuring ocean surface currents from geostationary satellite platforms. System studies indicate that multifrequency microwave radars can be used to measure surface currents, provided that the cross-product spectrum consistently displays a resonant peak that gives the necessary Doppler frequency-shift information. The long term goal of this research is to determine the realiability of multifrequency radars to determine ocean surface currents over a wide variety of ocean surface conditions.

The MIRSL will field test a C-Band, multifrequency radar that was specially designed for sensing ocean currents from a platform mounted on the shore. Cross product spectra will be measured for different surface conditions to determine if the resonant "ΔK" peak can dependably determine ocean current.

The measurements will be performed during August-November, 1986 near Camden, ME. The site for the radar platform overlooks deep water, which is subject to strong tidal currents. We plan to make measurements during severe weather in an effort to determine the radar's ability to measure the surface current under high wind speed conditions.

The multifrequency radar has been fabricated and calibrated at an outdoor test range at the University of Massachusetts.

COORDINATION, TECHNICAL DEVELOPMENT, AND SYSTEMS ENGINEERING IN THE DRIFTERS PROGRAM

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The long–term objective of the DRIFTERS 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 DRIFTERS Program is a cooperative effort among seventeen scientists and engineers from eight institutions. The present contract is to accomplish the following tasks: coordinate engineering and science activities by individual members of the program; represent the program to the sponsoring agencies, scientific planning groups (e.g., TOGA, WOCE, and ONR sponsored air–sea interaction experiments), and the oceanographic institutions and industrial companies who will eventually manufacture and deploy the buoy systems developed; begin the process of integrating the components of the FLUX drifter system; plan and recruit participants for needed future buoy systems; and pursue particular technical developments associated with meteorological sensors for the future FLUX drifter and with the air- and ship–of–opportunity–deployability of the buoy systems developed.

The approach utilized for these tasks involves frequent communication among members of DRIFTERS, other oceanographic groups, and the sponsoring agencies in order to coordinate program elements and to develop plans for particular buoy developments and deployments.

Accomplishments during the past, final year of the program include final formulation of the FLUX buoy systems design, initiation of field calibration studies for two new types of Lagrangian surface drifters, arrangement for reduced prices for commerical buoy transmitters, and formulation of plans for the use of thermistor drifters in TOGA and drifters of several types of WOCE.

This work is jointly sponsored with NOAA and ONR.

ADVANCED RADIO TRACKING SYSTEM (ARTS)

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Long-Term Interest: To develop a system for high precision tracking of Earth satellites which is based on using the Global Positioning System (GPS). Combined with precise satellite altimetry and improved knowledge of the ocean geoid, this system will yield unprecedented accuracy in the monitoring of ocean circulation through high resolution ocean topography.

Specific Objectives: To develop a flight-rated GPS receiver for TOPEX, to develop a globally distributed network of GPS ground terminals, to develop the precision orbit determination capability to process and analyze these tracking data, to conduct systems analyses in support of the flight and ground development and, to conduct a demonstration of this new tracking system during the TOPEX mission with the goals of achieving 1 decimeter or better accuracy in the TOPEX radial position and recovering significant new geoidal information for wavelengths of 1000 km and longer.

Approach: The system concept entails the concurrent tracking of GPS satellites by a global network of GPS terminals and by a receiver aboard TOPEX. The global network includes three NASA-DSN sites and as many as 15 sites operated by the DoD and by NOAA. The data streams from the DSN sites plus site specific tropospheric data will be compressed and transmitted at a rate of roughly 700 bps to a central ground data processing facility. The data from the non-NASA sites will be transferred on a non-real time basis. High accuracy orbits for TOPEX and the GPS satellites and also ground site positions and geoidal information will be obtained. The demonstration, which is currently planned as a flight experiment, will be conducted over the first two years of the TOPEX mission. The heritage of this system for high precision GPS-based tracking of earth satellites lies with the current development of hardware and software systems for high accuracy (0.01ppm) GPS-based geodetic applications.

Status: A series of ground demonstrations and technology development continues which is partially sponsored by Oceanic Processes and by Geodynamics. These tests have established our capability to determine GPS orbits from ground data and to recover baselines at an accuracy of around 0.1ppm with a repeatability in some components of about 0.03ppm. Future tests in FY86 and FY87 should demonstrate further improvement in system performance to a level of about 0.01 - 0.03ppm or about 3 cm on baselines of less than a few hundred kilometers length. For TOPEX, a demonstration of the GPS-based system for tracking earth satellites is included in the TOPEX mission plan. Preparations to acquire a flight-rated GPS receiver are complete. Preliminary system accuracy studies indicate that carrier phase observations in conjunction with a dynamic treatment of the TOPEX orbit, including adjustment of medium to long wavelength gravity terms, provide the most accurate performance. Other processing techniques including combining carrier phase and pseudorange observations used in a non-dynamic mode are being investigated. We have completed a new software package for analyzing the performance of GPS-based tracking systems. Its completion allows us to complete the functional design of the ground data processing system and the precision orbit determination software.

Inverse Methods: Combining Satellite and In-Situ Data in an Ocean Basin Model

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LONG-TERM INTERESTS: The creation of a spatially detailed model of the global ocean to investigate oceanic response to fluxes in atmospheric carbon dioxide.

OBJECTIVES: We wish to incorporate data into a tracer-based, 84-box Atlantic Ocean model that reflect chlorophyll pigment densities and the surface exchange of heat and water. Three objectives guide this research: (1) to clarify the inverse methodology and the influence of boundary values and constraints; (2) to describe new primary production and water motion for the Atlantic Ocean consistent with internal tracer fields, with external forcing at the ocean surface, and with patterns of chlorophyll densities as observed by the Coastal Zone Color Scanner (CZCS); and (3) to quantify the influence of primary production and its variability on the oceanic uptake of carbon dioxide.

APPROACH: Two primary tasks are associated with objective 1: one, to explore the model's sensitivity to possible variations in the satellite data; and two, to explore the mathematical characteristics of constrained inverse techniques. For objective 2, we want to develop (a) data sets of heat and moisture exchange for surface regions in the model, (b) a series of constraints of new primary production based on CZCS data, and (c) a method for adding a dynamic mixed-layer model to a tracer-based box model. For objective 3, we need to test the Atlantic Ocean model's transient response to a forcing from fossil fuel carbon dioxide.

STATUS: We have been testing a constraint matrix for the Atlantic Ocean model with which we will encode the qualitative color patterns from CZCS data. These tests, using current estimates on new primary production, have been successful. We are also resolving difficulties in the two-step iteration for smoothing the data fields. A paper summarizing our work with the 84-box model is in preparation.

Investigation of the Properties of Radar Backscatter from Sea Ice

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OBJECTIVES: The long-term objectives include: (1) describing the radar backscattering properties of sea ice, (2) improving the understanding of the physics of radar signal interactions with sea ice, (3) comparing signatures obtained with scatterometers, radiometers, and imaging radars to improve the ability to discriminate relevant features of sea ice, (4) developing procedures for applying signature knowledge to ice surveys, (5) ascertaining the best parameters for ice surveillance radars and radar-radiometer systems, (6) developing methods for using the spatial characteristics of sea-ice radar returns to aid in automated interpretation of radar images of the ice. Recent work has concentrated on analyzing observations made in the East Greenland Marginal Ice Zone during MIZEX 84, and on controlled experiments performed on an artificial ice sheet at CRREL. Work is starting on developing an expert system for radar image analysis based on the methodologies used by ice-image interpreters.

ACTIVITIES/ACCOMPLISHMENTS: In January through March we participated in the second year of a laboratory-based experiment to grow saline ice under semi-controlled conditions at the U.S. Army Cold Regions Research and Engineering Laboratory. Backscatter measurements were made for like and cross-polarizations at 5.2, 9.6, 13.6 and 16.6 GHz for incidence angles between 0° and 50°. Ice treatments yielded smooth and roughened surfaces with and without a dry snow cover. Extensive measurements were made during the growths of the ice sheets, yielding data sets for open water and ice of varying thickness. Much of the effort during 1985 has been on data reduction and correction for antenna separation and beamwidth, to yield plots of backscatter versus incidence angle for the various frequencies. A best fit of the measured backscatter coefficients to a physical optics scatter model yielded estimates of surface roughness and confirmed that surface scattering is dominant for the first year ice surface. At incidence angles above 15°, the returns separated into two groups. The snow-covered and rough gray ice show similar angular responses, due to volume and surface scatter respectively. The remaining surfaces show a more rapid decrease in return with incidence angle.

