NASA Technical Memorandum 86248

NASA Oceanic Processes Program

Annual Report—Fiscal Year 1983

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National Aeronautics
and Space Administration

**Scientific and Technical
Information Branch**

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PREFACE

As we pursue an FY-86 budget initiative to cover our Ocean Topography Experiment (TOPEX), as well as work to find a suitable spacecraft upon which we can fly our Ocean Color Imager (OCI), five recent events of note regarding funding support for the post-Seasat generation of ocean-related spacecraft have taken place. First, both the NASA Scatterometer (NSCAT) and the Navy NROSS satellite (upon which NSCAT will fly) have been included in the FY-85 budget submitted to Congress. Second, the ESA member states have agreed in principle to proceed with the hardware implementation phase for their ERS-1 which, once details have been worked out, will begin this summer or fall. Third, the Japanese Ministry of Finance has included support to proceed with the hardware implementation phase for their own ERS-1 satellite (different than ESA's ERS-1) which, once their legislature approves, can begin as soon as April of this year. Fourth, the Canadian government has approved an initiative to cover detailed design studies for their Radarsat and their contribution to ESA's ERS-1, as well as a ground station for direct reception of SAR data from both. Fifth, funds for a NASA ground station in Alaska planned for direct reception of SAR data from both ERS-1 satellites and Radarsat have been included in the FY-85 budget. With these activities underway, we can look forward with positive expectations for spaceborne ocean observations late this decade.

This, the fourth Annual Report for NASA's Oceanic Processes Program, provides an outline of these and other planned activities on the international scene, as well as an overview of our own recent accomplishments, present activities, and future plans. Although the report was prepared for Fiscal Year 1983 (October 1, 1982 to September 30, 1983), the period covered by the Introduction includes March 1984. 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. 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.

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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 five components; they and their respective program managers are: (1) Ocean Circulation -- Dr. William C. Patzert; (2) Air-Sea Interaction -- Dr. Patzert (Acting); (3) Ocean Productivity -- Dr. Wayne E. Esaias; (4) Polar Oceans -- Dr. Robert H. Thomas; and (5) Oceanic Flight Projects -- Mr. William F. Townsend and James R. Greaves.

Funds available to the Oceanic Processes Program in FY-83 amounted to approximately $17 million (M); this supported the project and study activities noted in Section II (with the exception of the separately funded Nimbus-7 and TIROS-N projects), as well as 87 specific research activities. The distribution of funding according to institutions was roughly as follows:

Jet Propulsion Laboratory	$9,600
Goddard Space Flight Center	2,800
Academic Institutions, etc.	3,500
Miscellaneous	1,100
Total	$17,000

On a project/study basis, the Ocean Topography Experiment (TOPEX) received about $4.7M. For the 87 specific research tasks, approximately $3.5M went to 35 investigators at academic institutions, $5.1M went to 42 investigators at NASA Centers, and $0.9M went to 10 investigators at other government and commercial institutions. In addition, the Information Systems Office at NASA Headquarters provided $2.0M for the Pilot Ocean Data System (PODS) at JPL.

Funds available for Oceanic Processes in Fiscal Year 1984 will rise to the $18.2M level, with Information Systems Office again providing $2.0M for PODS. An increase to $19.4M is anticipated for Fiscal Year 1985, of which TOPEX is anticipated to require between $5M and $7M, depending on the possible launch date.

Subject to approval of the FY-85 budget as submitted, the NASA Scatterometer (NSCAT) planned for flight on NROSS will receive an additional $15M to initiate development of the sensor and its associated data system.

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 same sensors. 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:

Allan, T.D. (ed). 1983. Satellite microwave remote sensing. Ellis Horwood Series in Marine Science. 526 pp.

Brown, O.B. and R.E. Cheney. 1983. Advances in satellite oceanography. Reviews of Geophysics and Space Physics, 21 (5) 1216-1230.

Davis, R.E. et al. 1983. Satellite data relay and platform locating in oceanography. Report of the In-Situ Ocean Science Working Group. Nova University/NYIT Press. 51 pp.

Gordon, H.R. and A.Y. Morel. 1983. Remote assessment of ocean color for interpretation of satellite visible imagery: a review. Springer Verlag Lecture Notes on Coastal and Estuarine Studies. 114 pp.

Husson, J.C. (ed). 1984. Space oceanology. Proceedings of a Summer School organized by CNES, Grasse, July 1982. Cepadues-Editions. 888 pp.

The Royal Society. 1983. The study of the ocean and the land surface from satellites. Phil. Trans. Roy. Soc. Series A 309. 222 pp.

Weller, G. et al. 1983. Science program for an imaging radar receiving station in Alaska. Report of the Science Working Group. JPL Report 400-207. 45 pp.

WMO/ICSU. 1983. Large-scale oceanographic experiments in the World Climate Research Program. Report of the JSC/CCCO Study Conference, Tokyo, May 1983. WCRP Pub. Series No. 1. 121 pp.

OCEAN CIRCULATION AND AIR-SEA INTERACTION PROGRAMS

The goal of the Ocean Circulation program is to determine the general circulation, heat content and horizontal heat flux of the oceans and their variability. The aim is to develop an understanding of the oceans role in climate. Specific objectives are to determine the geostrophic component of the ocean circulation. The proposed TOPEX mission, planned for launch in early 1989, forms the basis of this program. To provide a sound scientific framework for interpretation of satellite data, we emphasize theoretical studies, development of in situ ocean observing systems to complement satellite data, and the analysis of historical data collected from space. Numerical modelling studies aimed at assimilation of satellite data for both research and eventual operational use are also under development.

Significant accomplishments during FY-83 include: analysis of the Seasat data and long-wave (>1000km) global geoid models to determine the basin-scale ocean topography, further refinements of global tide models, production of synoptic (one month average) variability maps of surface topography in the North Atlantic, production of wave number spectra of ocean mesoscale variability from Seasat altimetry, and a study of the California Current response to wind forcing.

Recognizing that our future satellite missions will require complementary in situ observations to verify and calibrate the satellite data, we are jointly sponsoring with the National Oceanic and Atmospheric Administration (NOAA) and the Office of Naval Research (ONR) a program of technological development for drifting buoys. Known as DRIFTERS, this program will support TOPEX and NSCAT as components in the World Ocean Circulation Experiment (WOCE) and the Tropical Oceans/Global Atmosphere (TOGA) Program -- planned for the late 1980's. During this year, fabrication and field tests of a prototype satellite-linked multi-purpose drifting buoy (RELAYS) were completed at Woods Hole. Development of a self-contained acoustic doppler current profiler for use on either drifting buoys or moorings was initiated. Both the shipboard and bottom mounted acoustic doppler current profilers tested last year are now commercially available. Development of satellite transmission of environmental data via satellite is now operational, with four stations transmitting data from remote Pacific island stations. In the modelling studies, advances include: application of model and data analysis to the understanding of tropical ocean dynamics aimed at understanding El Nino, model refinements in the determination of oceanic surface wind conditions for application to atmospheric models, development of various numerical and analytic equatorial circulation models, and continued development of various modelling techniques for incorporating sea surface topography data.

The core of the Ocean Circulation program will continue to be the development of plans for TOPEX altimeter data. Emphasis will be on the development ocean circulation models that utilize and assimilate topography data. These activities will be focused toward 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. An update of the seasat altimeter data set is planned and analysis of these data will continue. Completion of various in situ instrument development tasks -- acoustic current profiling techniques, Pacific island stations transmitting via the GOES satellite link, and drifting buoy development -- is planned. As TOPEX nears New Start approval, high priority will be focused on planning for the scientific application of TOPEX data to important oceanographic problems.

The goal of the Air-Sea Interaction Program 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 (NROSS), scheduled for launch in early 1989, forms the basis for this program.

During the past year, accomplishments include: identification of the dependence of Seasat-SASS winds on sea surface temperature and atmospheric stability, continued refinements of techniques for using SAR data to measure ocean wave spectra and currents, continuation of a study to consider the feasibility for determining global ocean currents from geostationary satellites, comparison of aircraft surface contour and short pulse radar techniques for ocean wave spectra measurements for a fetch-limited sea, and the completion and distribution of 14 days of dealiased Seasat-SASS wind data. Work was initiated to: develop and evaluate techniques for estimating low-frequency latent heat flux over the global oceans, investigate underwater noise created by rain for use in calibrating radar rain measurements, and developing models that incorporate scatterometer wind fields.

The primary thrust in Air-Sea Interaction will be to initiate a program to improve our understanding of the relationship between scatterometry and the sea surface wind field. Of particular interest will be establishment of a sound physical basis relating radar backscatter to sea surface stress. A modest program that includes both theoretical and observational approaches will begin next year. Related to these activities will be the development of ocean models that incorporate scatterometer winds for application to the NSCAT data set. Plans for the scientific application of the TOPEX altimetry and NSCAT scatterometry data sets within WOCE and TOGA will have increasing importance in the Physical

Oceanography Programs. Of particular interest will be the joint utilization of these data.

OCEAN PRODUCTIVITY PROGRAM

The long range goal of the Ocean Productivity Program is to provide techniques to better understand the primary productivity of the oceans, its variability, how it is influenced by ocean circulation and the atmosphere, and how it in turn influences the marine food chain, the rate of global CO_2 uptake, and climate. The specific objectives are to assess and improve the accuracy of our capabilities to determine phytoplankton abundance and primary productivity based on complementary satellite, aircraft, ship, and in situ observations. We are concerned not only with the development and unambiguous physical interpretation of remote sensing techniques, but also with interfacing these techniques and data with a comprehensive research program involving data collection, analysis and interpretation.

During FY-83, we have seen major advances in the techniques for better determining chlorophyll pigment concentrations from the CZCS. These include refinement of sensor degradation and calibration corrections, and understanding of the effects on enhanced scattering by particulates and absorbance by dissolved organic material on the in-water algorithms. Within the oceanographic community, the capability for processing CZCS data has increased substantially with additional image processing capability and software availability. The University of Miami RSMAS image processing software was installed at JPL, and procedures have been developed to speed outside user access to the GSFC Atmospheric and Oceanographic Image Processing System (AOIPS), which has capability to apply several CZCS algorithms. As processing techniques become more objective, it is apparent that greater effort needs to be given to data availability and production of Level 2 and 3 data sets. Presently, over 40,000 Level 1 scenes are in the NOAA archive, and we expect that improved dial-up catalog search capability and the generation of a microfilm browse file will greatly expedite scene selection.

There has been further work by several investigators on developing and assessing the accuracies of techniques for extrapolating surface pigment concentrations derived from CZCS to vertically integrated phytoplankton concentrations and primary productivity. Additionally, initial work has begun on incorporating CZCS derived surface pigment fields in regional ecosystem models. Satellite ocean color parameters and sea surface temperature distributions have been used to perform an ecosystem classification for the northeast U.S. and Gulf of Maine region by NOAA's National Marine Fisheries Service.

With the increased need for utilization of CZCS data to prepare for the proposed OCI mission, there has been a reduction in priority of research relating to development of acoustical zooplankton techniques and in situ deployment of lidars. Work will continue at a reduced level on assessing the accuracies of fluorosensor techniques, and double pulse fluorometric methods for measuring photosynthetic potential.

Work is well underway for the production of consistently processed time series of pigment concentrations on a regional basis. These areas include: the West Coast of the U.S. (in several coordinated projects); the 1979 spring bloom for the Northeast U.S.; the Southeast U.S. bight region; the Gulf Stream Warm Core Ring region. These will result in Level 3 gridded, averaged data sets, and will be made available within a year to the oceanographic community.

The third Sea Surface Temperature Workshop was held in February 1984 to complete the comparison of large scale data sets from AVHRR, Nimbus-7 SMMR, HIRS/MSU, VAS, ships, buoys, and climatology for the months of December 1981, March and July 1982. This workshop activity was very successful in assessing the relative accuracies of the various techniques used to derive mean sea surface temperatures, and identified some systematic inconsistencies between the observations. This will be very useful for climatological and oceanographic studies, and for pointing out future research objectives.

The development of airborne techniques to aid in oceanic process studies, satellite ocean color algorithm development, and satellite data validation continues with the Wallops Airborne Oceanographic Lidar (AOL) being the primary instrument. As a result of past participation in oceanographic experiments, and recently via the participation in the Shelf Edge Exchange Processes Experiment (sponsored jointly by NASA and DOE), the Wallops P-3 with the AOL has gained an impressive measurement capability; this includes passive spectral radiance, fluorescence emission spectra with multiple excitation wavelengths, infrared thermal radiometry, AXBT deployment, and ship-aircraft communication and data telemetry.

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 sea-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 SSMI on an upcoming DMSP mission show greatest promise, and data from these sensors will have broad applications in both the scientific and the shipping 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 1988.

During the past year, we made considerable progress in the interpretation of passive-microwave data over sea ice. Research included field work on the ice surface, airborne measurements in the Bering Sea, and analysis of SMMR data over both polar regions. We have also begun a rigorous intercomparison of sea-ice algorithms using Nimbus-7 SMMR data over a region where Canadian researchers have extensive ground truth. The work is yielding an improved ability to distinguish different ice types, and a real potential for obtaining information about the ice surface--snow conditions, melt-pool extent, and albedo. We are continuing preparations for acquisition, processing, and archival of SSMI data based on recommendations provided by a science working group. This work will be done initially by the PODS at JPL. However, we are considering transfer of this function to the World Data Center for Snow and Ice at Boulder, Colorado, once the system is up and running.

We have made further progress in analyzing SAR data over sea ice. An automated technique for ice-type discrimination using SAR data is under development, and we have used sequential SAR images of the same region to deduce accurately the sea-ice velocity field in greater detail than hitherto possible.

A major goal of our program is to use satellite data to investigate sea-ice behavior, and we are making significant progress here also. Using passive-microwave data, we are studying melt-pool development in the Arctic, polynya formation in the Antarctic, and the marginal ice zone in both polar regions. We have also developed a ten-year time series of Antarctic sea-ice cover which clearly reveals strong interannual variability and an apparent long-term trend. The significance of this trend has been examined by modelling the sea-ice response to a climatic warming. This study has highlighted the need for long-term satellite monitoring of the sea-ice cover.

In December 1983 we published the report of a working group outlining a science program for ERS-1 SAR data over the Alaska region. In parallel with this effort, we have investigated establishing a SAR receiving station in Alaska. ESA has agreed in principle to provide SAR coverage over the region and, on the basis of the working group's report, we now plan to install a SAR receiver at a University of Alaska site in Fairbanks, assuming Congressional approval of funding for same in the FY-85 budget.

During FY-84, we plan to continue these programs with two major thrusts. First, we aim to intensify efforts toward compiling a set of sea-ice algorithms for the SSMI. We shall continue statistical analysis of SMMR data and analysis of field results acquired last year. In addition, we plan to obtain surface and airborne passive-microwave data during the Greenland Sea MIZEX (Marginal Ice Zone Experiment). This will be done in cooperation with ONR and ESA. By SSMI launch date (mid-1985), we aim to have the capability to produce, routinely, reliable estimates of sea-ice parameters. Our program will then be focused on research applications of the data with only peripheral activities in algorithm improvement.

We shall increase our efforts to automate analysis of SAR imagery to yield ice characteristics and ice motion. We aim to complete this work well in advance of the ERS-1 launch (1988). Before then, we plan to use data from the Shuttle Imaging Radar (SIR-B) experiment, due to fly next summer. We shall also develop plans for the follow-on experiment (SIR-C) which will fly in polar orbit during 1987 or 1988. Our long-term goal is for all-Arctic research using SAR and SSMI data in conjunction with in-situ measurements of weather, ice and ocean conditions obtained by remote buoys.

A new thrust next year will be towards investigation of the land-based polar ice using satellite data. Over the next decade, several missions will overfly the Antarctic and Greenland ice sheets. Between them, they provide the opportunity to obtain unique information. Altimeters can measure the shape and areal extent of the ice sheets; sequential surveys will reveal changes in ice-sheet dimensions. Altimeters also provide information about sea-ice characteristics and iceberg population. SAR data could be used for all-weather mapping in regions where conventional surveying is both dangerous and prohibitively expensive. Passive-microwave data reveal which portions of the ice sheet undergo summer melting, and they have the potential for interpolating estimates of snow-accumulation rates between the few points where in-situ measurements have been made.

Although ice-sheet investigations are peripheral to ocean research, we regard this as an important project, and one that is not currently included within NASA's research program. Moreover, the ice-sheet and sea-ice research communities overlap. Consequently, during the coming year we shall ask a science working group to assess the scientific potential of ice-sheet data from SSMI, Geosat, NROSS, and ERS-1, and to advise us on formulation of a well-focused research program using these data.

OCEANIC FLIGHT PROJECTS

The objective of the Oceanic Flight Projects effort is to develop and evaluate concepts for major flight experiments and supporting instruments that meet the observational requirements of the Oceanic Processes Program. Our major flight projects include TOPEX, which will support the needs of our Ocean Circulation program, the NASA Scatterometer for NROSS, which will support the needs of both the Ocean Circulation and Air-Sea Interaction programs, and an Ocean Color Imager (OCI) to support the Ocean Productivity program.

Ocean Topography Experiment (TOPEX)

During FY-83, we obtained the approval of the NASA Administrator to initiate Phase B detailed definition studies of TOPEX, which led to the release of an RFP to industry for satellite definition studies; we initiated the development of a brassboard model of the TOPEX Radar Altimeter; a Non-Advocate Definition Review of TOPEX was successfully conducted; and a New Start Review of TOPEX was held with the NASA Administrator. In addition, discussions between the NASA Administrator and the President of the French Space Agency (CNES) led to the initiation of a joint Phase B study with CNES considering the possibility of working together to satisfy mutually compatible objectives; in this case, CNES would launch TOPEX with Ariane, NASA would fly CNES instrumentation on TOPEX, and NASA and CNES would jointly conduct scientific investigations with the data.

Areas of emphasis for FY-84 for TOPEX include conducting Phase B studies with industry; completing the joint Phase B work with CNES; continuation of the Brassboard Altimeter development; and, in general, supporting the New Start review process associated with the consideration of TOPEX as a candidate FY-86 New Start.

NASA Scatterometer (NSCAT)

As a result of work in FY-83, a NASA Scatterometer budget proposal was submitted to Congress in January 1984 for consideration as an FY-85 New Start. Under this proposal, NSCAT would be developed and flown on the U.S. Navy's Remote Ocean Sensing System (NROSS). If Congress approves this proposal, it will be first New Start in the post-Seasat era for the Oceanic Processes Program.