The data analysis for the MIZEX 84 Summer Experiment is nearing completion. Several hundred data sets were obtained from the Heloscat helicopter scatterometer at 5.2, 9.6, 13.6 and 16.6 GHz between 0° and 70° incidence angle over a range of ice types. The data have been reduced to backscatter coefficients and summary statistics are being calculated for each sample area. The analysis was delayed by errors in the incidence angle encoder, which necessitated a file-by-file data correction effort. Interpretation of the results will continue in 1986.

FUTURE PLANS: As reduction of the MIZEX 84 helicopter-borne scatterometer data is completed, we expect to analyze these data to determine the best combination of radar parameters for ice-type identification in the summer. In view of the rapid temporal variations of contrasts during the summer, identification may require significant supplementary meteorological data. In addition, we will investigate first- and second-order textural measures as possible ice-type discriminators; preliminary indications are that some of these measures may be more successful in the summer than use of scattering coefficient amplitudes.

The results of the CRREL experiment will be analyzed to determine their impact on our understanding of the physics of the radar-sea ice interaction. To date this analysis has been delayed by study of ways to remove the antenna pattern effects, a study now completed.

We expect to continue the study of this interaction by using a very-fine-resolution radar to examine ice produced under different conditions in a cold-room laboratory. By controlling the environment in the room, many more controlled experiments should be possible than in any field experiment.

We hope to develop, over a period of time, an expert system for image interpretation. The method for doing so involves formalizing the interpretation facts and knowledge base used by expert human interpreters, developing or selecting digital image processing methods to extract as many of the relevant facts as possible from radar imagery, and developing the control structure of the expert system so that these facts may be applied to the knowledge base to complete classifications.

We also hope to use existing image simulation packages at The University of Kansas to apply the measurements made with the Heloscat system in MIZEX to the generation of simulated images, which may then be compared with images produced by airborne SAR in the same area. This tie between Heloscat and image data should permit better application of the Heloscat observations to determining image properties under conditions where images are not available. Moreover, it will permit studies of the effects of different radar parameters on images -- studies that would not be possible with actual imagers because they do not have sufficiently variable parameters.

This work is jointly sponsored by the Office of Naval Research and the National Aeronautics and Space Administration.

MICROWAVE REMOTE SENSING OF OCEANOGRAPHIC PARAMETERS

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Long-Term Interests: To advance the use of passive microwave techniques, in conjunction with other remote sensing and in situ methods, for measurement of oceanographic phenomena from space. These measurements will be applied to the understanding of problems in oceanography, ocean-atmosphere interactions, and climate.

Objectives: To analyze the measurement performance of the SMMR instruments on Seasat and Nimbus-7, and the SSMI on DMSP when launched, to improve measurement accuracies through refined retrieval techniques, and to demonstrate application of the data to oceanographic problems. To improve the capability for sea surface temperature measurement from space using microwave, visible/IR, and in situ sensors.

Approach: SMMR-derived geophysical quantities (SST, wind speed, water vapor, and cloud liquid water) have been generated at various spatial scales for the tropical Pacific ocean. These data sets are being examined and compared with other data sets, both spatially and in time sequence, to determine the stability and accuracy of the SMMR data on these scales. The data are then used to study the development of oceanographic and atmospheric phenomena. Workshops have been organized to assess present capabilities and coordinate future research in sea surface temperature measurement.

Status: Analysis of the tropical Pacific SMMR data sets has shown the ability of the SMMR to observe interrelated changes in sea surface temperature, wind speed, water vapor, and cloud liquid water during geophysical events such as the 1982 El Nino. Analysis is underway to determine if the accuracies are sufficient for air-sea interaction modeling studies. Three workshops have been held to involve remote sensing scientists and oceanographers in planning future research and instrumentation for sea surface temperature measurements. The findings have been documented in a series of workshop reports and in the open literature.

WORLD OCEAN CIRCULATION EXPERIMENT (WOCE): PLANNING FOR A U.S. COMPONENT

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Long Term Interests: A World Ocean Circulation Experiment is planned for the 1990's to improve our description and understanding of the global ocean circulation, with particular interest in how the ocean affects the earth's climate. WOCE will be part of the World Climate Research Programme's (WCRP) study of long-term climatic trends. Internationally, WOCE is directed by the WOCE Scientific Steering Group formed under the auspices of the Committee for Climatic Changes and the Ocean (CCCO) and the Joint Scientific Committee of the WCRP. Many nations are expected to take part in WOCE, and each participating country is expected to develop a plan for their national contribution. The planning effort described here, jointly supported by NASA and NSF, is intended to further the development of a U.S. component for WOCE.

Objectives: WOCE will use, on a global basis, satellites, ships, tide gauges, drifters and floats, current meters, and numerical modeling in a five year effort to improve our understanding of the ocean circulation. To successfully implement a program of this complexity, careful planning is essential. The U.S. planning program will: define the objectives of a U.S. component of WOCE; identify data needed and modeling efforts required to meet those objectives; work with NSF, NASA, and other agencies to estimate the physical needs and financial outlays required to support the U.S. WOCE efforts; entrain potentially interested U.S. scientists by encouraging their participation in planning activities; provide financial support for meetings, workshops and studies; communicate developing WOCE plans to the oceanographic community; and coordinate U.S. efforts with the components of the international WOCE.

Approach: A U.S. WOCE Scientific Steering Committee (SSC) has been constituted with C. Wunsch (MIT) and W. Nowlin (TAMU) as Co-chairmen. The SSC has formed working groups on the ocean surface layer, air ocean exchange, geochemistry, numerical modeling, global geostrophic circulation, and technology development. A joint WOCE/TOGA data management working group was formed with the goal of creating a single data management system to aid both programs. A U.S. WOCE Planning Office has been established to carry forward the activities of the SSC and to coordinate the efforts of the working groups.

Status: Planning activities for WOCE intensified in 1985 with many of the working groups holding workshops. These included four ocean sector meetings to consider key problems of the global circulation and discuss experimental work to be carried out in each ocean sector during WOCE. Much of the deliberations of the working groups has been integrated into Planning Report 3: A Status Report on U.S. Planning, published by the SSC in January, 1986. This report should be considered a statement of progress toward the development of a U.S. Science Plan for WOCE.

OCEAN COLOR INVESTIGATIONS USING THE MULTICHANNEL OCEAN COLOR SCANNER (MOCS)

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Long Term Interests: The primary goal of this study is to better understand ocean productivity through extending and improving the correlations between detected spectral radiances from the ocean and the concentration of chlorophyll bearing plankton.

Objectives: There are two objectives to this investigation. First, with the useful life of the Coastal Zone Color Scanner on Nimbus 7 coming to an end, it is important that another ocean color instrument be available to take part in cooperative studies of ocean productivity. The MOCS is an aircraft mounted instrument that can provide a synoptic map of the chlorophyll concentration in an area around research ships and in other limited areas where it is needed. Second, the MOCS can be used to define new algorithms for the detection and measurement of chlorophyll using the upwelling light signal from the ocean.

Approach: The MOCS has proved that through the spectral curvature algorithm, the chlorophyll *a* concentration can be measured reliably from aircraft. However, the instrument has not been used to its fullest extent because only the middle portion of the scan line has been used. Sun glint has been more of a problem than necessary. To remedy this, the system is being refurbished so that all of the data can be recorded, and it is being made smaller to fit in smaller planes. (It has been mounted in a P-3). It will be available for use in cooperative studies with oceanographic research programs both to provide limited synoptic chlorophyll measurements and to extend these measurements into other types of waters besides those off the east coast of North America. The spectral curvature algorithm has been shown to be valid when the aircraft is at a low altitude (150 m). Data obtained at a range of aircraft altitudes combined with atmospheric correction models will be used to extend the algorithm to higher altitudes.

Status: The refurbishment of the MOCS is proceeding. A 16-bit computer based on the 80186 chip has been added to the system, and a new 12-bit analog to digital converter has been tested. A removable hard disk memory system is replacing the nine track tape drive. The MOCS is expected to take part in a cooperative experiment at the mouth of the Chesapeake Bay in April 1986.