The Scatterometer emphasis for FY-84 will be on completing the on-going Phase B definition studies of both the space and ground elements, finalizing interfaces with the Navy, refining the cost estimate, and in general, preparing to start "bending metal" in October 1984, should the Congress approve our budget proposal as we hope.

Ocean Color Imager (OCI)

A joint NASA/NOAA Memorandum of Understanding for flight and operation of an OCI on NOAA's operational polar meteorological satellites was developed. Unfortunately, neither agency was successful in obtaining funding approval for an FY-85 New Start. Had the attempt been successful, OCI could have flown on NOAA-J in 1988. Because the polar satellites alternate between morning and near-noon missions (assuming that NOAA's two polar orbiter program continues), and because the OCI requires a near-noon orbit, the earliest possible flight opportunity now will be NOAA-L in 1990. With the addition of the Advanced Microwave Sounding Unit (AMSU) on the NOAA satellites beginning with NOAA-K in 1989, however, there is serious question as to whether the basic NOAA bus will be able to accommodate both the AMSU and an OCI. Studies to clarify this issue will be initiated this year. If the addition of an OCI to NOAA-L appears feasible, both agencies could propose an FY-87 New Start.

FY-84 activities will be concentrated on identifying platforms for possible future flight. In addition to our discussions with NOAA, we are also exploring the possibility of flying OCI on the French SPOT-3 satellite with a launch proposed for mid-1990. A feasibility study and cost estimate will be developed this year; an FY-87 New Start would be required for this option as well as for the possible NOAA option.

Advanced RF Tracking System (ARTS)

The Advanced RF Tracking System (ARTS) activity led to the development of two breadboard precision Global Positioning System (GPS) receivers which went in the field for testing at the close of FY-83. During FY-84, we expect the ARTS GPS field demonstration to be successfully completed and are hopeful that we will be able to consider a flight demonstration of this unique and innovative technology on TOPEX. The long-range objective of the ARTS activity is to develop and demonstrate a capability to obtain precise orbits for spacecraft, where the single-pass radial component of error is approximately five centimeters. Assuming that TOPEX is flown and an accurate determination of the tides is made, this will permit continuing altimetric monitoring of the oceans using spacecraft on an as-available basis.

THE 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 Caldwell McCoy of the NASA 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 EE (the Oceanic Processes Program), and is expected to occur when TOPEX receives a New Start.

In FY-83, PODS supported two 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 was developed, utilizing the University of Miami Display System Programs. Development of plans to process DMSP SSMI data for archival and research purposes are being developed in collaboration with NOAA's World Data Center A in Boulder, CO. Work continued on improvement of data links connecting PODS to outside users.

In FY-84, we will in develop a transition plan for the PODS. A review was held in December 1983 to aid in formulating the direction that this transition should take, and to ensure appropriate coordination with NOAA, NSF, and other data management and archival activities in meeting the data needs of the oceanographic community. The plans to develop a processing and archival system for SSMI will be completed. Results from the Third Sea Surface Temperature Workshop will be published. Development of remote work stations linked to PODS for working with large archived data sets efficiently will continue. Optical digital disk storage techniques will be implemented on an exploratory basis, and the implementation of a West Coast Chlorophyll-Pigment and Sea Surface Temperature Time Series will begin.

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). These groups include the Board on Ocean Sciences and Policy, Board on Atmospheric Sciences and Climate, Polar Research Board, Committee on Geodesy, Naval Studies Board, Committee on Earth Sciences (CES) of the Space Science Board, and the Space Applications Board. In addition to the CES report entitled, "A Strategy for Earth Science from Space in the 1980's--Part I: Solid Earth and Oceans," which was published year before last, the companion report, "Part II: Atmosphere and Interactions with the Solid Earth, Oceans, and Biota," is nearing publication. These two reports outline the scientific need, in concert with Earth sciences in general, for ocean observations from space.

In addition to working with these Academy groups, we are working with the Joint Oceanographic Institutions, Inc. (JOI) outlining 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. JOI expects to publish this report by early summer.

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. 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.

Table 2 outlines national and international ocean spacecraft activities for the next decade, which are at various levels of planning and development. 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. In response to the needs of our community, we are investigating options for obtaining access to data from these spacecraft and, for certain of them, the possibilities for flying one of our ocean sensors. In addition to the acronyms and definitions accompanying Table 2, we have included a brief descriptive paragraph describing each of the spacecraft listed and commenting on their present status.

Table 1. Recent NASA Science Working Groups

Science Working Group	Chairman	Established	Report
SSMI Sea Ice Research Science Working Group	Norbert Untersteiner, U. Wash.	December 1982	June 1984
ERS-1/SAR Sea Ice Study Team	Gunter Weller, U. Alaska	April 1982	December 1983
In-Situ Science Working Group	Russ Davis, Scripps	September 1981	March 1984
Satellite Ocean Color Science Working Group	John Walsh, BNL/Stonybrook	October 1981	December 1982
Satellite Surface Stress Team (S-Cubed)	James O'Brien, FSU	July 1981	July 1982
TOPEX Science Working Group	Carl Wunsch, MIT	February 1980	March 1981

Table 2. OCEAN-RELATED SPACECRAFT: NEXT DECADE

SATELLITE	SPONSOR	OCEAN-RELATED SENSORS/COMMENTS	LAUNCH	STATUS
GEOSAT	USN	ALT	1984	APPROVED
DMSP	USAF	MR	1985	APPROVED
	NASA	MR DATA PROCESSING FACILITY (PODS)		APPROVED
MOS-1	JAPAN	CS, IR, MR	1986	APPROVED
ERS-1	ESA	ALT, SAR, SCAT, IR	1988	APPROVED
	NASA	SAR DATA RECEIVING/PROCESSING FACILITY		APPROVED
NROSS	USN	ALT, MR, SCAT	1989	APPROVED
	NOAA	CONTRIBUTE BUS (NOAA-D SPACECRAFT)		PROPOSED
	NASA	CONTRIBUTE SCAT		APPROVED
TOPEX	NASA	ALT	1989	PROPOSED
ERS-1	JAPAN	SAR	1990	APPROVED
	NASA	UTILIZE SAR DATA FACILITY		PROPOSED
SPOT-3	CNES	PIGGYBACK ALT	1990	PROPOSED
	NASA	PIGGYBACK CS	1990	PROPOSED
GRM	NASA	SATELLITE-TO-SATELLITE TRACKING	1991	PROPOSED
ERS-2	ESA	ALT, SAR, SCAT, ?	1991	TENTATIVE
RADARSAT	CANADA	SAR	1991	PROPOSED
	NASA	CONTRIBUTE LAUNCH & PIGGYBACK SCAT		PROPOSED
MOS-2	JAPAN	ALT, CS, MR, SCAT	1992	TENTATIVE

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. There will be an initial 18-month geodetic mission to map the marine geoid, one map being produced in six months and having an 18-km equatorial track spacing. Following this, there will be an 18-month oceanographic mission, with an orbit having a 20-day-repeat cycle and a 150-km equatorial track spacing. In general, the mean sea surface data from the initial 18-month geodetic mission will be classified, with the residuals from this surface being unclassified.

DMSP This is a series of U.S. Air Force operational meteorological satellites in sun-synchronous orbit. For those satellites planned for launch between 1985 and 1991, there will be a microwave radiometer (the Special Sensor Microwave Imager, or SSMI) aboard having four frequencies over the range from 19 to 85 GHz. As SSMI data are useful in characterizing sea ice, snow cover, surface winds, and atmospheric water, NASA plans to acquire them for research purposes. (Unfortunately, the SSMI data are not useful in estimating sea surface temperature.)

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. MOS-2 is being considered as a tentative follow-on; however, the sensor complement and orbital characteristics are as yet undecided.

ERS-1 This is an ESA marine science and applications mission whose purpose is to establish, develop, and exploit ocean and ice applications of remote sensing data. A sun-synchronous orbit is planned. The ESA member states have agreed in principle to proceed with the hardware implementation phase for ERS-1 which, once certain details are worked out, is due to begin next summer or fall. ERS-2 is being tentatively considered as a follow-on mission; if done, it would utilize spares from ERS-1.

NROSS This is a U.S. Navy mission with NASA and NOAA participation. The NASA (the provision of a scatterometer) and Navy components are in the FY-85 budget submitted to Congress. As the NOAA component (the provision of a satellite bus) is not currently in the budget, the Navy has developed a back-up plan for provision of a bus. 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 will be an element of the overall DMSP program. In addition to the SSMI, it will carry a lower-frequency microwave radiometer for estimating sea surface temperature. Data from the NASA scatterometer will be used to complement TOPEX data in addressing the general circulation of the oceans.

ERS-1 This is a Japanese spacecraft with the same acronym as ESA's ERS-1. Its objective is to develop SAR technology and deploy it primarily related to terrestrial mapping for non-renewable resources. It will be in a sun-synchronous orbit and will have an L-band SAR with a two-year design life. Recently the Japanese Ministry of Finance approved inclusion of ERS-1 in the budget for their fiscal year which begins April 1, 1984. The implementation phase will commence once their legislature approves this budget.

TOPEX The Ocean Topography Experiment is a dedicated altimeter mission whose data--when combined with data from the NROSS scatterometer--will be utilized to advance our understanding of the general circulation of the oceans. The orbital characteristics are: inclination of 63 degrees, altitude of 1300 km, equatorial track spacing of 300 km, and track repeat of 10 days. Tracking will be provided by DMA's Tranet system, and a Shuttle launch is being considered. At the present time TOPEX is being proposed as an FY-86 start. If an FY-86 New Start is obtained and according to present schedules, TOPEX could be launched a month or so after NROSS.

POSEIDON This is a CNES program to develop and utilize satellite altimetry and an associated tracking system (DORIS) for ocean and ice studies. It is currently being considered for piggyback deployment aboard the French SPOT-3 spacecraft. This program is viewed as developing the basis for a low-power, low-cost, and long-term ocean and ice monitoring package deployable on spacecraft of opportunity.

TOPEX/ POSEIDON This is a joint NASA/CNES study currently underway. The concept under investigation is the deployment of the POSEIDON sensor package aboard the TOPEX spacecraft (along with the planned TOPEX sensors) and its launch by an Ariane rocket.

OCI — NASA is considering the launch of an improved version of the Coastal Zone Color Scanner (known as an Ocean Color Imager, or OCI) presently deployed aboard Nimbus-7. Although a specific spacecraft has not been confirmed for the OCI, the NOAA operational meteorological and French SPOT-3 satellites are being investigated.

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.

RADARSAT — This is a mission employing a C-Band SAR to monitor sea ice characteristics off the northern slope where the Canadians are interested in developing a petroleum field. It would provide the basis for sea ice forecasting. The Canadian government has recently approved funding to support detailed design studies both for Radarsat and its ground segment (which will also be used with ESA's ERS-1). NASA is considering participation in this mission via the provision of a Shuttle launch and a scatterometer sensor.

SPOT — This is a French version of the U.S. Landsat series. In addition to the terrestrial-oriented visible radiometers, SPOT 3 and 4 can each carry one or two additional sensors. SPOT 3, proposed for launch in mid-1990, is being considered as a platform for a NASA OCI.

ACRONYMS
(to accompany Table 2)

ALT	ALTIMETER
CNES	FRANCE'S NATIONAL CENTER FOR SPACE STUDIES
CS	COLOR SCANNER
DMSP	DEFENSE METEOROLOGICAL SATELLITE PROGRAM
ERS-1	ESA'S 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	MICROWAVE RADIOMETER
NROSS	NAVY'S REMOTE OCEAN SENSING SYSTEM
PODS	JPL'S PILOT OCEAN DATA SYSTEM
SAR	SYNTHETIC APERTURE RADAR
SCAT	SCATTEROMETER
TOPEX	OCEAN TOPOGRAPHY EXPERIMENT

SPACEBORNE OCEAN-SENSING TECHNIQUES
(to accompany Table 2)

ALTIMETER - (ALT) 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 - (CS) 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 - (IR) a radiometer that measures the intensity of radiation emitted from the sea in the infrared band in a broad swath beneath the spacecraft. Measurements yield estimates of sea surface temperature.

MICROWAVE RADIOMETER - (MR) 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 - (SCAT) 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 quilibrium with the local wind and from which the surface wind velocity can be estimated.

SYNTHETIC APERTURE RADAR - (SAR) a microwave radar similar to the scatterometer except that it electronically synthesizes the equivalent of an antennae 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

NIMBUS-7 OBSERVATORY

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

COASTAL ZONE COLOR SCANNER (CZCS)

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

CZCS collects approximately 15,000 two-minute scenes per year of screened data after deleting scenes with excessive cloud contamination. There are approximately 34,000 scenes of level-1 (Calibrated Radiance Tape) data archived with the NOAA Environmental Data Information Service (EDIS). Level-2 products have been produced and archived for 950 of these scenes. Many "Sea-truth" cruises have been conducted with coincident Nimbus-7 over pass data collected and validation studies performed. These show that pigment and diffuse attenuation coefficients calculated from CZCS measurements are well within the accuracy goals set for all but cases of high pigment concentrations for level-2 products.

Archival of the Level-1 products for the first year of operation was completed in April 1982 and for the second year in September 1982. Level-2 products for 800 scenes selected from the first 3 years of data will be available by September 1984. Additional Level-2 products are planned in subsequent years. An atlas will be prepared and archived in EDIS in 1984 with commentary on selected Level-2 scenes for U.S. coastal waters and open ocean areas.

Several significant contributions to both oceanographic and atmospheric optics have been published as has a Nimbus-7 Data Plan, Nimbus-7 User's Guide, and a CZCS data catalog.

SCANNING MULTICHANNEL MICROWAVE RADIOMETER (SMMR)
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Sea surface temperature, water vapor and wind speed over oceans, sea ice concentration, multi-year ice fraction, and a "snow parameter", all derived from SMMR measurements for year 1 and 2 are now available from the National Space Science Data Center (NSSDC). Presently year 4 data is being processed.

Based upon intercomparisons between several data months of SMMR retrieved parameters and conventional surface measurements over open ocean areas, the rms accuracies for the ocean/atmosphere parameters are as follows: sea surface temperature $\pm$ 1.6K; atmospheric water vapor $\pm$ 0.2 gm/cm^2; sea surface wind $\pm$ 2.5 m/sec. Due to the relatively large sensor "footprint" (150 km) and the effects of land contamination, the sea surface temperature measurements are restricted to areas more than 600 km from shore. Sea ice concentration and multi-year ice fraction algorithms meet their prelaunch goals of $\pm$ 5% accuracy for ice concentration and $\pm$ 15% accuracy for multi-year ice fraction.

The data is available in computer compatible tape and hard copy picture formats. A Nimbus-7 (year 1 and 2) Level II Data User's Guide will be available in May 1984.

Upgrading of the geophysical algorithm is being done as data is being validated. The U.S. Navy has been using SMMR data in real time to produce sea ice maps for operational forecasts. Additionally, SMMR data has been processed in semi-real time to produce sea-ice concentrations and sea-surface winds in support of various field experiments such as MIZEX-EAST (Summer 83) AMERIEZ (Winter 83), and the Norwegian Met. Service (Jan-March, 84). More of these types of activities are planned in the future (MIZEX 84, USGS snow runoff estimation, etc.).

TIROS-N/NOAA SERIES

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Project Objectives: 1) To provide spectral radiometeric information for more accurate sea surface temperature mapping and day/night cloud cover information. Also to provide higher accuracy and yield of atmospheric temperature and water vapor soundings over the oceans. 2) To provide a remote platform location and data collection capability over the oceans.

Instrumentation:

1) Advanced Very High Resolution Radiometer (AVHRR)
This scanning radiometer (4-channel on NOAA-8 and 5-channel on NOAA-7) provides stored and direct readout of radiometric data. The fifth channel was added to NOAA-7 to account for boundary layer water vapor and thereby increase the accuracy of sea surface temperature measurement in the tropics.
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. Its purpose is to receive and locate distress signals from ships and planes.

Current Status: NOAA-7 (launched in 1981) replaced the original TIROS-N (launched in 1978). This satellite operates concurrently with NOAA-8 (launched in 1983). The NOAA-7 is in a 1430 LST ascending orbit, while NOAA-8 is in a 0730 LST descending orbit at the equator. Both are in sun-synchronous orbits at an average altitude of approximately 830 km, with orbital peridos of 102 min. NOAA-7 will be replaced by NOAA F sometime after August 1984. NOAA F, like NOAA-7, contains the five channel AVHRR. It will also contain ERBE, to measure earth radiation budget, and SBUV-2, to measure stratospheric ozone profiles and total ozone burden.

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 dta 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 retreival products data, from February 1979 to present. Both tapes and picture imagery are available on request.

ALTIMETRY

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Satellite altimetry, as demonstrated on GEOS-3 and SEASAT, is an important new measuring technique in several areas of geophysics and oceanography. These observations have already improved knowledge of the marine geoid far beyond the state-of-the-art before altimeters were flown, and they have demonstrated the very great promise of the method for studies of the ocean circulation.

Altimeters provide an all-weather capability for measuring the surface elevation of the ocean and its changes through time. Because the surface elevation represents the pressure forces acting on the entire three-dimensional ocean circulation, the implications of successful measurement extend far beyond the determination (which is nonetheless still important) of the surface flows themselves, to the provision of a dynamical boundary condition on the full oceanic general circulation and its variability.

The NASA Ocean Topography Experiment (TOPEX) is directed at the provision of an altimetric system of adequate accuracy and precision for use in oceanography and geophysics. Present design envisions a three-year baseline mission of a system optimized for altimetric use. This optimization implies precise orbit determination, precise repetition every 10 days of the sub-satellite sampling points, and of appropriate instrumentation to make the major corrections to the terms contaminating the altimetric measurement (variations in the ionosophere and in atmospheric water vapor).

At present, TOPEX is moving into phase B with industry design study contracts having been made. A launch in early 1989 is envisioned. An interesting development of the past year has been the combination of the TOPEX studies with those being undertaken in France in their project POSEIDON. There is a high probability that TOPEX will be a joint project of NASA and CNES, the French space agency.

The possible availability of an altimetric mission has led the oceanographic community to begin planning surface measurements to take advantage of the first real global observations of the ocean, and of the anticipated NROSS satellite scatterometer which would be flown at the same time. This scatterometer would provide global observations of vector wind -- the dominant forcing function on the ocean circulation. The discussions have led to the World Ocean Circulation Experiment, a program to be carried out under the international auspices of the WMO/ICSU/SCOR/IOC World Climate Research Program in which many in situ observations would be made, the program being directed at many important issues: the role of the ocean in climate and climate change, the carbon dioxide transient; long-term behavior of the ocean and its effects on radioactive wastes, and the role of the ocean circulation in the biochemical cycles.

COLOR RADIOMETRY

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As a result of the launch of the Nimbus-7 Coastal Zone Color Scanner (CZCS) in October 1978 and the subsequent progress with data analysis, it is now possible to determine ocean chlorophyll concentrations from space to better than ±30% of in situ values in waters of little sediment or humic matter. The Satellite Ocean Color Science Working Group was established in October 1981 to consider the scientific utility of repeated satellite measurements of ocean color. The Working Group consists of J. Walsh, Chairman (Brookhaven National Laboratory, W. Barnes (Goddard Space Flight Center), O. Brown (University of Miami), K. Carder (University of South Florida), D. Clark (National Aeronautics and Space Administration), H. Gordon (University of Miami), J. Gower (Institute of Ocean Sciences), R. Holyer (Naval Ocean Research and Development Activity), W. Hovis (National Environmental Satellite Service), R. Kirk (Goddard Space Flight Center), J. Thomas (National Marine Fisheries Service), J. McCarthy (Harvard University), J. Campbell (Bigelow Laboratory), J. Mueller (Naval Postgraduate School), M.J. Perry (University of Washington), and R. Smith (University of California). During 1983-84, the Working Group met twice to discuss major scientific problems which may be addressed with the use of future ocean color sensors from spacecraft. With publication of the MAREX (MArine Resources EXperiment) program report, consisting of the Working Group's activities from 1981-1983, the major emphasis of the Group has been focused on both future launches of a CZCS follow-on sensor, an OCI (Ocean Color Imager), and data reduction/analysis of the present CZCS time-series. Possible candidates for 1990-92 launches of an OCI involve cooperative international and U.S. satellite programs. A subcommittee of the Working Group was formed to address the future spectral characteristics of such sensors. CZCS time series are presently being produced for the east coast of the United States (South Atlantic Bight, Mid-Atlantic Bight), the Gulf of Mexico, the U.S. west coast (Baja California to Vancouver Island), The Aleutians, the North Pacific (Ocean Station Pappa), off Peru, northern Brazil, and between Argentina and the Falklands, off South Africa, and within the North Sea - a second subcommittee was formed to develop specific recommendations for future CZCS data processing, priorities, and general availability of an eventual global data set.

IN SITU SCIENCE WORKING GROUP

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The *In Situ* Science Working Group was established 1) to identify the ocean science activities using satellite positioning and data relay, 2) to assess near-term satellite capabilities and the demands that will be placed on them, and 3) to recommend improvements to *in situ* and satellite systems.

The Working Group has prepared a report, Satellite Data Relay and Platform Locating in Oceanography. The report concludes that there are an increasing number of uses for satellite data relay, satellite locating of unmanned platforms, and accurate satellite navigation for ships at sea.

A system of the ARGOS type is well suited to the needs of unmanned platforms and the present ARGOS capabilities meet the needs of most anticipated users. The system presently operates well below saturation, primarily because the expense of ARGOS transmitters prohibits the deployment of large numbers of expendable instruments. There is, however, demand for data relay from a small number of platforms transmitting relatively large data volumes (order 10,000 bits/day) and this demand could saturate the present ARGOS systems. To meet this demand, the data capacity of ARGOS must be expanded or users must make use of GOES data relay while using ARGOS for locating.

Many at-sea operations are dependent on accurate navigation. The presently envisioned low resolution GPS will be adequate for most operational purposes but some scientific users (e.g. shipboard velocity measurements) will need access to the high resolution capability.

The Work Group's recommendations were:

1) Satellite scheduling should be consistent with the high value and direct cost of data which would be lost by a hiatus in data relay and locating services.
2) Support of *in situ* technology for exploiting satellite capabilities should continue.
3) The high accuracy GPS navigation capability should be made available to oceanographers.
4) Methods for reducing the cost of ARGOS transmitters should be found.
5) Methods for expanding ARGOS data relay capacity should be sought.

SAR STUDIES OF SEA ICE IN THE ARCTIC

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Introduction

It is generally agreed that the sensor with the greatest potential for sea ice studies is synthetic aperture radar (SAR). Sea ice features are characterized by a wide range of scattering coefficients so that good contrast exists between old ice, new ice and open water. Also SAR has high resolution, usually 10-100 meters, permitting the classification of ice in a given image and tracking of small features in sequential images. The table below shows the usefulness of SAR data in interpreting sea ice characteristics.

Sea ice characteristics	SAR data
Extent	Good
Movement and deformation	Good
Snow cover	Not Known
Ice thickness	Some
Internal geometry (floe size, lead patterns)	Good
Surface roughness	Good
Ice types	Some
Physical properties (temp., salinity, strength, etc.)	Some

A drawback of spaceborne SAR is that the associated data flow rate is so high that data cannot be stored on a satellite for playback while over a receiving station. This means that if one wishes to receive SAR imagery of important areas of sea ice, it is necessary to have a receiving station that is in range of the satellite while the satellite is viewing the sea ice. For the ice of the Western Arctic such a site would clearly be in Alaska. A similar station in Scandinavia, e.g. at Kiruna in Northern Sweden, could cover the Eastern Arctic. Three satellites are currently under development which will deploy SAR systems in polar orbits: the ESA ERS-1 satellite, launch 1988; a Japanese satellite, launch after 1988; and the joint Canadian/U.S. RADARSAT, launch around 1990.

Objectives

The objectives of a study just concluded (NASA, 1983) examined the benefits of establishing an Alaskan receiving station for SAR data, and assessed its potential in helping to solve scientific and operational sea ice problems, as briefly summarized below:

Potential Research and/or Operational Benefits

The geographical area which could be covered by an Alaskan receiving station includes a large variety of different sea ice features and processes such as the Beaufort Sea Gyre, the highly deformed ice over the continental shelves, high velocity extrusion and break-out of ice through the Bering Strait, and the conveyor-belt type circulation in the Northern Bering Sea which advects ice out to the ice edge.

Studies of these various ice regimes involving the disciplines of oceanography, meteorology and climatology are concerned with the response of the ice to dynamic and thermodynamic forcing as well as with feedback processes. Questions, for which answers are required include: What is the seasonal rheology of the pack ice? What are the heat, mass and momentum balances of the ice in the Beaufort Gyre, over the shelves and in the marginal ice zone? How does sea ice respond to climate changes and vice versa? What is the role of oceanic and meteorological features in the production, deformation and advection of ice in the Bering Sea and the Arctic Ocean?

Another set of questions can be asked in relation to engineering studies and in operational forcasting for ships in sea ice. What is the strength of annual and multi-year ice, pressure ridges and rubble fields? Where do these features occur seasonally? How may these ice types interact with offshore drilling platforms? Where can one efficiently route tankers through pack ice fields? When and where would invading ice threaten drillships operating in open water? SAR is also a useful tool in geology, glaciology and botany.

In summary, there seem to be numerous critical scientific and operational sea ice and other problems that could profitably be addressed if a SAR station receiving data under all weather conditions were established in Alaska.

NASA, 1983. Science program for an imaging radar receiving station in Alaska. Report of the Science Working Group, Jet Propulsion Lab., 45 pp. Dec. 1983.

SCATTEROMETRY FOR VECTOR STRESS MEASUREMENTS

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The Satellite Surface Stress Working Group was commissioned to suggest oceanic science that would be done if it were possible to determine the vector wind field at the sea surface. SEASAT demonstrated that it is possible to determine the wind speed and direction over the ocean to within very useful accuracies. While the oceanography community believes that it knows the relevant equations of motion for the ocean, it has never been capable of measuring the principal forcing function, the vector wind field, to calculate the ocean currents. One unequivocal conclusion the committee has made is that conventional wind data do not suffice to meet the research and application needs of the oceanographic community.

The required measurement is the vector horizontal tangential stress, which is the lower boundary condition for the atmosphere and the upper boundary condition for any wind-driven wave or ocean current model. It is recognized that considerable basic research will be necessary to interpret space measurements as vector surface wind stress.

The vector wind stress fields collected over the ocean will be used to drive a wide variety of ocean models. It will be possible to obtain quantitative estimates of upper ocean currents from these models. The vector wind stress fields are very important for many oceanographic problems.

Scatterometer data are extremely valuable for applications other than oceanographic research, such as meteorological modeling, special naval ocean products and industrial use. The impact of surface winds over the ocean on naval or industrial applications is sufficient to justify the investment in the scatterometer. The S^3 committee held its last meeting in February, 1984 where we approved the scientific opportunity document for the AO and the NROSS Scatterometer.

NASA Science Working Group on Sea Ice Data
from the Special Sensor Microwave Imager (SSM/I)

A draft report on the need for SSM/I data from the next DMSP satellite was prepared by the Science Working Group in June 1983 and discussed at a meeting at NASA headquarters by NASA scientific personnel and several members of the Science Working Group. The report was found to be technically sound, although in need of minor additions and clarifications. A major deficiency was found to be the introduction as being too technical and not sufficiently instructive for the non-expert. A more general introductory chapter is in preparation.

The final draft will also contain a description of technical developments in the Pilot Ocean Data Sylstem at the Jet Propulsion Laboratory. That draft will be submitted to all members of the NASA Science Working Group and to its NASA sponsor, for final updating and substantive editing. Style editing will be done at the Applied Physics Laboratory (University of Washington) where necessary graphic artwork will also be provided, and the report in its final, approved form will be produced.

A new development in the area of sea ice research is taking place in the Joint Scientific Committee of the World Climate Research Program. At the request of Prof. P. Morel, Director of the JSC, Prof. N. Untersteiner organized and conducted a workshop (supported by JSC funds) on the role of sea ice in climate modeling at Geneva (12-16 December, 1983). This workshop resulted in a brief review of the evidence of sea ice effects in atmospheric and oceanic climate, and a set of recommendations for further research. The recommendations pertain not only to climate-related modeling but also to the acquisition of new data, primarily from satellites and data buoys. While the NASA-SWG report emphasizes both scientific and operational aspects of sea ice data, the JSC workshop report addresses scientific issues only, and there is essential agreement between the two reports on the need for continued acquisition of sea ice data and their application to research problems. One of the recommendations by the JSC-sponsored workshop of experts is the creation of an ad hoc study group within JSC to consider the formulation of a climate-oriented sub-program on sea ice in the framework of the World Climate Research Program. This subject will be considered by the forthcoming meeting of the full JSC in Hangzhou, China, on 12-16 March 1984. It is to be anticipated that the operational use of sea ice data will remain an issue of the particular national requirements, but an internationally recognized and suitably defined sea ice research program would be highly desirable, bringing to bear on the problem not only increased and coordinated resources but also creating a broadly based scientific research strategy toward solving fundamental problems.

Norbert Untersteiner

OCEAN TOPOGRAPHY EXPERIMENT (TOPEX)

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Program Science Objectives: The primary objective of the Ocean Topography Experiment Program is to measure the sea surface topography of the ocean over entire ocean basins for a period of several years. These measurements will be integrated with subsurface measurements and models of the ocean's density field in order to determine the general circulation of the ocean and its variability. This information will then be used to: 1) understand the nature of circulation dynamics, 2) calculate the heat transported by the oceans, 3) observe the interaction of currents with waves and sea ice, and 4) test the ability to predict circulation from wind forcing.

Instrumentation: The objectives of TOPEX require that the satellite height above the sea surface be measured and combined with satellite orbit information. The first measurement is to be made by a satellite-borne radar altimeter derived from those flown on Skylab, Geos-3, and Seasat. The TOPEX altimeter will operate at two different frequencies to correct height measurements for the total ionospheric electron content. A three-channel microwave radiometer will gather data required for atmospheric water vapor correction. Orbit information will be determined from intensive tracking of the satellite by the Defense Mapping Agency's Tranet System. A second tracking system, an Advanced Radio Metric Tracking System (ARTS), may aid the orbit determination process if experiments are successful. Verification of both measurements will be made through laser tracking of a laser retroreflector carried on the satellite.

Current Status: TOPEX conceptual studies were carried out from February 1980 through September 1982. An orbit altitude of 1334 km (circular) and an orbit inclination of 63.4° were selected for the baseline mission to avoid aliasing tidal components in the topography measurements. This orbit will also provide an exact 10 day repeat coverage of the global ocean for the mission duration of three years or more. During FY'83 pre-definition studies were conducted to further optimize the mission design and plan for the implementation phase.

In June 1983 agreement was reached between CNES and NASA to conduct a joint study to determine the feasibility of a cooperative effort to perform a combined TOPEX/POSEIDON mission and achieve both organizations' objectives with a single satellite. NASA would provide the satellite bus and the full TOPEX sensor complement; CNES would provide a POSEIDON altimeter or a solid state amplifier for the TOPEX altimeter, a DORIS tracking system receiver, and an Ariane launch of the satellite to the desired orbit. Several coordination meetings have been held between CNES and NASA and the collaborative mission studies have been progressing well to date. These studies will be completed in FY'84 as will the definition studies for the NASA mission. Industry will support JPL with multiple NASA-funded satellite definition studies during FY'84. TOPEX is currently a candidate for a new start in FY'86, with a planned launch in early 1989.

Data Availability: TOPEX will begin to provide geophysical data records (GDRs) using verified algorithms about six months after launch and continuously thereafter. An interim GDR will be available within five days to provide information for scheduling mission sequences and for verifying algorithms. In addition, TOPEX plans to produce quick-look data within hours after acquisition. This quick-look data will contain wind and wave data and be provided in near-real time to Fleet Numerical Oceanography Center. Other data will be available for assessing performance and for conducting flight operations.

NROSS SCATTEROMETER PROGRAM

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Program Objective/Scope

The primary goal of the NROSS Scatterometer Program is to obtain accurate measurements of global oceanic winds for a period of three years which can be useful for oceanography and meteorology. NASA/JPL will provide a Scatterometer flight instrument to be flown as part of the Navy NROSS mission. An associated NASA research data processing system will also be developed to process the scatterometer wind data and to distribute them to research users in a timely manner.

FY83 Activites Summary

In FY83 a Phase A study was performed for the NROSS Scatterometer. The general performance requirements for the NROSS Scatterometer were obtained by integrating the requirements put forth in the NASA Satellite Surface Stress Working Group Report and those put forth by the NROSS project. Baseline designs of the flight instrument and the associated NASA research processing system which would meet these requirements were generated. Implementation plans and cost estimates for the project were also obtained. These results were submitted to NASA in a proposal for a new FY85 initiative.

Scatterometer Instrument

The NROSS Scatterometer design is an improved version of the SEASAT Scatterometer. It will observe wind vectors over a swath width of $\sim$600 km on each side of the subsatellite track. This provides observations of $\sim$90% of the global ice-free ocean at least once every two days with the planned NROSS orbit. In order to improve the wind direction ambiguity removal skill, there will be three antennas observing radar backscatter (σ_0) from the ocean from three different azimuth angles. The design also includes an on-board digital processor which will improve the coregistration of the σ_0 data from the three antennas.

Research Data Processing System

The NASA research data processing system will process all usable ocean scatterometer data to wind vectors and wind field maps within two weeks of data reception from the NROSS project. The processing system will be a dedicated system that is designed to operate at a real-time rate in order to avoid any data backlog. Raw and selected volumes of the processed data will be archived and distributed to the research users through a data management system.

Present Status

The NROSS Scatterometer is currently a planned FY85 new start, in support of a planned NROSS launch in October, 1988. In FY84, a Phase B study is being conducted which will generate a detailed system implementation approach and a refined cost estimate for the project.

ERS-1/SAR

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The European Space Agency (ESA) is planning to launch an Earth Resources Satellite (ERS-1) in 1988 with a SAR as part of its payload. The SAR will operate at C-band and will have a 30m resolution, 90km swath, and 20^{o} look angle. The satellite will be in a near-polar orbit.

This study investigated the different options of receiving the SAR data acquired over Alaska and surrounding oceans. The SAR operates only when the satellite is in view of an appropriately equipped station. Two options were investigated and costed: 1) to modify one of the present NASA/NOAA receiving stations in Fairbanks, and 2) to acquire a dedicated turn key station, install it on the University of Alaska Campus in Fairbanks. In this latter case, the station will be operated by personnel for the Geophysical Institute.

The study also addressed the feasibility of processing six minutes of data within 24 hours of acquisition in order to conduct demonstration experiments. The processor will be located in Fairbanks and will be similar to the Interim Digital Processor presently in use at JPL. The remainder of the acquired data will be processed at JPL by the Advanced Digital SAR Processor (ADSP).

Data acquired over the Alaskan region will allow researchers to investigate the dynamic behavior of polar ice through at least one full year. Both local (particularly along the Alaskan coast) and global dynamics are of interest for scientific and commercial purposes. The data will also provide some insight into wave-ice interactions in the ice margin zone. In addition, these data could be used for Earth resources research in Alaska, particularly with respect to geological mapping, forest inventory, river flood monitoring, and permafrost dynamics.

In FY83, a science plan was prepared and published. A preliminary implementation plan for the two station options and the SAR processors was also prepared, including schedule and cost.

PILOT OCEAN DATA SYSTEM

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In reponse to the need for more effective access to satellite data sets, the Pilot Ocean Data System (PODS) is being developed at the Jet Propulsion Laboratory. The objective of the system is to demonstrate techniques for the management and analysis of large satellite data sets for the ocean sciences. Complete geophysical data sets from the Seasat Altimeter, Scatterometer, and Microwave Radiometer (SMMR) and Geos-3 Altimeter have been compressed and stored in an on-line data system that provides rapid, selective access to data subsets selected by sensor, time, and location. A flexible, self-guided menu interface provides access for casual users to a growing inventory of data management and analysis tools. An investigator can interactively examine a data-set catalog, search an on-line bibliography, browse through sample data sets or apply assorted analytical tools to rapidly find a candidate data set and evaluate its utility for a specific application.

A relational data base management system (DBMS) manages the indexes into the very large satellite data files. Access to any desired segment of data can be obtained in minutes. In-situ data are managed directly by the DBMS, as the volume is more modest. Seasat, Geos-3, and correlative in-situ data now available require approximately 900 megabytes of on-line disk storage and about 50 gigabytes of off-line tape storage.