MICROWAVE RESPONSE OF ARCTIC SEA ICE

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Long Term Interest: Interest includes transforming microwave signal information into geophysical data products and the advancement of the understanding of the microwave signatures of snow and ice.

Objectives: Objectives include developing synthetic aperture radar (SAR) into an operational tool with which specific ice feature information will be extracted unambiguously, updating our understanding of the electromagnetic interaction with snow and ice, apply the quantitative relationships between the measured electromagnetic properties and physical characteristics to evaluate present and future microwave sensor performance with respect to system and environmental parameters, and to use newly acquired data to evaluate electromagnetic snow and ice scattering models and as inputs to enhance algorithm development and optimization in areas of ice concentration and type determination.

Approach: In the two most recent experiment series, MIZEX and CRREL TANK EXPERIMENT, descriptions of the scattering coefficients of the major ice types that are present in the marginal ice zone in summer and of evolving new ice under winter conditions were made. The analysis of the microwave and physical, chemical and electrical property data will be completed to better understand inter-relationships, the influence of summer melt on ice conditions and radar return, and the growth of new ice. In addition, SAR and passive microwave data acquired coincidentally with MIZEX near-surface observations will be analyzed statistically to strengthen the above results and to supply inputs for use in the development of information retrieving algorithms.

Status: Data reduction is nearing completion. Intercomparison of data from the near-surface microwave sensors, SAR, passive microwave imagers and profilers, and ice characterization measurements is underway. Preliminary results were discussed in four papers presented at IGARSS '85. Multiple papers which include discussion of the microwave response of sea ice and results from an inter-sensor comparison are targeted for a 1 July JGR special issue.

This work is jointly sponsored by the Office of Naval Research.

TIME DEPENDENT ALTIMETER STUDIES

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Long Term Objectives: To investigate two-dimensional mapping of altimeter data for the purpose of separating the mean and time varying parts of the altimeter signal. Time varying signals include tides, current variability and mesoscale eddy variability. Of especial interest is the conversion of altimeter data into estimates of the ocean tide as seen by conventional gauges, both in coastal areas and in the deep sea.

Specific Objectives:

(1) Patagonian Shelf: To generate shelf models of the Patagonian shelf tide, using a barotropic finite difference model with adjustable dissipation. Comparison of these models with altimeter height values should allow a better understanding of the shelf tide. A key objective is an estimate of the M2 shelf dissipation.

(2) Global Tide: With new high precision orbits that are now becoming available, partial determination of the M2 tide from Seasat data should be possible.

(3) pre-TOPEX: The models of Shwiderski and Parke and Hendershott are being compared to determine areas of disagreement. Understanding the source of disagreement should be useful for future modelling efforts and as a guide for future measurements.

Status:

Models of the Patagonian shelf have been generated. Comparison of the M2 tide along the Seasat locked orbit with the model results, shows distinctly the effect of shelf dissipation on the altimeter data. A Sun workstation has been purchased in order to continue this modelling effort. Further work should provide a quantitative estimate of the M2 dissipation.

Comparison of the Schwiderski and Parke-Hendershott models of the tide show distinct geographical differences, mostly at high latitude. Global crossover data show an essentially equal improvement regardless of which of the above models is included. Most of the large regional differences appear due to different choices of boundary values. In addition there are smaller ($\sim$5cm) broad scale systematic differences. These smaller differences are the dominant cause of differences in global integral properties such as dissipation.

The University of Texas doppler orbit has been recieved for the locked orbit period of Seasat, and included in an altimeter data set. Simple analysis of this data produces a M2 solution with a global accuracy of 20-25cm. A simultaneous O1 solution shows a distinct anomaly, perhaps due to zonal adjustments to the orbit performed at UT. A new UT orbit and the Goddard Doppler orbit have been received and are being incorporated with the altimeter data. Comparison of tidal results should be quite interesting.

Northern Hemisphere Sea Ice from Passive Microwave Observations

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Long-Term Interests: The principal investigator is interested in climate change, the role of sea ice in climate change, the interactions of sea ice with the ocean and atmosphere, and the utility of sea ice distributions as an indicator of the climate state.

Objectives: The purpose of this work is to utilize the 1973-1976 microwave data of the Nimbus 5 ESMR to determine and analyze the full annual cycle of Northern Hemisphere sea ice and to produce a high-quality volume presenting the data and analysis.

Approach: The basic approach consists of four steps: (1) Data reduction, involving elimination of data gaps by spatial and temporal interpolation, adjustment for an apparent 1976 calibration shift in the ESMR instrument, normalization of the satellite brightness temperatures, and conversion of the brightness temperatures to sea ice concentrations. (2) Data compilation and plotting, including the creation of various data products, such as color-coded maps of monthly averaged brightness temperatures and ice concentrations, and time sequences of ice area for both the full north polar region and for each of eight subregions. (3) Data analysis, using the images and plots from #2 to analyze the Northern Hemisphere sea ice cover, on a regional and hemispheric basis. (4) Production of an Arctic sea ice atlas from the images, plots, and analysis created under (1), (2), and (3).

Status: Data reduction, compilation, and analysis have been carried out and a draft version of the Arctic sea ice atlas from ESMR data has been created and sent to reviewers. All plots and maps have been generated (although some not in final form), and analysis has been done on monthly averaged brightness temperatures and derived ice concentrations for each of eight regions and for the Northern Hemisphere as a whole. Ongoing work includes final preparation of the images and revisions in the text in response to the comments of the reviewers.

ADVANCED OCEAN SENSOR DEVELOPMENT

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Long Term Interests: This RTOP (161-10-06) has as its long-term goal the development of advanced satellite altimetry instrumentation and techniques to support future missions and oceanic process program objectives.

Specific Objectives: The immediate objective of this activity is to complete a 3-year study of the issues involved with multibeam altimetry. The major product of this study will be the recommendation and specification of a spacecraft multibeam altimeter mission.

Approach: The general nature of this multibeam altimeter development activity was elucidated in a proposal entitled "Technology Studies in Support of an Earth Observing Radar." Components of the activity include the development of an aircraft modularized technology testbed, evaluation and support studies (including simulations and data processing technique development), application studies, and spacecraft platform suitability studies. Available tools for this program include the Wallops Windwave Tank Facility for studying the radar backscattering physics for the multibeam altimeter's viewing geometry, the Radar Altimeter Simulation System developed for the TOPEX Advanced Technology Model development, and the Goddard Space Flight Center P-3 research aircraft based at the Wallops Flight Facility.

Current Status: The multibeam altimeter proposal was submitted for peer review and approved by NASA Headquarters (approval letter dated January 14, 1986). Overall program planning and initial instrument design work are underway. An initial review of progress by the Headquarters program office is scheduled for April. Cooperative studies of mutual interest are in progress with NASA Langley Research Center and the Naval Research Laboratory. The principal investigator is a member of the Navy Remote Ocean Sensing System II advanced altimeter panel and the Earth Observing System Altimetric Systems panel. Both future spacecraft currently include a multibeam altimeter in their instrument complements. Analytical studies as needed from outside university and industry experts are being arranged.

A Multi-Sensor Approach for Measuring Primary Production from Space

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Long-term interests: to improve our ability to predict primary production from satellite- and aircraft-derived chlorophyll measurements.

Objectives: to develop a multi-sensor, remote sensing approach for computing primary production from space. This approach is based on our existing capability to measure -- from space -- the primary environmental parameters that regulate photosynthesis. These factors are the instantaneous shortwave radiation incident on the sea surface, the radiation experienced by phytoplankton in the recent past, ocean temperature, and nitrogen availability.

Approach: to analyze empirical, regional correlations of chlorophyll and primary production in context of environmental data obtainable from satellites. Regional chlorophyll-primary production relationships are usually noisy. Sources of variance in such relationships are being examined using a multi-variate approach based on inclusion of environmental forcing functions. Several parameters can be determined directly by satellite remote sensing; specifically, these include satellite measurement of instantaneous and previous-day short wave radiation from the GOES VISSR sensors, AVHRR sea surface temperature, and altimeter-derived winds. Other parameters can be indirectly inferred, by correlation with historical seasonal relationships (e.g., temperature, mixed layer depth, weather-station winds, nutrients).