Graphics workstations are connected to the PODS via a commerical communications network which transmits at 1200 bits/second. Tabular and graphic displays are available at the user's terminal while magnetic tapes, tabular listings, and hard-copy graphic products are shipped to investigators within 24 hours of generation via an express shipping service.

Future plans call for the acquisition of new data sets such as those from the Nimbus Coastal Zone Color Scanner (CZCS), Tiros Infrared Radiometer (AVHRR), and the DMSP Microwave Imager. Clorophyll measurements from the CZCS and sea surface temperature measurements from the AVHRR will be used to construct a time series data set for the West Coast of North America. This time series will have a temporal coverage of five or more years, allowing investigators to study the annual and interannual variability associated with mesoscale oceanic features. Data from the DMSP Microwave Imager will be used to construct daily, 50 KM resolution, ice extent and ice age maps for both polar regions. By the mid-1980s the Pilot Ocean Data System is expected to be supporting an on-line data base of 5 to 8 gigabytes and an off-line archive one to two orders of magnitude larger.

SECTION III - INDIVIDUAL RESEARCH SUMMARIES

Individual research activities supported in full or in part by the NASA Oceanic Processes Program in Fiscal 1983 are summarized in the following pages. Short descriptions of activities initiated in Fiscal Year 1984 are also included. The activities are listed alphabetically by senior principal investigator.

STUDIES OF OCEAN PRODUCTIVITY

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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 relate the ocean color signal received by the Coastal Zone Color Scanner (CZCS) to the vertical and horizontal distribution of phytoplankton biomass and production rates and to understand the coupling of physical and biological processes responsible for the temporal and spatial variability observed in CZCS and thermal imagery.

Approach: Satellite imagery will be compared with extensive field measurements of vertical and horizontal chlorophyll distributions and productivity with associated physical and optical data from the continental shelf off Vancouver Island, B.C. (with Dr. K. L. Denman). Also, CZCS imagery from the Coastal Ocean Dynamics Experiment (CODE) off northern California will be analyzed and compared to the detailed physical measurements. We will use statistical techniques to examine the relationship between the two types of satellite imagery and to study the effects of physical forcing. With R. W. Eppley, I will study the relationships between near-surface chlorophyll concentration and water column chlorophyll using a large data set from the Southern California Bight. Processing of satellite images will be done at the Pilot Ocean Data System using software developed at the University of Miami.

Current Status: Studies of satellite imagery and field data from Lake Tahoe, Calif.-Nev. have been nearly completed, and results will be published this year. Comparisons of productivity and surface chlorphyll are well underway, and the first results will be submitted for publication this year. Analysis of CZCS imagery from Vancouver Island has focused on the problems of atmospheric correction at high latitudes. Investigations of the time series are continuing. CODE temperature images have been analyzed by Kathryn Kelly (WHOI), and comparisons with CZCS images are underway. Analysis of the dominant modes of variability will begin shortly.

Relationship Between Phycoerythrin Fluorescence And Productivity In Marine Synechococcus

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Long Term Interests: The long term interests of the investigator are to establish reliable measures of physiological state of marine phytoplankton based on cellular photosynthetic and metabolic parameters, and to use these parameters to predict phytoplankton distribution, biomass and productivity potential in natural assemblages using laboratory studies. In addition, efforts are directed towards biological interpretations of remote sensing data for the assessment of phytoplankton biomass and physiological state.

Specific Objectives: The principal objectives of the current investigations are to describe the influences of environmental variables such as light, temperature and nutrients on photosynthetic performance and physiological state of the oceanic marine cyanobacteria in the Synechococcus spp. group. The relationships between photosynthetic and physiological state as it relates to *in vivo* fluorescence emission from the major photosynthetic pigment in these phytoplankton, phycoerythrin, are being examined in order to provide reliable assessment by remote sensing of their biomass, distribution and productivity potential in natural assemblages. It is anticipated that the studies will also provide insights into use of ocean color scanning for remote assessment of the marine cynaobacteria.

Approaches Used: Laboratory cultures of the various strains of Synechococcus spp. and diatoms are grown under controlled environment conditions (e.g. light intensity, light quality, temperature, etc.) and photosynthetic performance, pigment absorption and fluorescence, growth and cellular photosynthetic features are examined. Cultures are manipulated and mixed to simulate natural assembalges for the above analyses. Relationships beween the various cell parameters and the environmental factors are statistically analyzed to examine relatedness and to provide confidence limits on the biological interpretations.

Current Status: We have completed a series of detailed studies on the influences of a range of light environments on growth, biomass production, photosynthetic performance, light adpatation, and on the relationship between these physiological features and *in vivo* phycoerythrin fluorescence. We have found that in the marine Synechococcus 1) P_{max} is significantly and highly correlated to the relative yield of *in vivo* phycoerythrin flouresence; 2) these cells experience photoinhibition at high light but still maintain high steady state P_{max} levels under these conditions; 3) the molecular basis of the reduction in P_{max} at high light is due to losses in photosystem I activity; 4) the Synechococcus possess all the photosynthetic features essential to a successful mid-depth or low light distribution in the water column; and 5) it appears that remote fluorosening can reliably predict photosynthetic state of these phytoplankton in variable light environments. The relationships between phycoerythrin fluorescence and other environmental variables is under study.

PILOT STUDY AND EVALUATION OF A SMMR-DERIVED SEA ICE DATA BASE

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The long-term interests of the P.I. concern large-scale climate-cryosphere interactions and their significance for climate variability. Remote sensing data form a key tool for these analyses. The WDC-A for Glaciology/National Snow and Ice Data Center is developing archives of snow and ice data for the user community.

Objective: To provide an assessment of the Nimbus 7 SMMR-derived sea ice information by developing test products useful to the snow and ice community from the PARM-SS and MAP-SS data for 1979. User difficulties experienced in working with these data products and their development will be documented.

Approach: SMMR sea ice test products will be prepared, based on a survey of potential needs of the snow and ice community. This information, together with computer software developed to manage the data, will be used to generate graphical and tabular sea-ice data products. These products will then be made available to the snow and ice community. To check the SMMR data, independent sea ice information from charts in the WDC-A will be compared with the SMMR data.

Current Status: A questionnaire for potential SMMR data users was developed and distributed to survey the type of media and data products desired by the sea ice community. These results have aided in the direction of our development of SMMR products. These products, graphical and digital, are obtained from software designed to read selected (spatial and temporal) portions of the orbital (PARM-SS) and gridded (MAP-SS) SMMR data sets.

SHORT TERM CRYOSPHERE-CLOUD INTERACTIONS NEAR THE SNOW/ICE LIMIT

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The long term interests of the principal investigator concern large scale climate-cryosphere interactions and their significance for climate variability. Remote sensing data form a key tool for these analyses.

Objective: The objective of this activity was to develop a matrix of cryosphere and cloud data that will provide a basis for 1) analysis of their synoptic-scale interactions, and 2) sensitivity testing of planetary albedo parameterizations in climate models (the latter was performed under support from the National Science Foundation).

Approach: The approach utilized the US Air Force's DMSP (Defense Meteorological Satellite Program) 4 km resolution visible and IR imagery satellite data, supplemented as necessary by ground based observations and other data to determine cloud conditions in relation to snow cover and sea ice boundaries.

Current Status: Several related studies were carried out, utilizing both surface and/or satellite derived data. These vary from case studies of individual cloud/cryospheric events to large scale hemispheric/seasonal analyses of cloud vortex distributions. Synoptic models of cyclonic storms in middle and high latitudes have been developed using DMSP satellite imagery to classify the stage of development, and US Navy 'spot' data to calculate composite surface and upper air characteristics for each type of system. All of the analyses originally proposed have been completed and the results indicate strong relationships between the location of cryospheric boundaries, the cloud distribution, and the location and development of cyclonic activity. Modeling studies performed in collaboration with K. Shine (University of Oxford) indicate that numerical models of sea ice thickness and extent require careful consideration of the specified cloud cover, and that the seasonal variation of the cloud cover is important. A final report on the project is currently being prepared.

THE INFORMATION CONTENT OF SPACEBORNE SYNTHETIC APERTURE RADAR OCEAN WAVENUMBER SPECTRA

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Long Term Interests: Application of spaceborne microwave sensing to understanding the air-sea boundary, including the development of the directional wind-wave spectrum and its influence on the remote measurement of wind by scatterometry.

Specific Task Objective: 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 scatterometer and altimeter data.

Approach: Using digitally processed Seasat SAR data from passes 1339 (western North Atlantic) and 674 (Pacific Hurricane Iva), and relevant coincident data from the Seasat scatterometer and altimeter, develop a time-space history of both the driving winds and the resultant waves, and interpret in the context of established or improved wind-wave generation models.

Status: In the past year, using a comprehensive set of digitally processed data, we have been able to precisely track the spatial evolution of two separate wave systems as they evolve over a 900 km segment of pass 1339. Both dominant wave number and direction can be tracked (to a few percent and a few degrees, respectively). Furthermore, the SAR spectrum, through its radial asymmetry at very low wavenumbers, appears to reveal the local wind direction. The environmental bounds over which these results will endure, however, are presently unclear.

This work will continue in FY84, expanding to examine Pacific Hurricane Iva in the same way. Preparation will begin for a Rogue Waves experiment using Shuttle Imaging Radar (SIR-B) data in the Agulhas Current region off South Africa. Related work is sponsored by ONR, and by internal R&D funds.

NASA HIGH SPEED COMPUTING FACILITY (NHSCF)

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Long Term Interests: The long term goals of the NHSCF are to provide a first rate computing facility to support a subset of the NASA scientific research programs requiring high speed computing; to establish networking links with other NASA and NASA-funded computing resources to provide complementary support to the scientific community; to work toward simplifying the complexities of supercomputer use while maximizing scientific productivity; and to maintain the facility as a leading edge high speed computational resource by upgrading its functionality and capacity as requirements dictate.

Objectives: The objective of this activity is to provide support for the operations, system programming, and user support activities for the NHSCF. The NHSCF provides a very high speed computational resource and related services to support mathematical modeling and other research activities in the applications and space sciences disciplines, including global weather, severe storms, climate, upper atmosphere, oceans, and geodynamics.

Current Status: During 1982-83, the High Speed Vector Processing System was installed and integrated and passed acceptance testing. Delivery of major system components occurred in June/July 1982. Integration and unit testing was conducted at Building 22 from July through September. Acceptance testing of the integrated system began October 12, and ended December 20, 1982.

Productive use of the CYBER 205 by GSFC investigators began during acceptance testing. The facility currently operates 4 shifts per week. There are approximately 300 GSFC and outside users now using the facility.

Beginning in June 1983, block time assignments were allocated to each of the six major discipline areas using the NHSCF to ensure that each group would get its proper share of the 205 and so that job priorities within each discipline area could be managed by a designated discipline representative if desired.

Current NHSCF efforts are focused on solving technical problems, enhancing the accounting system, improving user support, developing documentation, and on increasing the staff to provide the computing support and services required by a growing user community. The facility publishes a monthly NHSCF Newsletter and is currently preparing a Users Guide.

GEOSAT ALTIMETRIC DATA--ACQUISITION AND APPLICATIONS

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Long-Term Interests of the Investigators: Long-term objectives of the investigators are to use altimetric data such as that from the GEOSAT Mission for oceanographic and orbit determination related research.

Objectives of this Task: The objectives of this task are: 1) to develop the interface between the Navy and NASA to ensure that GEOSAT altimetric data is made available to U. S. civilian scientists and 2) given the data form which security restrictions dictate, to perform error analysis and simulation studies aimed at assessing the quality and potential applications of GEOSAT altimetric data to oceanographic research problems.

Approach: The principal investigators are working closely with the appropriate elements of the GEOSAT Project Office, the Naval Ocean Research and Development Activity, the Defense Mapping Agency, the Naval Surface Weapons Center, NASA Headquarters, the Pilot Ocean Data System at the Jet Propulsion Laboratory and interested members of the scientific community to ensure that GEOSAT data is made available in as useful a form as possible, consistent with security restrictions. Furthermore, through simulation and other methods of error analysis, we will attempt to ensure that the computational procedure used to prepare the data for release compromises the integrity of the data as little as possible.

Current Status: We are working with the Navy, NASA Headquarters and the Pilot Ocean Data System to formulate plans for obtaining, processing and archiving select GEOSAT data sets. These include global winds, waves, altimeter crossing arcs and altimeter height residuals from a classified geoid in the North Atlantic. We also are examining ways in which high-precision altimeter crossing arc data from TOPEX can be used to increase the accuracy of sea and ice topography derived from such missions as N-ROSS and ERS-1.

AIR-SEA INTERACTION STUDIES FOR SATELLITE MEASUREMENTS

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Long Term Interests: We are investigating the relationship between marine winds, surface stress, and sea state in order to evaluate satellite microwave wind and stress measurement capabilities. Our long term interests include integrating this satellite microwave data into weather, pack ice, and ocean modeling.

Objectives: The objective of our current research is to study the relation between the scatterometer (SCATT) backscatter coefficient and the wind and sea state. We are using data taken from the NASA CV 990 airborne laboratory by L. Jones during the Storms Transfer Response Experiment (STREX) in conjunction with geophysical data taken from the NOAA P-3 and the NCAR Electra. We are also intercomparing Seasat SASS, JASIN, and MARSEN data sets. Our goal is to better understand the effects and responses of the SCATT to the disturbed sea state, particularly in the vicinity of mid-latitude cyclones, fronts, and small storm systems.

Approach: We are working in three related areas: the evaluation of simultaneous SCATT, wind, stress, heat flux, and visual data taken from the three aircraft during STREX; detailed theoretical and empirical studies of our air-sea boundary layer model near surface winds, aimed at improving the relation between wind and short wave sea state description; and collection and analysis of Seasat microwave data taken in mid-latitude cyclone regions to compare with STREX data.

Current Status: The previous work on STREX data revealed an unusual pattern in the low-level stress measurements in the post-frontal region. We have been examining SEASAT data for corresponding SASS signatures. In the process, we are attempting to refine the objective analysis in the vicinity of a front and develop compositing techniques for typical frontal regimes. The frontal passage provides a good example of sea state generation under a relatively quickly changed windfield. We have also participated in the Arctic Cyclone Study, where the NOAA P-3 and the NASA P-3 collected data through a front and in the post-frontal region.

RAPID SAMPLING VERTICAL PROFILER

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

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

In 1983 two tests of the RSVP were run, one as part of a short cruise on Puget Sound in June and one as part of a major expedition ("MILDEX") off Southern California in October and November. The instrument, winch, and data acquisition system behaved well, but problems developed with the data-link. Prototypes of four newly-designed data links are being tested in April 1984 thereby finalizing the design. A report with instructions covering the construction and deployment of this system, as well as the treatment of the data obtained, will be published by June 1984. A data report for the "MILDEX" cruise will also be issued at that time.

APPLICATION OF REMOTE SENSING TO STATISTICAL STUDIES OF OCEANIC PROCESSES

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Long-term interest of the investigator

Use of mathematical models and statistical techniques for studying processes that govern regional-scale distributions of phytoplankton biomass and primary productivity. Implicit is the need for a variety of sampling platforms to address processes in widely varying time and space domains.

Objective of this specific research task

To determine how mesoscale synoptic maps of phytoplankton biomass and surface temperature can be analyzed along with *in situ* measurements to provide information on the coupling of biological and physical fields. Specifically, what can be learned via the application of spectral analysis techniques to study spatial patterns on these scales.

Approach utilized for this task

We have analyzed spatial patterns in 4 synoptic data sets provided by aircraft remote sensors over the Nantucket Shoals area on May 7-9 1981. These data consist of simultaneous measures of phytoplankton biomass and surface temperatures over an area of approximately 5×10^3 square kilometers. Based on patterns of covariation between temperature and chlorophyll we divided the Shoals into 3 distinctly different subregions. Power and coherence spectra were computed for the 3 subregions separately and compared.

Status and progress

We found that temperature spectra for the 3 regions were essentially identical whereas chlorophyll spectra differed. In one region where chlorophyll varied linearly with temperature, their spectra were similar suggesting that chlorophyll in this region was distributed as a passive tracer. In the other 2 regions, chlorophyll patches were present and the relationship with temperature was definitely nonlinear. A manuscript describing this study has been tentatively accepted for publication in the Journal of Marine Research pending revision as prescribed by reviewers. A paper entitled "Basis for spectral curvature algorithms in remote sensing of chlorophyll" by J.W. Campbell and W.E. Esaias was published in Applied Optics, Vol. 22, April 1983, 1984-1093.

Studies of the Effects of
The Winds on the Tropical Oceans

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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 Niño-Southern Oscillation cycle, while specifying as little as possible.

Approach. We use a mix of analytic procedures and numerical models. The latter include a multimode linear adiabatic model based on Cane and Patton (1984), and the model of Schopf and Cane (1983), which includes both mixed layer physics and primitive equation dynamics.

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. Results have been obtained for the response to point sources and box sources (e.g. a 200 km box, representative of the resolution of current data sets). The next phase of the work will use fields of wind errors derived from operational products (e.g. NMC, FNOC) to estimate errors in calculated sea level. We will also consider errors due to the coarse resolution of operational products, with an eye toward the potential improvement offered by scatterometers.

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 1982/83 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 is being coupled with an improved version of the atmospheric response model of Zebiak (1982). Using a variety of initial perturbations in wind and SST, the model's analogue of El Niño events will be analysed.

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

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Long Term Interests: We are developing micro-processor-controlled *in situ* optical instrumentation and ocean constituent algorithms 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, gelbstöffe, and detritus concentrations from these data will also be developed.

Approach: We are developing a laboratory breadboard development model, with an *in situ* prototype to follow. A field-portable, 256 channel spectral radiometer is being used aboard ships and low-flying helicopters to gather data to develop a remote-sensing reflectance model for deriving the concentrations of ocean color constituents.

Current Status: We have assembled and tested the optical components for the laboratory breadboard model and have built and tested most of the signal processing circuits. Electronics integration is continuing at present. We have developed and successfully tested a remote-sensing reflectance model for dinoflagellate plankton populations and are implementing changes appropriate to measuring blue-green alga and other color groups. These models will be further tested on a cruise in May, 1984, in the Gulf of Mexico. Fluorescence quantum efficiencies have been calculated from field reflectance data which appear to detect populations stressed due to nutrient limitation/photo-inhibition.

Active-Passive Microwave Analysis of the Season Cycle of the Polar Oceans

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Long-Term Interests: Benjamin Holt and I are interested in developing applications of remote sensing to research on science and operational problems of the polar oceans. Remote sensing methods are effective for observing many characteristics of sea ice; thus, these methods are powerful research tools in these regions. A most interesting and important observational problem is to monitor the significant elements of the seasonal cycle of the sea ice and underlying water.

Objectives of this Task: The objective of this task is to improve the interpretation of active and passive microwave remote sensing data for sea ice. The two methods have individual strengths and limitations. This research is designed to reduce overall interpretation limitations by applying collective measurement strengths. The focus is to improve the observational quality of aspects of the seasonal cycle of sea ice, including albedo, snow cover, velocity, and perhaps later, type and concentration.

Approach: The approach is to examine the Seasat data set and data from SIR-B, Nimbus, Landsat, other satellites, and other platforms, notably buoys. Initially, the types of analysis to be used are:

1) Overlay of different data types for visual correlation.
2) Tracking of ice floe features on sequential images to determine fine-scale ice motion.
3) Seasonal changes, especially spring to summer to fall, in the emission and backscatter coefficients with concomittant changes in the ice cover and the energy, momentum, and mass fluxes.
4) Brightness and backscatter distribution analysis.
5) Comparison with surface data and aircraft data sets as available, principally from field work.

Current Status: This task began in FY 1982 with the establishment of software to utilize polar data from Seasat SASS and SMMR, with the development of techniques for overlaying SASS and SMMR data onto SAR images, and with the examination of altimeter pulse forms over sea ice. In the summer of 1982, a field study at Mould Bay NWT involving NORDA, U. of Washington, U. of Kansas, and AES of Canada was undertaken to improve satellite observations of sea ice. More such work may be done in the future. Work was also done on the efficient tracking of ice floes in sequential SAR images and on scene classification methods for SAR ice images. Papers are in preparation on SAR ice feature tracking, altimeter studies of sea ice, and results of the Mould Bay experiment. A comprehensive paper on the Seasat ice record is planned for later this year.

BERING SEA MARGINAL ICE ZONE PROCESSES AND REMOTELY-SENSED OBSERVATIONS

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Long-Term Interest: The long range goal is to improve the capability for making large-scale sea ice measurements from passive microwave space observations. Of particular interest is the extent to which high-frequency data can be used to remove ambiguities in distinguishing between various ice types, thereby overcoming current limitations in ice concentration retrievals. These limitations are most acute in marginal ice zones which are characterized by rapid spatial and temporal ice cover variations.

Objective: The primary objective is to assess the potential of using a more extended frequency range of passive microwave observations than is currently available from space for studying the definition of the ice edge and ice compaction in marginal ice zones. Other objectives are to assess the limitations imposed by poor weather conditions on the high frequency data and to provide an overview of the Bering Sea ice cover for studying large-scale ice processes.

Approach: The approach includes the acquisition and analysis of surface, aircraft and satellite observations made during the Bering Sea Marginal Ice Zone Experiment (MIZEX-WEST) in February 1983. The principal aircraft sensors on the NASA CV-990 are the passive microwave radiometers which span a frequency range of 10.7 to 183 GHz. Visible, photographic, and thermal infrared surface observations will be used in support of the microwave measurements. Satellite observations by both the Nimbus-7 SMMR and the NOAA-7 AVHRR will be compared with the surface and aircraft observations for the purpose of providing information on the spatial and temporal variability of the entire Bering Sea marginal ice zone.

Status: The field-operations portion of this study has been successfully completed. Seven aircraft flights were made over the Bering marginal ice zone with the NASA CV-990 as part of the MIZEX-WEST experiment. A flight report has been published (NASA TM 85020, April 1983) and the archival of the aircraft data is on schedule. Preliminary results of the experiment were reported in EOS (Oct. 4, 1983) by the MIZEX-West Study Group.

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. My long term interests include developing a tripartite 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 a tripartite 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 will be created for specific oceanographic experiments in which these facilities will be used for analysis of both in situ and remote sensing data.

This project was initiated in September 1982. At this writing we have installed the hardware/software system (the ESL, Inc. VAX/IDIMS) and have converted much of the Oceanographic specific software from Scripps Institution of Oceanography. We are actively working on communications links with URI, NMFS, and NEARSS. We anticipate installing software from the University of Miami and a digital APT system from NUSC during the coming year. An initial set of six field experiments were selected to test the system beginning in 1983; these tests are now underway.

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

A SATELLITE-LINKED OCEAN OBSERVING SYSTEM

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Scientifically, 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 (see R. Chase/Facilities for Oceanographic Remote Sensing Applications).

The objectives of this task 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 is a generalization of satellite-linked drifting systems used in the last decade; it permits data acquisition over a much broader depth range, with more and diversified sensors, and with a nominal one-year lifetime. Major innovations include providing measurements from two underwater observational systems, implementation of on-board current meters, extending a total systems communicator protocol, and transmission of all underwater systems data via satellite. Initially we plan to acquire 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. On-board current sensors supply relative current velocities, providing a means for field calibrating the Lagrangian response of the drifter.

Presently we have completed engineering designs; construction of two systems consisting of decoupled surface float (with controller, DCLS transmitter, and power supply), subsurface electromechanical cable, pressure/temperature module and acoustic receiver has been completed. These systems have successfully undergone initial field trials in January 1984 to test both the electronic and mechanical components.

LARGE SCALE WIND-DRIVEN OCEAN CIRCULATION

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

Specific Objectives: There are two primary objectives of the present work. The first is to evaluate the scientific usefulness of the satellite wind and sea surface elevation estimates from the Seasat instruments. The second objective is to statistically examine upper ocean response to wind forcing from the Seasat data and existing historical data.

Approach: The approach for determining the usefulness of satellite wind estimates consists of carrying out a statistical intercomparison of the three satellite wind speed measurements with each other and with available *in situ* measurements. The approach of the second objective is to form linear statistical predictors of the ALT-measured sea surface dynamic topography using wind stress and wind stress curl as forcing functions. This part of the study is focusing on the variability in the Antarctic Circumpolar Current region.

Current Status: Analysis of ALT and SMMR wind speed data from Seasat revealed a number of causes for the errors in both algorithms discovered in FY82. Efforts to produce corrected algorithms were initiated in FY83. The new, improved ALT algorithm will be completed by mid-FY84 and made available for application to Geosat and TOPEX data.

An analysis of Seasat ALT sea surface elevation measurements of the Antarctic Circumpolar Current (ACC) was begun in FY83. The results are very encouraging. Large-scale, coherent changes in the flow can be detected from the data. The dominant signal appears to be a general increase in the flow of the ACC over most of the Southern Ocean. This signal agrees remarkably well with flow changes measured by *in situ* bottom pressure gauges in Drake Passage. An attempt will be made in FY84 to relate these changes in the flow to wind forcing using SASS wind estimates.

LIDAR AND ACOUSTIC APPLICATIONS TO OCEAN PRODUCTIVITY

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Long-Term Interests: The long-term goal of this program is to understand the relationships between the physics and the biology of the upper mixed layer. To achieve this goal, it is important to understand the relationships between phytoplankton productivity and the vertical and horizontal variability of the ocean on spatial and temporal scales which are large compared to the scales of the biology. Included in the study are the relationship between chlorophyll abundances and phytoplankton productivity, the productivity of zooplankton in the upper mixed layer and the dynamic interactions between phytoplankton and zooplankton.

Objectives: The objective of this research is to develop in situ instrumentation capable of examing the three-dimensional structure of the ecological systems involved in ocean productivity, and to apply that instrumentation to the study of selected ecological systems. The emphasis is on optical and acoustical techniques that will permit the remote observation of the plankton population in the ocean from in situ platforms.

Approach: The approach is to develop an in situ LIDAR instrument capable of the range-gated measurement of the vertical distribution of fluorescence and spectral reflectance from chlorophyll and other pigments. This instrument will also provide a measure of the optical properties of the water column and a remote measurement of temperature and salinity. In addition, the development of a linearly frequency modulated sonar will permit the range-gated measurement of the vertical distribution of zooplankton species in the euphotic zone.

Status: A collaborative effort with Drs. D. Kiefer and J. SooHoo to examine spectral signatures from phytoplankton and certain aspects of phytoplankton physiology is in progress. These measurements have led to the development of a model for the spectral distribution of the quantum yield for phytoplankton fluorescence, and an understanding of some of the nonlinear processes involved in the generation of fluorescence signatures. A chirp sonar instrument has been constructed which operates at multiple frequencies in the range between 0.25 and 5.0 MHz, and is capable of range-gated measurement over a range of 40 M. This instrument has been used to study the small scale temporal and spatial variability of zooplankton size class distributions in Saanich Inlet in collaboration with Drs. R. Pieper, D. Macka, and K. Denman. These studies have yielded data for an intercomparison of the chirp sonar with classical techniques for the estimation of zooplankton size class distributions, and for the study of the vertical distribution of size classes and of the small scale spatial and temporal scales of those distributions.

ADVANCED LOCATION AND DATA COLLECTION SYSTEM

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Objective: The objective is to define requirements and performance of a system offering low cost platforms and having sufficient capacity to meet ocean requirements of the next decade. At the same time, develop techniques for simplifying and reducing the cost of buoy data collection platforms (DCPs) used with the Argos system.

Approach: Through design studies and system simulations advanced concepts were evaluated and a recommended system was defined and specified. Existing capabilities (e.g., Argos and GOES) are constantly being evaluated and tested for improvements leading to lower cost electronics while also maintaining reasonable accuracy and overall performance.

Current Status/Progress: A system concept study based on combining interferometry with doppler measurements was completed. The concept improves location accuracy and capacity while permitting use of inexpensive transmitters. During the reporting period, analysis of multipath effects on phase angle accuracy was underway and is nearing completion A brief look at phased array antennas with beam forming was also considered, but appears to offer no obvious advantages over interferometry. Further study is not planned for this activity, however future flight opportunities are being evaluated.

Laboratory and field tests were conducted with Argos equipment to measure performance with non-compensated (low cost) oscillators. Results were as predicted in that stable ocean temperature environments appear more than sufficient to hold drift within acceptable limits for 1-2 km location accuracy during 15 minute satellite passes. An algorithm was also developed which estimates and compensates for frequency drift of sources exhibiting linear drift characteristics. In cooperation with the SARSAT Project, a procurement action was initiated for a 1000 unit purchase of packages specified for Emergency Location Transmitters (ELTs) and Argos compatible buoy transmitters. The intent is to exploit the similarities in system specifications while maximizing the quantity for lowest per unit cost. The procurement cycle is underway and will hopefully develop a commercial source for low-cost units; 300 buoy units are called for; following delivery laboratory and field evaluations are planned.

DEVELOPMENT OF A SELF-CONTAINED ACOUSTIC CURRENT PROFILER

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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 forcing, upwelling, and upper ocean fronts.

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 currents at many depths.

System development is subcontained to RD Instruments which has experience in bottom-mounted and shipboard acoustic profilers. Primary emphasis is development of highly directional acoustic transducers. Techniques being investigated are (1) polyvinylidene fluoride (PVFD) piezoelectric films, (2) amplitude shaded solid ceramic cylindrical piston transducers, (3) shaded phased arrays to generate several narrow beams without mechanical steering, and (4) acoustic lenses. Selection and development of a data recording method is subcontracted to Woods Hole Oceanographic Institution. Their initial task is to select a recording media to meet the data volume, size, and power consumption requirements of a self-contained profiler.

Various transducers have been tested but a choice has not been made. PVFD presents performance and manufacture advantages but, to date, transducer efficiency is inadequate. Shaded and phased arrays are better understood but implementation presents manufacturing difficulties. System configurations and processing techniques under investigation include efficient motion compensation, pulse-to-pulse coherent processing, first and second spectral moment methods of estimating Doppler shift, and pulse shaping techniques. Data recording will be on 1/4" magnetic tape using streamer cartridge drives which have advantages of economy, physical size, and total data capacity. The power up/down sequence required to conserve energy will require an intelligent controller. A commercially available drive will be evaluated and used for controller design with overall goals of 30 Mbyte storage, self-contained battery, and physical size to fit a 6" diameter pressure case.

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 productionality between the two. Different ocean regions are being examined and empirical limits determined. 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. Collaborators are Dr. Mark Abbott (JPL and SIO) and Dr. U. Heyman (visiting from the University of Uppsala). The historical data sets were collected under DOE and NSF support to the University of California, San Diego.

A FEASIBILITY STUDY OF THE DEVELOPMENT OF A MOORED FLUOROMETER TO SIMULTANEOUSLY ESTIMATE PRIMARY PRODUCTIVITY AND CHLOROPHYLL IN AQUATIC SYSTEMS

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The long term objectives of the oceanographic research effort at BNL are (1) to quantify the exchange of materials and energy across the edge of the continental shelf and (2) to develop a quantitative understanding of the role of oceanic biota in biogeochemical cycling of energy related elements such as carbon and nitrogen. To resolve these issues it is necessary to understand the factors governing the distribution and production of marine phytoplankton. To help achieve this understanding, we developed moored fluorometers with xenon flash tubes and low power consumption which will be placed across the continental shelf in 1984, 1986 and 1988 as part of a DOE funded Shelf Edge Exchange Program (SEEP). These fluorometers are designed to measure the *in vivo* fluorescence of chlorophyll *a* in phytoplankton, thereby providing a basis for estimating biomass.

The objective of this research project is to explore the potential of using xenon-flash fluorescence yields to simultaneously estimate ongoing photosynthesis as well as phytoplankton biomass. The project is designed to test general principles of the relationship between photosynthesis and fluorescence.

The project is based upon a "delayed double flash" approach, where the change in fluorescence yield of a weak flash, following a saturating exciting flash, is an index of the electron flow around Photosystem II. This approach is adaptable to moored fluorometers as well as laser induced aircraft systems.

The basic research on this project suggests that the delayed double flash system is extremely promising for nondestructive estimation of ongoing photosynthesis. The preliminary results have been published and more extensive data sets are being analyzed.

OCEAN CIRCULATION FROM SATELLITE ALTIMETRY

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Long-Term Interests: My long-term interests in satellite altimetry are its applications to the study of the general circulation and variability of the ocean. The dense and global coverage of a multi-year altimetric mission will eventually allow one to make a description of the surface geostrophic currents of the oceans over a wide range of temporal and spatial scales. Before the advent of such a mission, I am interested in exploring the full utility of existing satellite altimeter data for studying these problems.

Specific Objectives: (1) Determination of the wavenumber spectrum of oceanic mesoscale variability using Seasat altimeter data. (2) Review of progress in the application of satellite altimetry to ocean circulation problems. (3) Examination of the utility of Seasat altimeter data for studying the large-scale temporal variability of ocean currents (collaboration with Dudley Chelton of Oregon State University).

Approach: The difference in the altimetric sea level profiles measured along repeat tracks is used to compute the wavenumber spectrum of mesoscale sea height variability. Crossover differences (the difference in altimetric measurements made at the ground track intersections) are used to construct time series of sea level variations. We then use a network of such time series to study the temporal evolution of ocean currents.

Status: (1) The results of the mesoscale sea height spectrum are described in Fu (1983a). (2) A survey of the progress in the applications of satellite altimetry to ocean circulation problems is presented in a review paper (Fu, 1983b). (3) The crossover-difference technique has been applied to the Seasat data in the Antarctic Circumpolar Current area. The results have demonstrated that the quality of Seasat data is good enough to detect large-scale temporal variability of this current. A manuscript describing the results is in preparation. We plan to extend the computation to equatorial regions where extensive sea level records are available for comparison.

SAR STUDIES OF OCEAN INTERNAL WAVES

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Long-Term Interests: A spaceborne synthetic-aperture radar (SAR) has the ability to map the radar backscatter modulation produced by internal waves through their interaction with short surface waves. The long-term interest of this study is to explore the utility of SAR observations for studying ocean internal waves, especially those in shallow areas where the surface expressions of internal waves are the strongest.

Specific Objectives: The objective of the research carried out in the past year was the study of the internal waves in the Gulf of California using Seasat SAR images. We were particularly interested in exploring (1) the relationship between the internal waves and tides in the Gulf, (2) the energetics of the internal waves, and (3) the significance of internal wave generation to the tidal dissipation in the Gulf.

Approach: The temporal variability of the internal wave field revealed by nine exactly repeating images was compared with the variations of tides in the Gulf. A nonlinear internal wave model was used to estimate the wave amplitude, from which the rate of internal wave generation by tides was computed and compared with the tidal dissipation rate.

Status: The results of the study are described in Fu and Holt (1984). There are three main conclusions: (1) the wave activity is highly correlated with the tidal cycle; (2) the wave amplitude is about 50 m (peak to peak); (3) the generation of internal waves accounts for about 10% of the dissipation of the dominant M_2 tide in the Gulf.

AN INVESTIGTION 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) compare horizontal flow fields based on the observed differences in the position of identifiable features (Lagrangian tracers) in CZCS imagery obtained on succesive days with current measurements; (b) compare the CZCS thermal and color imagery; (c) study the seasonal variability of the phytoplankton pigment concentration; and (d) attempt to compute the net sources of phytoplankton pigments from observations of color and thermal imagery on sucessive days.

Approach: The test area chosen to carry out the study is the Middle Atlantic Bight, a region of intense study in 1982 by virtue of the Warm Core Rings Experiment (WCRE). WCRE 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: Software for the generation of flow fields from color and thermal imagery acquired on successive days by (1) following identifiable features (patches), and (2) using the heat equation with constant source-sink, has been developed and installed at the RSMAS Remote Sensing Center. Method 1 has been applied to two CZCS Orbits in 1979 resulting in a very reasonable flow field in the vicinity of a WCR (no surface data). Continuation of research using this method, however, has been hampered by the paucity of well defined plankton "patches" at times when significant surface truth was available. Therefore, the major effort in this area will be devoted to method 2. A preliminary analysis of Middle Atlantic Bight thermal and color imagery for Spring 1982 resulted in a temperature-pigment time series, which clearly shows the seasonal warming of the Slope and Shelf waters and the onset and decay of the "spring bloom" of phytoplankton with the onset of the vertical stratification of the water column.

MICROWAVE EMISSION FROM POLAR SURFACES

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Long Term Interests: Our interests are to determine the extent to which passive microwave remote imagery can most effectively be used to investigate large scale effects of sea ice on the interaction between the ocean and atmosphere. The regional energy balance and the dynamics of sea ice are controlled by the ice extent and thickness distribution and are especially sensitive to the fractional areas covered by thin ice types and open water, where vertical energy exchange rates are greatest. Because microwave radiometry can be used to determine ice concentration as well as ice type distribution to useful levels of accuracy, it can provide considerable data needed for sea-ice-air interaction.