Status: The proposed research is in an early stage. Data sets are being collected for multi-variate analyses of chlorophyll, enviromental parameters, and primary production.

The project is conducted through the auspices of the Ocean Basin Carbon Fluxes Program in the Interdisciplinary Research Program in Earth Sciences, sponsored by NASA Space Science and Applications. The project is in collaboration with Catherine Gautier, Scripps Institution of Oceanography.

ANALYSIS OF COASTAL SYSTEMS OF WASHINGTON USING SATELLITE REMOTE SENSING OF OCEAN COLOR AND TEMPERATURE

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Long-term interests: to understand the distribution of phytoplankton in high latitude eastern ocean boundary current regions, rates of primary production, and the underlying physical and biological factors responsible for the observed patterns of variation in phytoplankton biomass and production.

Objectives: (1) to describe the annual and interannual variability in pigment concentration and distribution patterns on the Washington shelf and slope waters, using historical Coastal Zone Color Scanner archived images; (2) to examine these patterns in context of physical interactions, using archived satellite sea surface temperature patterns, historical hydrographic data, and current meter data; and (3) to develop and test a regional algorithm for determing primary production, by combining information from a large multi-year historical data set on the depth distribution of pigments, rates of primary productivity, and temperature with satellite imagery.

Aproach: to analyze archived satellite imagery for ocean color and temperature in context of the available historical data on the biology and physics of Washington coastal waters obtained from ships, current meter morring, and other data records. The availability of coincident ship-determined chlorophyll measurements with Coastal Zone Color Scanner images will also provide information on the behavior of chlorophyll algorithms in high latitude, high phytoplankton biomass regions.

Status: The proposed research is in a very early stage. The analysis of historical data to determine the relationship between primary production and chlorophyll is underway. A microVAX II workstation will be installed in the summer to allow local processing of ocean color and temperature data to level 3.

OCEANOGRAPHIC AND METEOROLOGICAL RESEARCH BASED ON THE DATA PRODUCTS OF SEASAT (NAGW-690)

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Long Term Interests: (1) To develop improved models for radar backscatter from waves on the ocean and to use backscatter measurements to recover vector winds over the ocean. (2) To contribute toward improved numerical computer-based waves, weather and ocean circulation models. (3) To improve the present Monin-Obukhov theory. And (4) to study the errors of conventional measurements.

Objectives of Present Research: (1) Part of (1) above is done in collaboration with M. A. Donelan of C.C.I.W., implications for the SASS data and for N-ROSS and other scatterometers will be covered in future papers. (2) An invited paper on the subject has been published and is given in the bibliography. (3) C. M. Tchen is working on the problem. (4) A paper is 70% complete on errors of ship reports and ways to improve data buoy reports.

Approach: The study of radar backscatter theory and data will be continued. Ways to invert the problem and deduce winds from backscatter will be developed so as to include sea surface temperature, specular backscatter, Bragg scattering and the state of development of the waves.

Current Status: Recent publications cover past results. Present results will soon be submitted to appropriate journals. We believe that we have shown the inadequacy of power law models. A correct backscatter model must include sea surface temperature effects, specular backscatter at incidence angles greater than 20^{0} and the effects of wedges and spilling breakers. The effects of wedges and spilling breakers are not soley a function of the local wind speed. Participation on the TOWARD committee has provided valuable insight on current activities on measuring backscatter from aircraft and fixed platforms.

SIR-B WIND SHADOW SUPPORT PROGRAM
(Subcontract 6690-84 with Univ. of Kansas
(R. K. Moore, P.I.), Primary Contract with JPL).

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Long Term Interests: To study the winds around islands for a wind-shadow effect in the lee of the islands.

Objective of Present Research: To analyse Challenger SIR-B data obtained for passes over Jamaica, in the Bahamas over Nassau and other islands, if possible.

Approach: The U. S. Air Force made low level (500 foot) wind measurements around Puerto Rico that show the effect sought and through the Bahamas during Hurricane Josephine. The data have just become available for SIR-B. The backscatter model results described for NAGW-690 also cover L-Band.

Current Status: Analysis of data is in progress but slant range variations in the reduced data mask effects being sought.

CALCULATION OF GEOSTROPHIC AND EKMAN TRANSPORTS FROM ALTIMETER DATA

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An analytical procedure to objectively analyze sea surface topography was developed in the frame work of a simple, frictional, wind-driven ocean circulation model of Stommel. The procedure allows the determination of the total flow from a given sea surface topography instead of just the geostrophic contribution and it is also well-behaved in low latitudes and across the equator in computing the circulation. The method is based upon calculating characteristic stream functions for the flow field in a basin of a given geometry via the solutions of a homogeneous elliptic equation. These stream functions are then used to solve an inhomogeneous linear balance equation to derive a set of height field functions appropriate to the given basin. In terms of these characteristic functions for the stream function and the height field, it is possible to show from a theoretical basis that the expansion coefficients in the representation of an arbitrary sea surface topography and the associated flow field are identical. Hence, a given sea surface topography over a basin can be expanded in terms of the height field functions to objectively analyze the field, calculate the expansion coefficients in a least squares sense, and synthesize the total flow using these coefficients with the stream function modes.

The method has been applied to an ideal rectangular ocean on a beta-plane with excellent results. These results have been written up. Calculations are also completed for a constant depth wind-driven circulation for the Atlantic-Indian Ocean basin geometry, and calculations are underway to obtain the characteristic functions with real-bottom topography taken into account.

COMMITTEE ON CLIMATIC CHANGES AND THE OCEAN

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The Committee on Climatic Changes and the Ocean (CCCO) is sponsored jointly by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the Scientific Committee on Oceanic Research (SCOR) of the International Council of Scientific Unions, (ICSU). It works in cooperation with the Joint Scientific Committee (JSC) of the World Meteorological Organization (WMO) and ICSU. Together with JSC, the CCCO is responsible for planning oceanic aspects of the World Climate Research Program (WCRP).

The CCCO has initiated two major ocean studies--TOGA and WOCE. TOGA is concerned with the effects on the global atmosphere of variability in the tropical oceans. WOCE, (World Ocean Circulation Experiment) is concerned with the global ocean circulation and the transformation of water masses. In both programs ocean-observing satellites will play an essential role, supplemented and calibrated by ocean surface and subsurface measurements from research vessels, drifting and anchored buoys, ships of opportunity, and fixed observatories for measuring sea level on islands and coasts.

The CCCO held its seventh session in Paris, 14 to 21 January 1986. At this meeting it considered the implementation plan for the World Climate Research Program and the preparations for the first WMO/IOC intergovernmental informal planning meeting for WCRP in May 1986. The discussion in the planning meeting will be based in part on four major planning items produced during 1985 with CCCO participation: the TOGA scientific plan; the TOGA implementation plan; the WOCE scientific plan; and the WCRP implementation plan. The committeee also received a proposal from its CO2 advisory panel for a global ocean carbon research and monitoring program. It agreed that the ocean's role in determining the atmospheric content of carbon dioxide is an essential element of the climate problem, and it accepted responsibility for studies of the changing carbon dioxide content of the ocean on climatic time scales.

The committee also received a report of its committee on paleoclimatology. It recognized that paleoclimatic measurements imposed restraints on present climatic models; abrupt climatic changes are considered particularly important as are data on seasonal, interannual and decadal climate variations in the past. There was also an extensive discussion and recommendations for long-range monitoring of the secular change in sea level, with an attempt to separate steric from mass changes in the ocean waters and both from changes in the position of the measuring gauges. Finally, planning and development of ocean observing programs for climate research was reviewed and discussed, particularly actions taken by IOC and WMO in response to the Ocean Observing System Development Program.

TOPEX RADAR ALTIMETER ADVANCED TECHNOLOGY MODEL

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Long Term Interests: To develop the spaceflight qualified Radar Altimeter and related sensor and geophysical data reduction algorithm specifications for the Jet Propulsion Laboratory (JPL) Ocean Topography Experiment (TOPEX) Project, to verify the on-orbit performance of this instrument, and to participate in the validation of the TOPEX geophysical data to be released to the science community.