Objectives: Our present objective is to see how well multifrequency radiometric data can distinguish among various sea ice types throughout the year in different parts of the Arctic Basin. Particular emphasis is placed on the period from the beginning of summer through fall freeze-up, when the state of the ice is undergoing rapid changes in response to the large input of solar radiation.

Approach: Surface based measurements are made of passive microwave signatures over sea ice in a region. They are staged from field camps or icebreakers, and the instruments are transported to the sites by sled or helicopter. Dual polarization brightness temperatures are obtained at 10, 18, 37, and 90 GHz. At each site spatial and angular variations are obtained for individual ice types. Physical properties of the ice are determined such as temperature and salinity, grain size, and estimates of free water distribution.

Current Status: During the past year we have reduced the data from experiments at Tuktoyaktuk and Mould Bay NWT and submitted the results for publication in JGR. Observational studies were carried out in the Bering Sea (MIZEX West) in Feb. 83, in the northern Greenland Sea (MIZEX East) during the summer, and at CRREL. A fourth radiometer (90 GHz) was acquired, tested, and used in both cases, which showed a much greater sensitivity to surface ice conditions and weaker response to ice versus open water. We have been serving on the NASA Science working group on the DMSP/SSMI, and are also participating on a Naval Studies Board committee for applications of remote sensing techniques to sea ice problems. Finally, we are in the process of constructing a fifth radiometer which will operate at 6 GHz. Fifty percent of our support is provided by ONR on Contract N00014-81-K-0460.

Sea Surface Temperatures

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Long-term Objective: Sea surface temperatures are basic measurements in ocean and climate observing programs, and studies involving remotely-measured SST range from experimental and numerical studies of energy exchanges at the near-surface ocean-atmosphere boundary, to regional monitoring and mapping of variations in surface currents and mesoscale eddy fields. The goals of this investigator are to apply reliable, highly precise mid-infrared observations of near-surface temperatures to problems in the meso- to large-scale thermal coupling of the ocean-atmosphere boundary regime.

Specific Objective: Initially, the focus of this project is to determine the reliability with which spaceborne surface temperatures can be derived in the 8-13 micron wave range.

Approach: Radiative transfer simulations have been performed, utilizing the JPL ATMOS system, for a wide range of water vapor and temperature conditions, and the modeled surface contributions to the outgoing radiances have been considered in terms of field observations from presently earth-orbiting IR sensors.

Current Status: A preliminary evaluation of the multiple-viewing angle method, as an alternative to the multiple-wavelength atmospheric correction approach, has been made for a wide range of oceanic and atmospheric conditions. The preliminary results suggest serious limitations in the use of this technique (as with the multi-channel correction method) that relate to the strong non-linear extinction assosciated with the water vapor absorption continuum.

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The general objective of this research program is to develop fundamental SAR system models and efficient information extraction methods for oceanographic applications. These system models require integration of basic aspects of hydrodynamics, electromagnetic scattering, SAR system theory and statistical inference.

The specific objective of this research grant was the derivation, implementation, simulation, and application to actual SAR complex imagery, of both ad hoc and optimal algorithms to estimate sea surface height information. This work is based on a fundamental SAR imaging model for a two-scale sea surface previously derived by the PI. The ad hoc model was based on the use of phase information and limited a priori knowledge of the sea surface nature: while successful in a specific use, it was limited in its applicability by the SAR bandlimiting effect. By incorporating structural knowledge of the SAR system, along with a priori statistical knowledge of the sea surface, the optimal (minimum mean-square error) algorithm overcomes this bandwidth limitation to a large degree, and provides estimates of the long wave parameters and short wave sample function. The algorithm recursively processes successive range traces, in the manner the data is generated. This work has been completed. Further examination, extension and application to actual SAR data is required to establish the algorithm.

Ocean Modeling and Data Analysis Studies

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Long term interests center around understanding the physical processes that determine 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 fields over the ocean from conventional and remotely stressed data.

Current status of work is that: (i) two papers concerning tropical surface temperature change mechanisms, their connection to wind stress changes and their application to understanding the global scale El Nino phenomenon have been accepted for publication and the research is continuing; (ii) a paper concerning the roles played by mesoscale turbulence in the dynamics of the recirculating flow in an idealized ocean has been submitted for publication and the research is continuing; (iii) several refereed publications and reports on aspects of surface winds and stress in the tropics have been accepted or prepared, and a new calculation of stress is being undertaken to correct deficiencies in the present formulations that use the drag coefficients suggested by Bunker; (iv) studies have been begun to investigate the effect of SEASAT SASS winds on the surface fluxes produced by atmospheric models, using various data assimilation procedures.

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

NUMERICAL MODELING OF SEA ICE DYNAMICS AND ICE THICKNESS CHARACTERISTICS

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This research effort is motivated by a long-term interest in air/sea interaction in the presence of an ice cover. Of particular interest is the nature of sea ice dynamics and the role it plays in air-sea interaction and, more generally, in climatic change.

The overall objective of this program is the development and utilization of numerical models for simulating the large-scale dynamics and thermodynamics of sea ice. Particular emphasis this year has been placed on examining the role that sea ice dynamics plays in climatic change.

For this purpose a series of sensitivity simulations to atmospheric warming were carried out using a modified version of a dynamic/thermodynamic model (Hibler and Ackley, 1983) of the Weddell sea ice pack. For comparison, simulations were also carried out using simpler versions of this model obtained by removing various aspects of the full physics, but employing the same atmospheric and oceanic forcings. The hiearchy of models investigated included models with only a thermodynamic ice cover, models with in-situ leads but no ice transport, and a fully coupled dynamic/thermodynamic model that includes transport, leads and ice strength-thickness coupling. All models employed a 60-m-thick oceanic mixed layer, together with a spatially and temporally varying heat flux into the mixed layer from the deep ocean. The heat flux was generated interactively by using a fixed fraction of the ice growth and cooling rates from the full dynamic/thermodynamic model. The same spatially and temporally varying heat flux fields (with an average of about 13 W m^{-2}) were used in all sensitivity simulations.

In general, models including full ice dynamics effects were found to be less sensitive to atmospheric warming than thermodynamics-only models, while models with specified lead fractions were more sensitive than thermodynamics-only models. The decreased sensitivity in a fully coupled model was found to depend on the ice velocity field also being modified by the atmospheric warming. In all cases the fully coupled model had a greater seasonal swing of ice extent than the thermodynamics only model and fixed lead fraction model. All models exhibited an enhanced sensitivity in the summer ice extent as compared to winter, with this effect being relatively less pronounced in the thermodynamics-only model.

With regard to air-sea heat exchanges, models including leads and full dynamics exhibited a reduced sea-to-air heat exchange over ice-covered regions under warming conditions, while the thermodynmaics-only model showed an increase. In the control simulations the sea-to-air exchanges through the ice cover were about five times larger in the full model than in the thermodynamics-only model.

Sensitivity of the fully coupled model to oceanic forcing and variable thickness parameterization was also investigated. In the standard control run, temporally and spatially varying heat fluxes were found to reduce the seasonal swing of ice extent as compared to constant heat flux values. Similarly, in comparison to a 30 m mixed layer, a 60 m mixed layer decreased the winter ice extent and, hence, reduced the seasonal ice extent variation. A variable thickness treatment of the ice cover increased the mean thicknesses while minimally affecting ice extent.

A paper describing these simulations has been accepted for publication in the proceedings of the Fourth Ewing Symposium on "Climate Processes: Sensitivity to Solar Irradiance and CO_2" (to be published by AGU).

APPLICATIONS OF LASER TECHNOLOGY

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Long Term Interests: To demonstrate that existing airborne laser technology and electronic systems can provide valuable, synoptic, quantitative, physical chemical, and biological oceanographic data. As such, these systems can enhance the scientific understanding of the ocean surface as well as the subsurface water column. Interests include using laser systems to improve calibration of satellite color scanners and altimeters.

Specific Objectives, Approach, and Progress: A. Biological and Chemical Oceanography. The objective in this area of research is to demonstrate an accurate method of measuring chlorophyll *a* and other phytoplanktonic photopigment concentrations by measuring integrated laser induced fluorescence (LIF) at 685 nm with a calibrated airborne laser fluorosensor. Warm Core Ring (WCR) Experiment data have been obtained during four separate overflights of WCR 82-B and additional data will be obtained in FY84 in the Shelf Edge Exchange Processes (SEEP) investigations. The latter field experiment will be conducted in cooperation with the Brookhaven National Laboratory. Analysis is aimed at the quantification of results from these missions, and the production of synoptic contour plots of fluorescence data as well as data obtained from the Passive Ocean Color Subsystem (POCS) of the AOL. Water Raman backscatter, as well as PRT-5 and AXBT temperature data recorded simultaneously with the fluorescence and ocean color data will also be utilized. Comparing airborne laser chlorophyll *a* measurements with moored fluorometer shipboard and CZCS data is considered high priority for understanding phytoplankton dynamics and ultimately primary productivity. The SEEP field mission represents the first time that satellite, aircraft, shipboard, and moored fluorometry data have been taken in the same oceanic region. The goals of this task will be achieved through corroboration with participating scientists in the WCR Experiment and the SEEP experiment to be conducted. An important additional objective is to test airborne in-water ocean color algorithms using shipboard radiances and chlorophyll extractions concurrent with moored fluorometry data. B. Physical Oceanography. The objective in this area of research is to demonstrate the remote measurement of water column optical attenuation using laser-induced water Raman and Mie backscatter decay as a function of depth. Better quality airborne depth-resolved water Raman data, complete with diffuse attenuation sea truth, as well as improved deconvoluted algorithms, are needed to remove lidar system response. A secondary objective in the physical oceanography area is to evaluate the depth and surface scattered distribution of power relative to sea surface elevation under varying wind and wave conditions. These observations are essential to develop an understanding of water surface scattering and reflectance properties due to the distribution of small scale wave structures. The observations are also important for achieving a fundamental understanding of the effects of the water surface on lidar measurements made within the water column.

MICROSCALE OCEAN SURFACE DYNAMICS

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Long Term Interests: To understand air-sea interaction processes through microscale ocean dynamic studies. Air-sea interaction processes control the flux of momentum, energy, mass, and heat from air to water and vice versa; therefore, any changes in the air or water will be reflected in corresponding changes of the surface microscale structures in the form of wind waves. Consequently, the study of microscale ocean surface dynamics will increase our understanding of air-sea interaction processes, and will also provide us with the foundation for proper interpretation of microwave remote sensing data.

Specific Objectives: (1) To study the detailed statistical characteristics of the ocean surface, (2) to study the spatial and temporal relationship of the wind waves, and (3) to study the evolution of wind waves and their relationship to the turbulence intensity of the surface layer. The approach adopted here is to conduct a selected number of carefully controlled experiments at the wind-wave-current interaction facility at Wallops Flight Facility (WFF), and to check these results in the field. Theoretical analyses will be emphasized at the same time. Our aim is to understand the basic physics of the processes. Therefore, our approach is analytical and physical rather than empirical.

Progress: All the studies are in progress. Major findings to date are summarized as follows. (1) From theoretical studies, we established a new nonlinear mapping method to produce a non-Guassian joint probability density function of slope and elevation for the ocean surface wave field. Based on his model we also computed the electromagnetic bias for the radar altimeter. The result agrees well with the empirical ones. (2) Conduct laboratory experiments to compare with the theoretical results. The agreements are very well. (3) Reanalyzed the laboratory wind wave data and published scatterometer data, we proposed an explanation for the bias in the Seasat Scatterometer wind stress result. Furthermore, improvements on the scatterometer algorithm, and hardware are also proposed.

MICROWAVE RADAR OCEANOGRAPHIC INVESTIGATIONS

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Long term interests are in the remote sensing of ocean surface waves and surface conditions, electromagnetic interactions, wave dynamics and upper ocean dynamics.

Task objectives: The prime objective of this task is the development of a spaceborne microwave observing system for wind and ocean wave spectrum measurements. In previous years we have demonstrated the feasibility and accuracy of the Radar Ocean Wave Spectrometer (ROWS) technique for remotely measuring the absolute directional wave height spectrum. The technique utilizes short pulse radars in a near-nadir conical scan mode to map the directional slope spectrum in wave number and azimuth and can be implemented at low cost by modifying existing short pulse satellite altimeters. The current specific objectives of this task include a) the definition of a Space Shuttle demonstrational instrument, b) further refining and validating the ROWS technique, principally through joint flights with E. Walsh's Surface Contour Radar (SCR), and c) utilizing the aircraft ROWS data for basic investigations of wave physical processes.

Current status: The hindcast study with V. Cardone (Oceanweather Inc.) based on Fall '78 Mission ROWS data in an intense storm in the Norwegian Sea is being concluded and a paper is being prepared for journal publication. The study has shown how the remotely sensed directional wave data can be used to pinpoint wind field specification errors and correct model physics errors; for example the study indicates that current-generation wave models have directional relaxation rates which too fast. A detailed comparison of a Fall' 78 Mission file with a pitch-roll buoy has shown overall excellent agreement between the ROWS inferred and buoy directional spectra, to within a few degrees in mean directions and directional spreads as functions of frequency. The observed spectrum is nearly identical to the classical SWOP spectrum, and shares with the SWOP spectrum a similar bimodal structure that accords with the Phillips resonance condition. The January 1983 fetch limited MASEX data in both off-nadir spectrometer and nadir altimeter ('wind-wave radar') modes have been processed. A preliminary comparison with SCR data shows good agreement, despite colocation problems. The MASEX data support the hindcast study result, showing that off-wind components are essentially decoupled from the downwind component. Total mean square slopes are found to be independent of fetch and linear on u-star. A summary of these recent results is given in the Proceedings of the URSI Commission F Meeting, Israel May 14-23, 1984.

ACOUSTIC PROFILING OF UPPER OCEAN CURRENTS

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Oceanic fronts occupy scales smaller than synoptic scale eddies, yet are often associated with these disturbances when water mass contrasts are present. Mechanisms by which these fronts are formed and are dissipated are among the long-term interests of the principle investigator. The ability to survey upper ocean currents greatly improves the chances to gain new insight into not only the dynamics of upper ocean fronts, but also other scales of variability as well; including the Gulf Stream, warm and cold core rings, and internal gravity waves.

The objective of this research task is to be able to routinely and accurately measure upper ocean currents from a ship using acoustic-Doppler techniques. During the past year most of our effort has been devoted to data collected during the Warm Core Rings experiment. Several manuscripts written, or in the process of being written, are utilizing the observed upper ocean currents to define ring location and structure and, when combined with CTD measurements, are providing (1) reference level velocities for geostrophic extrapolation of currents to the deep ocean; (2) establishment (together with satellite derived SST) of the existence of cyclonic "ringlets" on the periphery of warm core rings, (3) estimation of mass, heat, and salt transport of shelf water entrained by a ring and (4) investigation of dynamical balances of sub-ring scale phenomena.

One of the more interesting "technical" discoveries under point 4 above is that fluctuations in <u>vertical</u> velocity can be made from shipboard acoustic-Doppler measurements. Vertical current fluctuations in the seasonal thermocline of several cm s^{-1} can be linked with vertical shears to internal wave dynamics: in particular to a highly directional, high frequency, first mode internal wave. In July of 1984 a short three-day experiment in Massachusetts Bay will exploit our capability for measuring vertical and horizontal velocities of internal waves. We plan to track a non-linear packet of tidally-generated internal waves as it propagates and eventually dissipates in shallow water at the coastline. This effort will be the final NASA-funded research in our program for acoustic profiling of upper ocean currents.

SCATTEROMETER APPLICATIONS TO NUMERICAL WEATHER PREDICTION

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Long term interest: To utilize scatterometer wind data to improve global surface wind analyses and numerical weather prediction.

Objectives of this specific task: a) To assess the effect of scatterometer winds on numerical weather prediction and to develop techniques to increase their beneficial impact; b) To determine global surface fields of surface stress and heat fluxes.

Approach: a) Development of a 4-dimensional Seasat analysis/forecast system to dealias and assimilate SASS winds and generation of surface fluxes; b) Development and implementation of objective and subjective dealiasing schemes; c) Comparison of forecast skills made from analyses with and without SASS data; d) Utilization of data generated from a simulated "nature" model to assess potential impact of scatterometer data.

Current status: A version of the GLAS Analysis/Forecast System that includes an objective dealiasing scheme as an integral part of the analysis cycle has been developed. With this system, SASS data were objectively dealiased for the period 0000 GMT 7 September to 1200 GMT 13 September 1978. In addition, the first 3.5 days of objectively dealiased fields were subjectively enhanced on the McIDAS system.

Global fields of surface wind stress, wind stress curl, and surface fluxes were derived from the GLAS analysis forecast system using subjectively dealiased SASS winds. The instantaneous GLAS wind analyses were found to be in excellent agreement with subjective analyses. The 10-day averaged GLAS stress fields were found to be in good agreement with published fields.

Two SASS forecast impact studies have been performed using the GLAS and NEPRF analysis/forecast systems. With the GLAS model, five assimilation/forecast experiments were conducted which differed only with respect to the inclusion or exclusion of objectively or subjectively dealiased SASS winds or VTPR soundings (Baker et al., 1984). In general, the results of these experiments show a negligible effect of the SASS data in the Northern Hemisphere. In the Southern Hemisphere, the SASS data are found to have a positive effect on the analyses and forecasts but less than that of the VTPR data, and the impact of the SASS data is reduced when VTPR soundings are utilized, indicating some redundancy between the two datasets. Occasionally large forecast differences were noted over the Southern Hemisphere oceans.

Two analysis cycles were run with the NEPRF analysis/forecast system and 3-day forecasts were performed from the same initial conditions corresponding to the GLAS experiment (Duffy et al., 1984). Both analyses used VTPR soundings and differed only with respect to the inclusion or exclusion of objectively dealiased SASS winds. The SASS forecast impact in the NEPRF system was found to be similar to that of the GLAS experiments including VTPR: it was statistically negligible, and specific cases of positive and negative impact tended to cancel on the average.