Specific Objectives: In the pre-project era to participate with JPL's TOPEX Development Flight Project Office in the planning and study activity associated with obtaining approval for the TOPEX Flight Project. To design and develop a breadboard Radar Altimeter capable of demonstrating the TOPEX 2-centimeter precision measurement requirement to remove "Risk" from the Flight Project. To provide JPL information for calibration of the TOPEX Radar Altimeter and the planned data processing algorithms, and to assist them in the development of an overall TOPEX mission plan. To establish resource estimates for the TOPEX Flight Project Radar Altimeter, its associated data processing algorithm development, and flight mission support.

Approach: The stringent 2-centimeter precision requirement for ocean topography determination necessitated examining the applicability of existing Radar Altimeter designs for their applicability towards TOPEX. As a result, a system configuration has evolved using some flight proven designs in conjunction with needed improvements, i.e., a second frequency or channel to remove the range delay or apparent height bias caused by the electron content of the ionosphere, higher transmit pulse repetition frequencies for correlation benefit at higher sea states to maintain precision, and a faster microprocessor to accommodate two channels of altimetry data. Additionally, an examination of the associated data processing algorithms required to support a TOPEX-class Radar Altimeter was undertaken to establish the utility of the then current Radar Altimeter data processing algorithms.

Current Status: The TOPEX Advanced Technology Model Radar Altimeter under development by The Johns Hopkins University/Applied Physics Laboratory (JHU/APL) over the past 3 years is nearly complete, with final testing to be accomplished in June 1986. Earlier this year, testing at the subsystem level of the Radar Altimeter provided convincing evidence that 2 centimeter precision altimetry is indeed achievable for the TOPEX Mission. A radio-frequency compatibility test with the TOPEX Radiometer Engineering Model has been established for April 1986 to ascertain whether any harmonic frequencies from the Radar Altimeter C-Band channel will interfere with the 21 and 37 gigahertz channels of the Radiometer. A detailed Radar Altimeter Pre-Project Algorithm Freeze Report has been prepared and distributed. The contractual documentation for use between JHU/APL and NASA for the development of the Flight Project Radar Altimeter is being established.

SAR AND MICROWAVE REMOTE SENSING OF SEA ICE

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Long-Term Interests: Our work is directed towards sea ice dynamics, ocean dynamics and the remote sensing of the surface of polar oceans. We wish to apply satellite observations to climatological studies of ice mass and momentum balance, and ocean circulation and water mass formation; to make the geophysical data derived from satellite sensors more easily accessible, and more accurate; and to maximize geophysical information that can be derived from multiple satellites and sensors.

Objectives: The goals of this research are to be prepared to extract useful geophysical data when ERS-1 and other SAR satellites are launched, and to demonstrate the applicability of these data to polar scientific problems. Our immediate objectives are: to develop techniques to extract ice velocity, concentration and concentration change from imagery; to describe spatial and temporal statistics of ice velocity and concentration for development of efficient SAR sampling schemes; to investigate the relation between ice deformation and concentration change; to use non-continuum models of ice velocity for the interpretation of spatially detailed data available from SAR; and to study the ice mass and momentum balances with ice kinematic and concentration data, and geostrophic wind data.

Approach: This research relies on the availability of high resolution SAR imagery from SEASAT, the Space Shuttle, and aircraft. Digital image processing is a central tool for developing automated methods for extracting geophysical data from imagery. Much of the research relies on measuring ice displacement with high spatial resolution; we have measured displacement over 100 km square scenes on a grid of points 2.2 km apart. Hence, high geometric fidelity of the images is crucial. Such observations show intimate details of the ice velocity field, provide a very accurate estimate of mean deformation, and allow area change of individual leads to be measured.

Status: Our algorithm for ice displacement is based on cross-correlations between small areas of two images. It performs well on rigid, slowly rotating pieces of ice characteristic of central arctic winter pack. Improvements in deforming and fragmented ice are being explored. Spatial statistics show that ice velocity has no spatial derivative, although mean deformation over areas on order 100 km square can be defined, and its spatial variability measured. Observations of open water formation and loss and their relation to deformation have been made from SAR images. Each pixel is classified as ice or open water. The image is subdivided into many small areas, and the changes in the number of pixels of open water are counted in each area. All increases and decreases are separately summed. The mean deformation of the image is measured. Comparison is made with parameterizations of open water change used in ice models. The analysis is in progress; we are presently evaluating the accuracy of the method.

This research is jointly supported by NASA and the Office of Naval Research.

COUPLED OCEAN - ATMOSPHERE DYNAMICS

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Long Term Interests: Interaction between ocean and atmosphere on interannual and longer timescales.

Objectives: The objective of the present study is to refine and verify our theory for the tropical ocean/ atmosphere vacillation known as the El Nino/Southern Oscillation (ESNO). We are turning our interest to the question of how the annual cycle affects the ENSO behavior, how ENSO may work as the primary mechanism in long term mean heat export from the tropical ocean, and how the Pacific interacts with the other oceans through the global atmosphere.

Approach: A numerical model simulation of the coupled ocean-atmosphere led to vacillation with a spectral character very similar to observations. The model has led to much simpler theoretical paradigms which can be solved readily, identifying the non-linear oscillator at work. The details of the oscillator are being further explored through more detailed models and theory.

Current Status: The oscillator has been discovered to operate via unstable coupled Kelvin waves in the central to eastern portion of the basin, which provide the basic energy input to the vacillations. The period is set by the radiation of uncoupled oceanic Rossby waves to the west and their reflection from the western boundary, together with a non-linear limitation on the growth of the unstable mode. The resultant system oscillates with a period several times longer than the waves transit time.

In our solutions, no annual cycle was present in the external forcing (the solar radiation field), yet the system vacillates because of the non-linear oscillatior. We are examining how the annual cycle disturbs or phase-locks the oscillator, without substantially altering the operative mechanism. We are currently conducting further investigations to determine the role of vertical structure, large scale heat fluxes and the annual cycle in modifying the behavior of the system. The ocean model is being updated to include many layers in the vertical, and additional physics are being added to the atmosphere model.

Bio-Optics, Photoecology, and Remote Sensing of Gulf Stream Warm Core Rings and the Southern California Bight

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Long Term Objectives

The long term objectives of this research are: to study the fundamental processes influencing the distribution and variance of phytoplankton biomass; to continue the development and utilization of multiplatform (ship, aircraft, and satellite) sampling strategies for the study of ocean processes; to optimize these sampling techniques for the estimation of regional and global phytoplankton biomass; and to increase our understanding of the interrelationships between physical and biological processes in the upper layers of the ocean.

Specific Objectives

Specific objectives include the continued quantitative assessment of the spatial and temporal variability of chlorophyll in the Southern California Bight (SCB) and within Gulf Stream Warm Core Rings (WCR) and their environs. Ship, aircraft and satellite data are being used to investigate: the statistics of multiplatform sampling strategies; the physical and biological processes leading to chlorophyll variability (Joyce et.al.,1984; Evans et.al., 1985; Smith and Baker, 1985) and primary productivity (Brown et.al., 1985); and the relationship of this variability to the distributions of organisms at higher trophic levels (Dunlap, 1985; Smith et.al., 1986).

Approach

Our approach is to quantitatively describe and mathematically model the marine photoenvironment and the corresponding bio-optical ocean properties in order to optimize the accuracy of multiplatform sampling. This includes: the development of state-of-the-art shipboard oceanographic equipment and methodologies (Smith et. al, 1984); the development of data handling procedures for the merging of contemporaneous ship and remotely sensed data (Smith and Baker, 1984,1986); the development of models with which to link chlorophyll concentrations and the subsequent optical properties; the development of numerical models for the assessment of flow fields from remotely sensed data (Stow, 1985); and the quantitative analysis of ship and satellite time series data. Our research also emphasizes collaborative work with several universities and NASA research groups.

Status

For the SCB we are working to improve techniques for assessing regional phytoplankton biomass and primary productivity (Smith, 1984) and are in the process of analyzing several years of CZCS and ship data in order to provide a pigment time series for this region. An article describing the mesoscale ecology of cetacea in the California Current has been accepted for publication (Smith et. al., 1986), a thesis describing the abundance and distribution of cetacea in the California Current system as observed from ship and satellite data has been completed (Dunlap, 1985) and is being prepared for publication. For our research in WCR several articles have been published (Joyce et.al., 1984; Evans et.al., 1985; Brown et.al., 1985; Smith and Baker, 1985) and others are in progress.