Experiments were conducted to assess the model sensitivity to low level wind specification. GLAS model forecasts were generated from initial conditions in which the correct 1000 mb or 1000 and 850 mb wind fields were replaced by the corresponding fields from 24 h earlier. The results indicated that the model forecast was sensitive to surface wind data where large analysis errors were present and that the effect of SASS data would be enhanced if higher levels were also affected in the analysis. As an application of these results, high resolution limited area model experiments were conducted in which subjectively dealiased SASS winds were used to alter higher level wind analyses for the QEII storm initial conditions. This resulted in improvements to the prediction of the intense cyclogenesis in this case.

To make maximum use of scatterometer data in global models, a higher horizontal and vertical resolution version of the GLAS model with an improved PBL formulation is being tested. In addition, a 3-D multivariate optimal interpolation analysis with potential for time-continuous assimilation is under development.

GEOGRAPHIC VARIATION IN THE RELATIONSHIPS OF TEMPERATURE SALINITY, OR SIGMA-t *VERSUS* PLANT NUTRIENT CONCENTRATIONS IN THE WORLD OCEAN

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Long term interests include various aspects of phytoplankton behavior and physiology as they contribute to the optimization of primary production and the explanation of community development. Specifically, studies are underway concerning dinoflagellate diurnal vertical migration, the interaction of these behavorial responses with photic zone currents and the large scale variation in growth conditions for all phytoplankton groups.

The general objectives of the present research project are to investigate how reliably the concentrations of plant nutrients (nitrate, phosphate and silicate) can be predicted from temperature salinity and sigma-t determinations throughout the world ocean. These predictions of plant nutrient concentration can be used to modulate a future primary productivity algorithm based on satellite determinations of chlorophyll *a* concentration.

The approach used for this task begins with the acquisition of the appropriate subset from the NODC data base and of recent data from ongoing projects from areas of special interest. These data are divided into appropriate geographic units, displayed on x-y scatter plots for various factor combinations, gleaned of outliers far removed from the main trend, and statistically analyzed using polynomial regression techniques. In addition, a percentile analysis of the variables is performed to determine various tendencies in the data base. The final result is a series of tables including the coefficients of the regression relationships, the r^2 values for the overall relationships, the variance-covariance matrix to allow the calculation of confidence limits for specific predictions and a series of percentile estimations.

During the last year, a complete data base for the world ocean has been acquired from NODC. Ocean areas 1 and 2 have been analyzed and tables summarizing the plant nutrient relationships with temperature and sigma-t have been generated. The remaining ocean areas will be sequentially processed during the current grant period.

AIR SEA INTERACTION STUDIES

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Long term interests. Our interest is to measure, understand, explain and parameterize the physical processes occurring at the air-sea interface. We are also concerned with the interpretation of remote measurements from aircraft or satellites in terms of the relevant air-sea parameters.

Objectives of this specific research. Our goal under this grant was to understand a) the physical processes which affect sea surface temperature patterns observed from remote platforms and b) to evaluate the drag coefficient at high wind speeds and especially its dependence on sea state, water depth and currents.

Approach. Two quite separate projects were pursued during the Marine Remote Sensing Experiment, which took place in the German Bight during late summer and fall 1979. The first project was a study of the sea surface temperature patterns associated with a topographically induced oceanic front, which occurs regularly in the German Bight, and how these surface signatures depend on meteorological conditions. For this work we collaborated with German and Portugese colleagues in analyzing sea surface temperature data obtained from aircraft and from satellites, and numerous hydrographic ship surveys. Surface momentum and energy fluxes were calculated at University of Washington. The second project involved direct measurements of wind stress by us and direct measurements of wave height and mean atmospheric and oceanic parameters by the German Hydrographic Office and the Max Planck Institute for Meteorology at the PISA mast in the German Bight.

Current Status. Both of these projects are finished. The surface signature of the temperature front in the German Bight was found to be strongly dependent on the atmospheric forcing. During calm and strong insolation it was masked by a shallow thermocline, while during high windstress and surface cooling the front which remains continuously in the salinity pattern was also seen at the surface in the temperature pattern. The drag coefficient study showed the importance of water depth and sea state. At high wind speeds, when the longer waves feel the bottom in the North Sea and steepen, the drag was higher. Effects of varying swell direction ahead of and behind an atmospheric frontal system resulted in large changes in the drag coefficient across the front. The results of these studies have been published (see references).

VALIDATION AND APPLICATION OF THE SEASAT-SMMR GEOPHYSICAL ALGORITHMS

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

Objectives of this specific task. The first objective was to validate the Scanning Multichannel Microwave Radiometer (SMMR) products, and the second one was to use the data in a scientific investigation. We soon narrowed our task to include only the three highest frequencies measured by this instrument, from which one can calculate total integrated water vapor, cloud liquid water and rain rate.

Approach. The validation work was completed in the first two years of the grant. For the applications we have studied North Pacific Cyclones during September 1978. The SMMR produced patterns of integrated water vapor, integrated liquid water and rain rate were compared with surface analyses, ship reports, radiosonde information, GOES-West infrared and visible satellite imagery and coastal rainfall information. Together, these data sources form a unique view of the large mesoscale structure of a midlatitude cyclone.

Current status. The results of a study of five cyclones are the following:

The water vapor distribution was found to be related to the location of the surface fronts, as defined in the classical sense, throughout the development of a cyclone. At a cyclone's beginning stage, there is at least twice as much moisture on the warm air side of a frontal zone as on the cold air side. However, at its mature stage, maximum integrated water vapor content lies along the cold front, and on either side of the maximum there is a sharp decrease in water vapor and the air is especially dry in the cold air sector.

The distribution of integrated liquid water agrees qualitatively with corresponding cloud patterns in satellite imagery and appears to provide a means to distinguish where liquid water clouds exist under a cirrus shield. Areas of mesoscale rainfall, of the order 50 x 50 km^2 or greater, within a midlatitude cyclone can easily be detected using the SMMR information. In addition, ship reports of rainfall intensity agree qualitatively very well with SMMR derived rain rates.

This work was sponsored jointly by NASA and NOAA.

NIMBUS 7-SCANNING MULTICHANNEL MICROWAVE RADIOMETER (SMMR)
ATMOSPHERIC WATER

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Long term interests. I am interested in exploring the possibilities inherent in the totally new information of distributions of atmospheric and oceanic parameters that a Scanning Multichannel Microwave Radiometer (SMMR) can provide.

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

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

Current status. In the continued work on Nimbus 7 SMMR data under a new grant, we are looking at atmospheric water parameters as they can be obtained or calculated from the archived first year data. For integrated cloud liquid water and rain rate we use unofficial algorithms and the archived brightness temperatures, since for these two parameters no approved algorithms exist. We have compared SMMR results to weather maps, GOES-West visible and infrared satellite images, a radar on the coast and coastal raingauge data for several mid-latitude cyclones as they reach the U.S. west coast.

The fronts, analyzed with all available independent data, are consistently located at the leading edge of the strongest gradient in integrated water vapor. The cloud liquid water content, which unfortunately has received very little *in situ* verification, has patterns which are consistent with the structure seen in visible and infrared imagery. The rain distribution is also a good indicator of frontal location and rain amounts are generally within a factor of two of what is observed with rain gauges on the coast. Furthermore, the onset of rain on the coast can often be accurately forecast by simple advection of the SMMR observed rain areas.

FLUORESCENCE STUDIES OF PHYTOPLANKTON PIGMENTS: A COMPARISON OF CLASSICAL AND LASER SPECTROSCOPY

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The goal of this study is to determine whether laser-induced fluorescence of photosynthetic pigments in the sea will provide valuable information about the growth and distribution of marine phytoplankton. We wish to develop methods necessary for the measurement of small-scale distribution of phytoplankton for the characterization of pigment composition of natural populations and for the determination of primary production. This development is being carried out, in part, at J.P.L. under a study entitled "LIDAR and Acoustics Application to Ocean Productivity: Instrument and Concept Development." Dr. Donal Collins, Principal Investigator. The instrument development by that study will make use of multiple excitation bands to detect fluorescence from various phytoplankton pigments. A major objective of this work is to guide in the selection of excitation bands and to evaluate the energy requirements for an *in situ* LIDAR system.

Spectral absorption and spectral emission and excitation of chlorophyll a fluorescence were measured for several cultures of marine phytoplankton. The batch cultures consisted of photoadapted cells of representative species from the Bacillariophyta, Chlorophyta, Dinophyta, Chrysophyta, and the Cyanobacteria. All three spectra varied with species and with photoadapted state. The fluorescence excitation spectra were most variable, and the emission spectra were least variable.

The differences in spectral absorption and fluorescence excitation were caused primarily by changes in the types and concentrations of photosynthetic accessory pigments. Under low light conditions, the excitation by accessory pigments increased relative to the excitation by chlorophyll a. The fluorescence yield for the blue region of the spectrum, where chlorophyll a is the major absorber, is low relative to that in the blue-green region, where absorption by accessory pigments predominates. Changes in absorption spectra are less marked, but two features recur. First, in the blue-green region of the spectrum, absorption is enhanced in the low light cells relative to that of the high light cells. Second, the ratio of absorption at 676 nm to that at 435 nm increased in the low light cells.

Changes in the fluorescence emission spectra were relatively small, spectral shifts limited to a range of about 4 nm. In all species, the peak emission of low light adapted cells shifted to longer wavelengths than the high light adapted cells. The shift appeared to be related to the cellular concentration of chlorophyll and to be caused by the reabsorption of fluoresced light. A mathematical description of such a process was derived, and the calculated shifts in emission were then compared with the measured shifts.

APPLICATION OF SATELLITE REMOTE SENSING TO FISHERIES

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Results from research conducted at the National Marine Fisheries Service, Southwest Fisheries Center (NMFS/SWFC) in La Jolla, California, provide examples of the utility of satellite oceanic remote sensing as a tool in fisheries research. Capabilities have been developed to define the spawning habitat and to describe ocean processes in relation to spawning of the northern anchovy using ocean infrared thermal imagery and ocean color imagery observed by orbiting satellites. Infrared and visible color data from satellites and concurrent albacore catch data have clearly shown that the distribution and catchability of albacore are related to oceanic fronts. Results show that commercially fishable aggregations of albacore are found in warm, blue oceanic waters near temperature and color fronts adjacent to the seaward edge of coastal water masses. Further, studies using satellite imagery in conjunction with field experiments have yielded results suggesting that water clarity as it relates to albacore being able to see food organisms, may be an important mechanism underlying the aggregation of albacore in the warm, blue water associated with oceanic fronts, rather than thermal-physiological reasons as was hitherto believed. In studies underway dealing with the ecology of marine mammals, preliminary results indicate that the distributional patterns of selected marine mammals off the coast of southern California are related to oceanic features detectable in infrared and color imagery from satellites.

Infrared temperature and ocean color imagery from satellites have been used to monitor the effects of the 1982-1983 El Niño along the U.S. Pacific Coast. Infrared thermal imagery has shown warm sea surface temperatures with the greatest anomalies near the coast, weakened coastal upwelling and changes in circulation patterns. Phytoplankton pigment images from the Coastal Zone Color Scanner indicate reduced productivity during El Niño, apparently related to weakened coastal upwelling. The satellite images provide direct evidence of meso-scale changes associated with the ocean-wide El Niño event.

This work jointly sponsored by National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

REMOTE SENSING OF AIR-SEA EXCHANGES IN HEAT AND MOMENTUM

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Long-Term Interests: Using space-borne sensors to study the exchanges of heat and momentum between the atmosphere and the oceans.

Specific Objectives: Developing technique to estimate ocean surface latent heat flux with satellite observations and applying the technique to study upper ocean heat budget and sea surface temperature anomalies in equatorial Pacific.

Approach: (1) A simple statistical technique will be developed to determine monthly mean marine surface layer humidity from the integrated water vapor measured by space-borne sensors. (2) The surface layer humidity will be combined with wind speed and sea surface temperature measured from space-borne sensors to determine the latent heat flux with bulk parameterization method. (3) The latent heat flux will be examined in conjunction with other factors (solar insolation, 3-D advection etc.) to ascertain the role of latent heat flux in upper ocean heat budget and evolution of sea surface temperature distribution.

Current Status: In FY'83, a study which unambiguously related SAR images over the Gulf Stream to intermittent momentum transport due to thermal plumes which align themselves with secondary flow in an unstable atmospheric boundary layer was completed and the results were published. A study in the systematic error of scatterometer wind as functions of sea surface temperature and atmospheric stability was also completed and the results were published. Studies on surface layer humidity and latent heat flux are in progress.

OCEAN CIRCULATION AND TOPOGRAPHY

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Long Term Interests

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

Specific Investigation Objectives

The specific objectives of the present work are to compute global as well as detailed regional maps of mean sea surface topography from satellite altimeter data and to use these data in conjunction with independent observations and models of ocean circulation and the geoid to derive information on dynamic ocean processes. Simulation studies will be used to obtain a quantitative understanding and to separate observational and analysis errors.

Approach

The major error source in the computation of mean sea surfaces is radial orbit error. Over regions of a few thousand kilometers on a side, crossover adjustment techniques have been used to remove orbit error. On a global basis upgraded force models and data processing techniques have been used to reduce orbit error. The altimeter data referenced to the improved orbits are being gridded and contoured in the form of topography maps. Geoid and dynamic topography data are being analyzed for accuracy.

Status

The global Seasat altimeter data set has been analyzed using crossover techniques to eliminate radial orbit error. The data have been gridded on a 0.5° grid with a precision of about 10-20 cm. Analyses of the Seasat and GEOS-3 altimeter-derived mean sea surfaces and satellite-derived geoids have revealed the major gyres of the general ocean.

Development of Island Stations for Satellite Read-Out of In-Situ Sensing of Environmental Properties

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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, such as sea level and water temperature and make the systems available to other users. 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 and Progress: As of February 1984, six island stations are installed and operating routinely: Christmas Island, Tarawa, Nauru, Majuro, Ponape and Honolulu. Sea level and temperature is measured. Hardware and software was developed (in-house and in conjunction with manufacturers) to sense sea level and temperature, encode the data, up-link to the satellite, access and record the returned data and distribute it to users. Techniques, personnel and procedures were developed for installing and monitoring these stations at remote tropical island sites. An FM radio link system is now laboratory operative and is ready for testing in the field to feed measurements from sensing sub-station to a central satellite up-link. Five of Professor Wyrtki's tide gauge stations have been instrumental and are providing data routinely.

ADVANCED OCEAN SENSOR DEVELOPMENT

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Long Term Interests: To further develop satellite altimetry and related instrument techniques in order to support future missions and oceanic process program objectives. To advance the key technology required and to develop a physically unambiguous basis for interpretation and quantitative utilization of these microwave observations.

Specific Objectives: (1) Continue to develop an end-to-end altimeter simulator system with timely capabilities to support the on-going program. (2) Continue to develop and maintain current, a radar altimeter system exercise for laboratory testing. (3) Continue development of an ocean microwave facility capability for the shuttle. (4) Continue studies of new microwave techniques for application to long range program needs. (5) Maintain current, the long range plan.

Approach: Existing altimeter data and existing design information will be utilized along with error budget information as a basis for the development of new system concepts. Long range program needs will be used both for setting priorities and as guidance in choosing between competing techniques. The key elements of this comprehensive instrument development activity are:

- theoretical study,
- computer simulation,
- wavetank and tower investigations,
- laboratory breadboard systems,
- aircraft system testing and experimentation,
- shuttle experiment facility development/testing.

The approach of first establishing a sound theoretical basis, then simulating and laboratory testing prior to field or flight testing provides the most economical approach.

Current Status: A 10 year plan that became available April 1982, has now been updated. Wavetank instrumentation has been designed, installed and initially tested. Data gathering activities have begun and are expected to escalate during this FY. Studies on solid state transmitters have been conducted. A shuttle mission conceptual design has been developed and further definition is planned. Work has begun to develop concepts for the next generation aircraft instrumentation.

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

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The Microwave Remote Sensing Laboratory (MIRSL) of the Department of Electrical and Computer Engineering at the University of Massachusetts has studied the feasibility of making ocean surface current measurements using coherent radars mounted on satellites. This two-year study was sponsored by NASA under grant NAGW-276.

Preliminary results suggest that satellites in geostationary orbit may be suitable platforms for multi-frequency radars that could map ocean surface currents over areas as large as 10^7 km^2. We have studied the effects that satellite motion, background backscatter from the ocean surface and receiver noise have on the system's ability to obtain current maps. Our example system has an area resolution of 30 km x 30 km and the system signal-to-noise ratio (S/N) is 10 dB for an average transmitted power level of 400 W. Although significant progress has been made to improve the signal-to-noise ratio, it is not clear that a power ratio of 10 dB assumed in our example system can be reliably achieved. Unfortunately, there is not enough experimental data available to know the answer to this question.

Proposed work

A large scale experimental program is needed to determine the reliability of obtaining S/N ratios greater than 10 dB. Before such a program is undertaken, however, our present results need to be critically discussed with oceanographers and other scientists interested in radar measurements of ocean surface currents. This critical discussion should be aimed at:

1) Reviewing the radar system analysis conducted under grant NAGW-276:

   The goal of this discussion will be to confirm that appropriate radar technology is available for satellite current mapping applications.

2) Reviewing existing dual-frequency measurements and discussing the prognosis of obtaining adequate S/N ratios.

3) Proposing a measurement program to demonstrate that appropriate S/N ratios can be achieved:

If the prognosis for obtaining S/N values greater than 10 dB is judged to be good for a wide variety of ocean conditions, a measurement program should be proposed that verifies this prognosis.

224:64

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 year include an open meeting of DRIFTERS and the presentation of several technical papers at the NOAA Buoy Symposium in New Orleans (April 1983), completion of an arrangement with the Ocean Engineering Department of W.H.O.I. for the employment of the FLUX Drifter Project Engineer, and the development of plans for lower cost buoy transmitters, future data telemetry requirements, cheaper meteorological drifters, cycling pop-up drifters, air-deployment capabilities, and the use of buoys in WOCE and TOGA.

This work is jointly sponsored with NOAA and ONR.

EFFECTS OF ENVIRONMENTAL STRESSES ON THE PHYSIOLOGY OF MARINE PHYTOPLANKTON: IRON AND MANGANESE DEFICIENCIES

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I am interested in the influence of hydrographic boundaries on the distribution of phytoplankton species and color groups, and on identification of environmental factors (especially trace metals) that define hydrographic boundaries.

The objectives of this research are to study the effects of iron and manganese on cellular energetics of phytoplankton and identify how these influence fluorescence excitation spectra of phytoplankters from various environments of the open ocean. The long-range goals are to predict trace metal effects on natural communities, especially as these effects account for observed differences in eutrophic and oligotrophic waters, and determine the effects of these metals on spectra as perceived by remote sensing.