RADAR STUDIES OF THE SEA SURFACE

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Long-Term Interests: 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 interest is to use radio signals to study surface waves, geostrophic currents, winds and oceanic rainfall.

Specific Objectives (Satellite Oceanography): The usefulness of satellite data depends to a great extent on the degree with which the user community understands satellite measuring techniques, their accuracies, and their applicability. To contribute to this understanding, I have completed a review of the results of the Seasat mission. The results were summarized in a Nasa report, and were the basis for a one day meeting at the Jet Propulsion Laboratory. The satellite has revolutionized our ability to observe the sea from space, and has contributed to our understanding of the ocean, especially marine geophysics.

(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 offers a new method for calibrating rain rate. A graduate student working with me at the Scripps Institution of Oceanography, J. Nystuen, has developed a theory of rain-induced noise, based partly on numerical computations, that explains many of the features in the spectra of rain noise that he has measured in a laboratory tank, in a lake, and in the ocean. He finds a useful correlation between noise and rain rate; and, based on this work, the Scripps Institution of Oceanography has awarded Nystuen a doctoral degree.

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

MICROWAVE REMOTE SENSING MEASUREMENTS OF OCEANS AND ICE

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Long Term Interests: To investigate the physics of radiometric emission and radar backscatter from the ocean and sea ice and to develop good quality algorithms to quantify the geophysical parameters.

Specific Objectives: (1) Analyze available aircraft and satellite microwave remote sensing data for developing improved algorithms to enhance interpretation of data that will be collected by new satellite systems. (2) Conduct field experiments using our own remote sensing systems to observe emission and scattering processes in connection with surface truth.

Approach: We are continuing to process SeaSat data to develop improved algorithms to qualify sea ice. Weather correction of SMMR data is one example of algorithm improvement. We now have a weather correcting algorithm in place which significantly improves the sea ice retrieval, particularly in the marginal ice zone. As a direct fall-out of this research, we have been asked to modify the algorithm to produce surface winds from SSM/I data and to verify the results after launch by comparing the SSM/I winds with buoy winds. Similarly, we have analyzed SeaSat scatterometer data collected over the polar regions and have developed a theory which seems to model the experimental data quite well.

As another activity, we are continuing to develop a more accurate windspeed model for radiometric emission for the sea. We are in a unique position to do this because our C-Band Stepped Frequency Microwave Radiometer (SFMR) participates each year in the NOAA Hurricane experiments.

Status: A M.S. thesis describing the weather corrected algorithm is in the final stages of completion. The algorithm not only improves the remote sensing estimates of sea ice type, but it also derives other environmental parameters such as ocean windspeed and atmospheric water vapor content. When complete, the thesis will be distributed to the sea ice community.

The SFMR provided real-time ocean surface windspeeds during the 1985 Hurricane season, and the results pointed to a significant improvement in the windspeed algorithm.

DETERMINATION OF OCEAN CIRCULATION AND THE GEOID USING SATELLITE ALTIMETRY

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Long-Term Interests: Using satellite altimetry to investigate (1) large-scale (basin-scale at this moment) ocean circulation, (2) the geoid, (3) large-scale oceanic variability, and (4) mesoscale variability.

Objectives: (1) To produce a global geoid estimate by removing the dynamic topography (derived solely from hydrographic data) from the altimeter derived mean sea surface. (2) To estimate how much the dynamic topography (derived solely from hydrography) is in error. (3) To devise specific methods to remove the orbital error in the recovery of basin-scale dynamic topography and oceanic variability from satellite altimetry.

Approach: Given the altimeter derived mean sea surface and the dynamic topography from hydrographic data, one can estimate the global geoid (up to certain harmonic degree) from regional data, such as the Pacific region. If another global geoid estimate is derived from data outside the Pacific, the difference of these two estimates gives us an estimate of the uncertainty in hydrography (such as the level of no motion assumption). As a prerequisite, the orbital error (which significantly affects the gross shape of the altimeter derived mean sea surface) must undergo a rigorous investigation.

Status: (1) The effect of the orbital error is reported in Tai and Fu (1986). (2) It appears the broad slope of the dynamic topography derived from hydrography is definitely in error. However, any definitive conclusions must wait for a rigorous error analysis.

SYNTHETIC APERTURE RADAR IMAGE PROCESSING FOR TRACKING, DISPLAY AND PREDICTION OF SEA ICE DYNAMICS

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Long-Term Scientific Interests: Sea ice covers some 20×10^6 km^2 of the ocean surface influencing weather and climate, both locally and globally. It is also a dominant factor at high latitudes for both commercial and military activities. The importance and variability of sea ice, coupled with the hazards and difficulties of *in situ* observations make aircraft and satellite remote sensing of sea ice cost effective as well as valuable.

Research Task Objectives: Remote sensing from satellite synthetic aperture radar (SAR), such as instruments aboard the SEASAT (NASA), ERS-1 (ESA) AND RADARSAT (Canada) spacecraft, provides an excellent means for observation of sea ice motion and deformation. Radar images can be collected day or night and through clouds, thus giving SAR significant advantages over photography. NASA is planning to install a tracking station at Fairbanks, Alaska to receive SAR sea ice data from the ERS-1 satellite (1989). However, tracking sea ice features over a series of co-spatial images separated in time is a tedious and time consuming process to do manually, even when computer assisted. The objective of the research reported here is to automatically identify and track features in sea ice images in order to observe (and ultimately forecast) sea ice motion and deformation.

Research Approach: The fundamental data set is a pair of SAR images of the same geographical region collected a few days apart. These images are about 100 km square at 25 m. resolution. The first step is an averaging process to reduce the resolution and make the number of sample points more tractable. Two approaches for subsequent processing are being investigated. The first concentrates on a particular type of feature, namely lead-floe boundaries. SAR images of sea ice are reduced to a collection of such features, thus reducing the search space. For example, a 16,000 point image would be reduced to a set of about <100 features, each containing some tens of points. Leads are allowed to expand or contract by appropriate cutting of lead-floe boundaries. Boundary segments are classified according to their suitability for use as tracking features (tie points). A guided correlation scheme is used to search a 'test' image for matching boundary features. Ice velocity and distortion estimates are obtained by considering the displacement and rotation of features.

The second approach involves an image processing algorithm called hierarchical correlation. An image is first highly averaged to lower the resolution and make a straightforward block correlation algorithm tractable in terms of computation time. The ice velocity field established from the low resolution correlation is then used to guide further correlations at higher resolution. Results of these two fundamentally different approaches are to be compared with their strengths and weaknesses noted.

Current Status: Progress on the first ice tracking approach can be summarized as follows:

1. Lead-floe boundaries identified in SAR images
2. Lead-floe boundary segments classified
3. Correlation algorithms (to match image features) developed
4. Correlation algorithms given first-order tests on real SAR data
5. Algorithm improvements now underway

Progress on this approach was reported at the North American Radio Science meeting in June, 1985. This research is also supported by the Office of Naval Research.

MULTI-PROPERTY MODELING IN TWO-DIMENSIONS OF OCEAN CARBON FLUXES

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Long-Term Interests: Ultimately, to quantify the role of the marine biosphere as an agent in the global ocean's chemistry and therefore as a participant in the earth system. This work involves modeling of major biogeochemical properties on an ocean basin or global ocean scale, with emphasis on carbon fluxes and on coupling surface and deep (below surface) ocean properties to each other.

Objectives: To simulate ocean biogeochemical property distributions for the deep ocean along with surface chlorophyll concentrations for comparison to GEOSECS property distributions for the Atlantic and Pacific Oceans and CZCS large-scale patterns of surface chlorophyll concentrations.

Approach: A two-dimensional, meridional model incorporating mixing processes and bottom water formation will be constructed. It includes internal source terms for organic tissue oxidation and calcium carbonate dissolution. For surface chlorophyll concentration prediction, biological processes (such as growth rates and grazing) and physical processes (such as horizontal and vertical advective and diffusive circulations) will be mathematically resolved at a comparable level. Two-dimensional profiles of total carbon dioxide, dissolved oxygen, nitrate, carbon-14, alkalinity and silicate will be produced to ensure all the biologically-modified properties for which we possess global data are modeled as a system.

Status: This research just began under the Interdisciplinary Research Program in Earth Science: Ocean Basin Carbon Fluxes. A manuscript has been submitted, "Temperature vs. nutrients as factors creating large-scale ocean surface anomalies of pCO_2".

APPLICATION OF SURFACE CONTOUR RADAR TO OCEANOGRAPHIC STUDIES

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Long-Term Interests: To use the perfectly registered maps of topography and radar backscattered power derived from the Surface Contour Radar (SCR) to: (1) measure oceanographic parameters directly, and (2) evaluate the ability of satellite systems to measure them remotely.
Objectives: Improve on the SCR data processing techniques and establish its credibility in the oceanographic community. Analyze data from the SIR-B and NOAA Arctic Cyclone Experiments.
Approach: SCR data will be compared with in-situ sensors, other remote sensors, and the results of simulations and models.
Status: The SCR is now a mature instrument which is viewed as a standard in the oceanographic community. Walsh et al. (1985a) established the credibility of the SCR and demonstrated the limitations of pitch-and-roll buoys. In October 1984 the SCR documented the directional wave spectrum on a series of flights off the tip of South America in support of the SIR-B experiment. The agreement in the directional wave spectra among the SCR, the Radar Ocean Wave Spectrometer (ROWS) and SIR-B was remarkable (Beal et al., 1986). The SCR data processing techniques are being continually improved (Walsh et al., 1985b) and the SCR observations are starting to make a major impact on the field of oceanography. There are significant disparities among the growth rates measured by in-situ investigators for fetch-limited waves. The SCR is being used to examine the reasonableness of the various growth rates and is leading to new insights into the manner in which waves are generated. Analysis of SCR data (Fedor, L.S., E.J. Walsh, D. Cavalieri, 1986: Observation of sea ice using the 36 GHz Surface Contour Radar. IEEE Trans. on Geoscience and Remote Sensing, submitted for publication) from the NOAA Arctic Cyclone Experiment of January 1984 on the scattering and topographic characteristics of the sea ice off the coast of Greenland indicates that the SCR could play an important role in ice studies such as MIZEX. Electromagnetic (EM) bias is one of the major uncertainties in the TOPEX altimeter error budget since no open ocean measurements of it have been made at either of the K_u or C-band operating frequencies of TOPEX. Plans are being made for the SCR to measure the ocean surface topography in two dimensions while the backscattered power would be measured simultaneously at optical (AOL), K_a band (SCR), K_u band (ROWS) and C band (UMASS scatterometer) to determine the EM bias at all four frequencies simultaneously.

Simulation Analysis of Non-stationary CZCS Time Series from Continental Shelves

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Long-Term Interest: The role of continental margins in the global transfer of carbon and nitrogen among their atmospheric, terrestrial, and oceanic reservoirs.

Objective: To analyze CZCS time series of the spring bloom (February-May), between 1979 to 1984, within shelf and slope waters of the mid-Atlantic Bight, in order to accurately specify the seasonal and interannual carbon and nitrogen fluxes from estuaries to oceanic waters.

Approach: CZCS images from the mid-Atlantic Bight are too infrequent for the necessary daily sampling interval to resolve algal ($0.5\ day^{-1}$) and wind event ($0.2\ day^{-1}$) contributions to changes in phytoplankton biomass detected by successive overflights of the NIMBUS-7. Simulation analysis of seasonal phytoplankton response to daily changes in wind forcing, nutrient resupply, grazing and sinking losses are being used to interpolate the CZCS time series. Between January and July 1979, for example, only 45 images are available for the mid-Atlantic Bight, constituting a 25% data recovery, irregularly spaced in time. Drs. Otis Brown and Bob Evans of RSMAS, University of Miami, are processing the 1979-1984 images, while J. J. Walsh and D. A. Dieterle of USF are performing the simulation analyses.

Status: A 1979 time series of CZCS images during northwest wind events in March, April, May, and June has been compared to shipboard under-way chlorophyll maps and fluorescence/temperature/depth profiles taken during cruises in the same time period. A manuscript, "Satellite detection of phytoplankton export from the mid-Atlantic Bight during the 1979 spring bloom," has been accepted by Deep-Sea Research. A barotropic circulation sub-model has been developed at USF to simulate the flow response to winter-spring wind events. Using this sub-model, the simulated algal populations over 3 depth layers within the mid-Atlantic Bight are now being compared to the 1979 CZCS data set. Preliminary model results suggest that 10% of the primary production of the spring bloom on the shelf may be exported to slope waters. Compilation of all of the 1979-84 CZCS time series is now under way at RSMAS.

Collection of the shipboard data from the mid-Atlantic Bight was sponsored by DOE and NOAA.

SCATTEROMETER MEASUREMENT ANALYSIS FOR WAVE AND ENVIRONMENTAL EFFECTS FOR ALGORITHM ENHANCEMENT

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Long Term Interests: To model the combined effects of ocean surface winds and waves on the measured radar cross section and Scatterometer data so that new algorithms can be developed to improve the accuracy of mean surface wind estimates. The joint effects of average surface roughness and spatial variations induced by long ocean waves and wind turbulence will be incorporated into this model. In addition, the discovery of these new dependencies point the way towards future study of oceanographic and atmospheric motions that could not be observed previously with microwave radars.

Specific Objectives: To create new multi-variable model functions for the radar cross section and show how these models fit the acquired data in several experiments with smaller errors than a simple wind speed model. The goal is to create more accurate geophysical model functions for NSCAT applications.

Approach: The immediate objective is to make maximum utilization of the current data acquired from ocean towers and aircraft experiments that include a wide range of geometric and environmental parameters. A valuable test will also come from a reexamination of some SEASAT data with supporting wave and environmental data. If new dependencies are discovered, then previous tower radar studies will be verified. New aircraft data acquired with the AMSCAT onboard the ARC C-130 during FASINEX will be studied for similar dependencies.

Current Status: The SEASAT data has been divided into stable and unstable (with respect to air-sea temperature) collections. The stable group infers a mean surface wind that differs from the buoy winds by an amount that often increases with the wave height. The unstable data shows a dependence on the Monin-Obukhov length in addition to the wind. The analysis of the FASINEX data will begin in the near future. The challenge here will be to incorporate the radar system geometric parameters with the several geophysical variables into an accurate and easy-to-use model function.

SSMI DATA PROCESSING AND EVALUATION

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Long-Term Interests: To apply satellite microwave remote sensing to oceanographic and meteorological problems, with emphasis on efficient data processing systems.

Objectives: This investigation will provide NASA investigators with global maps of SSMI water vapor, cloud water, rain rate, and wind speed over the world's oceans. The capabilities and limitations of SSMI as an oceanographic and meteorological sensor will be assessed.

Approach: There are three phases in the investigation. The first phase is a pre-launch evaluation of SSMI capabilities. In this phase, the data collected by the SeaSat and Nimbus-7 microwave radiometers (SMMR) are used as a benchmark to predict the performance of SSMI in measuring water vapor, cloud water, rain, and wind. Our primary concern is the SSMI wind speed retrieval accuracy. SSMI will be relying on the 19 and 37 GHz channels to measure the near-surface wind speed. The second phase is to implement the SSMI data processing system and to do an initial sensor evaluation. The algorithm to be used does a one-step transformation from microwave antenna temperatures to environmental parameters. The first three months of SSMI data will be analyzed to determine if the sensor is operating properly and if the environmental products look reasonable. Histograms and global maps of the environmental products will be generated and compared to climatology. These comparisons will provide the means to remove biases in the SSMI radiance measurements. In the third phase, the SSMI products will be delivered to collaborating oceanographers and meteorologists. In particular, the utility of these products for studying the ocean heat flux and mid-latitude cyclones will be ascertained.

Status: The pre-launch evaluation has been completed. Global wind speeds were computed from the SMMR 21 and 37 GHz channels and were compared to scatterometer (SASS) winds, NOAA data buoy winds, and winds coming from the SMMR 6.6 and 10.7 GHz channels. The results indicated that SSMI will measure wind speed to an accuracy of about 2 m/s at a 150 km resolution. The implementation of the data processing system is now in progress.

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

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Objectives: The objectives of this project are to understand the capabilities of satellite altimetry and related measurements for the purpose of determining the general circulation of the ocean and its variability.

Specific Objectives: (1) Understanding the details of altimetric measurements as instrument systems, including all sources of error ranging from orbits to instrumental noise. (2) Understanding optimum and sub-optimum, but computationally efficient, methods for handling altimetric data for studying the ocean. (3) Using altimetric data to constrain models of the ocean circulation.

Approach: Detailed analysis of the existing SEASAT observations, including the "correction channels", to determine the frequency/wavenumber structure of the errors and their correction. Use of optimal estimation theory (including inverse methods) for analyzing data and its combination with dynamical/kinematical models in various forms.

Status: We continue contact, prior to the AO, with the TOPEX/POSEIDON project, for understanding of design issues for that program. Ground support planning for the project continues through US and international WOCE organizations. Re-analysis of the SEASAT data for error budgets in more detail than has been done in the past. This work, because of the size of the data set, is being transferred to a supercomputer. Have analyzed the optimal use of tide gauges (paper submitted for publication). General study of inverse/optimal estimation methods combined with dynamical models (various papers published). Awaiting release of GEOSAT data to try to use in western North Atlantic and northeast Pacific. Studying relationship between topography and geoid for optimal geoid estimation.

*Partially supported also by the National Science Foundation.

PHOTOECOLOGY, OPTICAL PROPERTIES, AND REMOTE SENSING OF WARM CORE RINGS

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Long-Term Interests: The study of cellular optics is at the basis of understanding how light is partitioned in the sea. Our work focuses on measurements of fluorescence and light absorption in algal cultures and marine bacteria in an attempt to establish an empirical analytical model of the causal variation and the interrelations between the light harvesting and emission processes.

Objectives: To observe fluorescence and absorption processes in natural populations and relate these to oceanographic processes. This approach continues to upgrade the interpretation of information obtained by active and passive remote sensing data, and supplies the concepts for future remote sensing techniques.

Approach: The fluorescence and absorption characteristics of phytoplankton populations were measured in conjunction with physical and chemical parameters associated with the anticyclonic processes. While validating algorithms for water color and Lidar measurements, change in optical properties were compared to the physical/chemical features associated with warm core rings.

Status: Considerable variation has been observed in the light attenuation properties of algae associated with these systems. This variation produces a non-linearity in the relationship between $\underline{K}$ and chlorophyll, and occurs at chlorophyll values less than 0.5 $\mu g/\ell$. Comparative analysis of phytoplankton, detritus and water, confirms the dominance of phytoplankton color in Case 1 waters. Case 2 waters exhibit a much higher dominance of attenuators other than phytoplankton pigment. The measurements of cellular fluorescence have demonstrated that procaryote populations of differing short wavelength light absorbers appear to be associated with different water masses of warm core rings. Indications are that in clear oligotrophic waters, blue absorbing procaryotes are more abundant than green absorbers. This distribution seems to be a function of overall water clarity, hence a chromatic adaptation appears to be involved. Comparison of optical cross-sections indicate that procaryotes represent about 10-20% of the total.

This work was supported by NASA, ONR, NSF, and the State of Maine.

ANAYSIS OF SEA ICE DYNAMICS

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LONG-TERM INTEREST: Investigation of the dynamics and variability of Arctic and Antarctic sea ice and determination of the validity of alternate methods for extracting geophysical parameters from satellite data.

SPECIFIC OBJECTIVES: 1) To investigate the large-scale dynamics and variability of the Arctic and Antarctic sea ice and associated oceanic and atmospheric processes, and 2) to evaluate the usefulness for scientific studies of geophysical parameters such as open water concentration, multiyear concentration, and thin ice coverage that are derived from SMMR multifrequency passive microwave observations.

APPROACH: Multifrequency passive-microwave SMMR data in orbital-swath format are mapped into daily polar-stereographic maps. Sequences of the spatial distribution of sea ice parameters derived from the microwave data are examined on daily to seasonal time-scales to quantify the changes in ice concentration and multiyear ice distribution and to study the convergence and divergence of the ice pack.

STATUS: In the Arctic, preliminary studies have shown that the multiyear ice distributions derived from the SMMR data can be used to study drift of the multiyear ice pack, interannual variations in the multiyear distribution, and the convergence and divergence of the ice pack during winter. The boundary of the multiyear ice pack is well-defined in the microwave data and the large-scale drift of the ice pack is indicated by the displacement of the boundary. Interannual variations in the multiyear drift pattern and variations in the overall distribution are being analyzed and compared with ice modeling results.

GEOSAT ICE ALTIMETRY DATA PROCESSING

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LONG-TERM INTEREST: Investigation of the dynamics and variability of the Antarctic and Greenland ice sheets and floating ice shelves.

SPECIFIC OBJECTIVES: 1) To process the GEOSAT altimetry data acquired over ice to obtain valid ice elevations for glaciological research and 2) to validate the ice elevation data set and make it available to the scientific community.

APPROACH: Data processing techniques that account for differences in the operation of the ocean radar altimeters over ice surfaces have been developed for Seasat, but need to be improved to handle the more extensive data set expected from GEOSAT. Algorithms for computer "retracking" the waveform data will be optimized and the means to edit automatically the waveform corrections will be developed. Methods for atmospheric and tide corrections will be adapted and applied to the data. Several levels of data sets including ice elevations with corrections in orbital format, a geo-referenced data base, and gridded elevations will be produced and archived.

STATUS: The retracking software developed for Seasat has been improved to minimize computer time while maintaining the same precision in the retracked correction. Also, the requirment for visual editing of invalid fits of the waveform function to the data has been eliminated. The retracking algorithms have been tested with Seasat data and the software has been modified for GEOSAT data formats. Preliminary processing will commence upon release of the data by the U.S. Navy.

ICE MARGIN MAPPING BY SATELLITE ALTIMETRY

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LONG-TERM INTEREST: Investigation of the variability of the Antarctic ice shelves and ice sheet margins by long-term observation of the position of the ice shelf front, ice rises, grounding lines, and ice sheet margins.

SPECIFIC OBJECTIVES: 1) To determine the position and elevation of the seaward ice margins of the Antarctic ice shelves and grounded coastal margins north of 72°S, and 2) To analyze elevation profiles for evidence of ice rises and grounding line positions.

APPROACH: The basic approach is to utilize the Seasat radar altimeter data set to derive the geographic coordinates of the seaward ice margins and ice shelf elevations. The major effort consists of a detailed analysis of the Seasat data in the vicinity of the ice-to-ocean and ocean-to-ice boundary crossings. The basic technique of ice-shelf margin mapping was demonstrated by the analysis of the successive altimeter waveforms (reflected radar signals) along a few Seasat tracks crossing the ice shelf-ocean boundary (Thomas et. al., 1983). The same technique is expected to apply to the ice "walls" where grounded ice calves directly into the sea. Semi-automated techniques are developed to analyze the entire set of Seasat boundary crossings and to map most of the Antarctic coastline north of 72°S. Ice shelf elevation profiles will be referenced to a common ocean surface. The elevation profiles will be analyzed for evidence of ice rises and the positions of grounding lines, and will be used to estimate ice shelf thickness.

STATUS: The Seasat radar altimeter data along the entire Antarctic coastline north of 72° is being analyzed using interactive software on an HP9845C. The procedure includes display of the waveforms in the vicinity of each ice margin crossing, examination and correction of the track points, display of apparent elevations, and calculation and mapping of the ice margin position. Approximately 70% of the coastline crossings have been analyzed and the positions are being compared with existing maps and Landsat imagery.

SECTION IV - BIBLIOGRAPHY

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-88987		

4. Title and Subtitle	5. Report Date
NASA Oceanic Processes Program. Annual Report - Fiscal Year 1985	August 1986
	6. Performing Organization Code EEC
7. Author(s)	8. Performing Organization Report No.
	10. Work Unit No.
9. Performing Organization Name and Address Oceanic Processes Branch Earth Science and Applications Division NASA Office of Space Science and Applications Washington, DC 20546	11. Contract or Grant No.
	13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546	14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

This, the Sixth 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 Fiscal Year 1985 (October 1, 1984 to September 30, 1985), the period covered by the Introduction extends into June 1986. Sections following the Introduction provide summaries of current flight projects and definition studies, brief descriptions of individual research activities, and a bibliography of refereed journal articles appearing within the past two years.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Oceanic Processes General Circulation Air-Sea Interaction Ocean Productivity Sea Ice	Unclassified - Unlimited Subject Category 48

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	160	A08

For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1986