The approach is to evaluate the role of the trace metal nutrients, iron and manganese, on photosynthesis as evidenced by changes in fluorescence excitation spectra, pigment composition, growth rates, and trace metal quotas. Trace metal stresses can be expected to cause several types of effects on the physiological processes of marine phytoplankton which would cause changes in their fluorescence excitation characteristics: changes in photosynthetic rate, structural changes in chloroplasts, changes in chloroplast migration rates, and changes in pigment concentrations. The correlation of specific spectral changes with specific physiological changes should provide insight into factors governing distribution, biomass and spectral properties of phytoplankton.

Two years of a projected three-year study have been completed. At this point, it is clear that manganese and iron can limit phytoplankton distributions. Manganese, at least, appears to be competitively inhibited by copper; iron nutritional needs are influenced by copper, but the site of action is unknown. Cell quota studies (underway) may elucidate. The relationship between chlorophyll content and chlorophyll fluorescence is clearly a function of trace metal nutrition. Fluorescence intensity increases with increasing deficiency, most probably due to energy loss from a stressed photosynthetic system. The relationship between chlorophyll content and primary productivity, also, is influenced by the state of manganese and iron nutrition. That is, the two nutrients affect photosynthetic efficiency. Thus, chlorophyll biomass data, whether determined by fluorescence or light absorption, cannot be converted to estimates of primary production without knowledge of the composition of the assemblage and its nutritional state.

SEA SURFACE TEMPERATURE WORKSHOP

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A Sea Surface Temperature (SST) Workshop activity was initiated as a means for assessing the present state-of-the-art in measuring global SST's from space. Substantial progress has been reported on the accuracies of SST's derived from various satellite instruments. A scientific assessment of these sensor capabilities is necessary as a prelude to the planning of future marine surface observation missions with a sea surface temperature component.

The objective is to design and conduct a scientifically controlled experiment to evaluate the accuracies of four satellite SST sensors for the same time periods and areas. The sensors are the AVHRR, HIRS/MSU, SMMR, and VAS. Additional objectives are to identify the relative strengths and limitations of each method for operational and research use, and to recommend future hardware and software directions. The workshop will use the facilities of the NASA Pilot Ocean Data System.

The approach being used for the workshop is to identify a number of time periods and regions for which all sensors were operating satisfactorily. SST's are then generated from the sensor data using current algorithms, on temporal and spatial scales appropriate to each sensor. In parallel, high quality in-situ SST data are assembled, and all data sets are installed on the PODS computer system for analysis. Consistent analysis techniques are applied to each data set, and the results examined at special workshops held for this purpose.

Two workshops were held in 1983 and a final workshop will be held in 1984. Reports of the workshops have been published and a series of papers are planned for publication in the open literature.

MICROWAVE REMOTE SENSING OF OCEANOGRAPHIC PARAMETERS

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Long-Term Interests: To advance the use of passive microwave techniques, both alone and 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-atmopsphere interactions, and the cryosphere.

Specific Objectives: To analyze the measurement performance of the SMMR instruments on Seasat and Nimbus-7, to improve the measurement accuracy through refined retrieval techniques, and to demonstrate the application of the data to oceanographic problems. Optimization procedures are being investigated to determine sensor configurations (frequencies, view angles, etc.) and efficient data processing for future passive microwave sensors.

Approach: Ten-day and monthly averages of the four SMMR-derived geophysical quantities (SST, wind speed, water vapor, and cloud liquid water) are generated at various spatial scales and contoured on the JPL Pilot Ocean Data System. These data sets are then 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 used to study the development of oceanographic and atmospheric phenomena.

Current Status: Analysis of the three-month Seasat SMMR data set has been concluded. Some tuning of the SSTs and wind speeds is necessary to remove bias effects prior to their use in scientific applications. Nimbus-7 SMMR data are being similarly analyzed for longer-term studies in the Tropical Pacific and Polar Regions.

COUPLED ICE-OCEAN DYNAMICS IN THE MARGINAL ICE ZONE

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Long Term Interests: The P.I. uses analytical and numerical models to elucidate the physics of upper ocean circulation. The present NASA contract deals with the 2 - 15 day time scale of the ocean circulation near and under the Marginal Ice Zone (MIZ).

Objective: The P.I. has a long-term program to develop new models of the atmosphere-ice-ocean dynamics in the MIZ. We wish to understand the effect of ice hydrodynamics and thermodynamics on the adjacent ocean circulation.

Current Status: Our work is aimed at the modelling of mesoscale processes such as up/downwelling and ice edge eddies in the marginal ice zone (MIZ). For the ice modelling purposes the constitutive equations of ice are formulated on the basis of the Reiner-Rivlin theory.

A 2-dimensional coupled ice-ocean model is used for the study. The sea ice model is coupled to the reduced gravity ocean model (f-plane) through interfacial stresses. The model geometry is an east-west channel with cyclic boundary conditions, and open boundaries to the north and south.

The model testing has been done by studying the upwelling dynamics. Based on the fact that air-ice momentum flux is much greater than air-ocean momentum flux, the Ekman transport is bigger under the ice than in the open water. With winds parallel to the ice edge, the ice on the right, produces upwelling. This is opposite to what would happen if the ice were treated as a static rigid lid.

With the notion that the variation in the ice cover in cross-ice direction leads to up/downwelling, then the variation (in ice cover) parallel to the ice edge can also lead to enhanced up/downwelling regions, i.e. wind forced vortices. Currently this idea has been tested with different disturbances in the ice field and the results are encouraging. The upwelling enhancements are weak if the model is quasi-linear. Steepening and strengthening of vortices is provided by the nonlinear terms. In fact, upper layer thickness of 25 - 30 meters as observed does lead to nonlinear dynamics.

C-BAND MEASUREMENTS OF RADAR BACKSCATTER FROM ICE

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LONG-TERM INTEREST: To ascertain quantitatively the ability of radar systems to measure relevant properties of sea ice and to determine the optimum parameters for radar systems that can make such measurements. In general, the application of microwave remote sensing to sea ice research problems and understanding the underlying physics.

OBJECTIVES: To make fundamental radar backscatter cross-section measurements of as many types of sea ice, at as many sites, in as many regions, and under the influence of as many different seasons as possible; to establish the ability of radar to discriminate ice features; to identify optimum frequency, polarization, and incidence angles for discrimination; and to develop a better understanding--theoretical, empirical and experimental--of radar-ice interactions.

APPROACH: A series of remote sensing experiments coupled with extensive ice characterizations has been performed over the 4-8 GHz range. Newly formed and multiyear ice at the start of the growing season, second-year and first-year ice under cold conditions, first-year and multiyear ice during the summer melt season, and ice in a marginal ice zone have been investigated. These varied data sets will be used to further improve criteria for instrument system design and to aid in image interpretation once the instruments are in operation. Measurements were also made at 8-18 GHz frequencies*. These data are being analyzed and a comparison of scattering coefficients will be made. Collaboration has taken place with R. Ramseier of RadarSat and T. Grenfell of the University of Washington in the ice characterization and active/passive microwave measurements. Future investigations include the investigation of the microwave properties of the marginal ice zone at the transition to summer conditions and the controlled active/passive microwave study of an artificially grown sea ice sheet.

STATUS: Significant progress has been made in the reduction of the above data sets. We are currently occupied with data analysis, preparation for reporting the results of past and present work. An extensive work has just been completed which details the theoretical modeling of the backscatter properties of sea ice under cold conditions.

*Related work is supported by ONR.

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. The mean is related to marine geology. 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 guages, 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 available partial determination of the M2 tide from Seasat data is possible. A modified response analysis will be used and the results compared with existing models. This form of analysis should be ideal for the addition of data from future missions. (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. (4) Mean sea surface and residual variability: The mean sea surface is strongly related to the geology of the ocean floor and crust. The residual variability in constructing this surface provides a statistical view of short length scale (<500km) ocean variations during Seasat. (5) Although the Seasat mission length was small, it should be possible to map some real variations in the ocean height in the 300-2000km length scale range. Areas for investigation of these phenomena are the Somalia eddy off Somalia and the Antarctic Circumpolar current

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. 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. A model of S2 was rerun with a realistic atmospheric pressure forcing to see if this would explain the anomalously high Q found and discrepancies with satellite perturbation results. Short length scales in the mean ocean surface have been used to investigate shallow mass anomalies (dominantly sea floor topography) in the poorly mapped southern oceans. Numerous new new features were identified, including a major new seamount near the Conrad rise in the Indian Ocean. A new spreading center was discovered near Easter Island by a ship survey partly motivated by evidence found in the mean sea surface.

STUDIES IN SEA ICE MODELING AND OCEAN/ICE COUPLING

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Long-Term Interests: These include climatic change, the role of sea ice processes in climatic change, the interaction of sea ice dynamics and thermodynamics with the ocean and atmosphere, and an understanding of the utility of sea ice distributions as an indicator of the climate state.

Objectives: The objectives of this task are to examine sea ice phenomena and the nature of ice-ocean coupling through numerical modeling, and to identify and analyze the important processes affecting ice-ocean interactions.

Approach: Sea ice phenomena are examined through numerical calculations with a thermodynamic/dynamic sea ice model described in Parkinson and Washington (1979, JGR, 84, 311-337). By varying initial conditions and forcing fields and analyzing the resulting simulations, the model is used to determine the numerical cause of various simulated phenomena (such as the Weddell polynya) and to predict sea ice conditions under changed atmospheric or other boundary conditions (such as increased atmospheric temperatures). For examining ocean/ice coupling, a two-level ocean model described in Schopf and Cane (1983, JPO, 13, 917-935) is being extended to include multilevels, thermohaline physics, mixed-layer dynamics, and deep circulation. After completion of the ocean model and numerical coupling of the ocean and ice models, idealized studies are planned over a wide range of parameters, followed by more realistic studies aimed at examining the ways in which the ocean can provide heat flux at the base of the ice, the impact of the heat flux on sea ice distributions, and the sensitivity of the ocean circulation to sea ice behavior.

Current Status: Studies determining (1) the strong dependence of the modeled Weddell polynya on the specified wind fields and (2) the response of the Antarctic sea ice to atmospheric temperature changes ranging from a 1 K decrease to a 5 K increase have been completed with the sea ice model. The initial numerical coding of the revised ocean model has been accomplished and the ocean numerics are now entering a validation phase with a simple β plane box model. Subsequent to a successful validation of the numerics, the model will be adjusted to a polar grid, with realistic input data, prior to coupling with the sea ice calculations.

STUDIES OF SHELF CIRCULATION UTILIZING A BOTTOM-MOUNTED ACOUSTIC DOPPLER PROFILING CURRENT METER

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Long Term Interests: Principal research interests related to this project are the dynamical description of shelf circulation features and the development and evaluation of new ocean instrumentation.

Specific Objectives: Specific objectives of this research task are (1) the development and evaluation of a bottom-mounted doppler acoustic profiler which is capable of horizontal velocity measurements over 100+ meters of the water column with a vertical resolution of 2m and an accuracy comparable to that of mechanical current meters; and (2) Utilization of the fine vertical resolution of the acoustic doppler measurements to examine the detailed structure of coastal currents.

Approach: A self-contained bottom-mounted Doppler Acoustic Profiling Current Meter (DAPCM) was constructed and deployed for several months on the Northern California Shelf. The DAPCM was positioned adjacent to a conventional current meter mooring in order to facilitate evaluation of profiler performance through a detailed intercomparison.

Status: Comparison between the Doppler profiler and VACM and VMCM current meters has been completed. The results of this comparison show that the acoustic profiler measures currents as accurately as the mechanical meters with which it was compared. The results of these tests have been published in the proceedings of two technical conferences and a more comprehensive journal article is in preparation. The planned scientific analysis of the structure of measured shelf currents has begun.

ACOUSTIC APPLICATIONS TO OCEAN PRODUCTIVITY

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Our long-term goal is to measure the dynamics of biological productivity in the upper mixed layer of the ocean. Techniques presently exist for estimating chlorophyll (phytoplankton) biomass. These can be used to calibrate the large-scale chlorophyll maps derived from satellite sensors. The chlorophyll measurements, however, represent only that portion of the phytoplankton biomass which remains after zooplankton grazing. In order to determine the levels of oceanic productivity, we also need to estimate the levels and impact of the zooplankton.

This project is a joint USC and JPL (D. Collins, Jet Propulsion Laboratory) program to develop and test an acoustic technique (chirp sonar) to rapidly measure zooplankton distributions in the ocean. This component will be integrated with other projects which are developing laser sensors to concurrently measure chlorophyll biomass. Both the acoustic and laser systems will be able to obtain range-gated data from a finite number of bins over a distance of 20-50 m.

A chirp sonar was modified to operate at the ultra-high acoustic frequencies needed to record scattering from zooplankton. Field tests were conducted in Saanich Inlet, British Columbia, Canada in May and November, 1983, in conjunction with scientists from the Institute of Ocean Sciences (IOS), Sidney, B.C., on board the Canadian Survey Ship VECTOR. Biological samples were collected using a plankton pump and BIONESS net system (D. Mackas, IOS). Concurrent data from an electronic, zooplankton particle counter were also collected (D. Mackas, IOS), and CTD and chlorophyll fluorescence profiles were obtined (K. Denman, IOS).

Predicted scattering from the biological samples (pump) and particle counter data were calculated using scattering models. Calculated scattering generally agreed with measured chirp sonar data (.44, .88, 2.2, 5.5 MHz) from the May cruise, even though the acoustic and biological samples were slightly separated in time and space. For the November cruise, two pair of broad-band transducers were used which increased the range and number of frequencies tested. In addition to vertical profiles from this cruise, time-series comparisons at a constant depth of acoustic, biological, and particle counter data are being processed.

This project was also supported by the Institute of Ocean Sciences, Sidney, British Columbia, Canada.

OCEANOGRAPHIC AND METEOROLOGICAL RESEARCH BASED ON THE DATA PRODUCTS OF SEASAT

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Long Term Interests: To contribute toward improved numerical computer based weather, ocean circulation and ocean wave predictions and toward an improved scatterometer design for NROSS on the basis of an understanding of the data from the SASS. The approach is to utilize more accurate initial value specifications of the synoptic scale planetary boundary layer over the oceans (with mesoscale, i.e. sub-grid effects correctly filtered out). This may be derived from data from satellite sensors such as scatterometers, passive microwave radiometers, IR and visible sensors, sounders and altimeters.

Objectives of Present Research: (1) To help to understand some of the results obtained in studies by Woiceshyn, Boggs, Wurtele, et al. of the Mode 3 and Mode 4 SASS data. (2) To demonstrate the results that can be derived from the SASS winds using statistical methods. (3) To study how the water waves that are the Bragg scatterers are related to the moving air. (4) To study the asynoptic data assimilation problem. (5) To study mesoscale turbulence.

Approach: As enumerated above, (1) has just been started. (2) has been completed for portions of four REVS with a contractor's report to be submitted in photo-ready form. Realistic synoptic scale wind divergence, wind stress and wind stress curl fields were found. (3) has been partially completed in the form of a paper by Donelan and Pierson (1984). (4) has been completed as a contractor's report and (5) is not moving along fast enough.

Current Status: See Bibliography for papers published, or in press. On (1) above, the SOS wind recovery algorithm is being compared to the one developed at CUNY. (2) Further interesting synoptic patterns will be studied in a similar way. (3) Attempts to modify the power law assumption using Donelan's results will be made. Studies of mesoscale turbulence will be continued. Contractor's Reports nearly complete are Pierson, W. J., W. B. Sylvester, and R. E. Salfi, Synoptic Scale Wind Field Properties from the SEASAT-SASS and Sylvester, W. B. A Seasat-SASS Simulation Experiment to Quantify the Errors Related to a ± 3-Hour Intermittent Assimilation Technique.

REMOTE SENSING OF THE COASTAL OCEAN AND A LARGE LAKE BASIN: COMPARISON WITH THE STATISTICS OF CHLOROPHYLL AND TEMPERATURE PATTERNS DERIVED FROM FIELD DATA

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Long Term Objectives: The spatial and temporal distributions of organisms in the sea are controlled by various physical, chemical, and biological factors. We seek to identify which physical (and chemical) factors and biological processes dominate in a given region for a specified period and over what spatial and temporal scales they act.

Specific Objectives: (1) Test the utility of synoptic satellite imagery in extending or replacing field measurements of chlorophyll and surface temperature on several different spatial scales, (2) characterize and quantify chlorophyll and temperature "patch" distribution in different regions of the lake and coastal ocean, and (3) attempt to explain the forces which govern the formation and transformation of these patterns.

Approach: (1) Collection of images from the CZCS (on NIMBUS-7) and AVHRR (on NOAA-6 and TIROS-N) that contain Lake Tahoe, California-Nevada, and the west coast of British Columbia, Canada. The images coincide with previous field measurements of the three-dimensional chlorophyll and temperature fields in these water bodies. (2) Consideration of various statistics that emerge from an analysis of the spatial patterns seen in both satellite images and field measurements. Indicators include covariance and correlation statistics, spectral and coherence estimates, and empirical orthogonal functions (EOFs). (3) Comparison with field data to discern, for example, whether subsurface measurements (perhaps depth-averaged measurements) reflect the information obtained via satellite and the extent to which external factors, like wind speed and solar radiation, predict the observed patterns. (4) Analysis of two numerical models (a circulation model and a two-dimensional turbulence model) to establish if these can generate patterns observed in the satellite imagery and/or field data.

Status: We have archived over 300 images. All are registered to uniform grids for each region. The temperature data reveal coherent patterns in Lake Tahoe (as defined by EOFs) that have simple physical interpretations and can be predicted by a numerical circulation model. Application of algorithms which convert radiances from CZCS imagery to chlorophyll continues. Visual inspection of CZCS images show discontinuities that agree with those seen in field data. Patterns off British Columbia are more complex. Detailed interpretations await comparisons with maps obtained from objective analyses of field data. Application of a two-dimensional turbulence model shows patterns that are similar to those obtained from satellite imagery. Theoretical investigations with random and autocorrelated growth rates in both turbulent and deterministic flow regimes are underway.

MEASUREMENT OF CURRENT PROFILES USING A DOPPLER ACOUSTIC LOG

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We seek to describe the variability of ocean currents on vertical scales longer than a meter and horizontal scales exceeding a kilometer. We have developed an acoustic instrument which measures the relative velocity between a ship and the water. This instrument operates by measuring the Doppler shift in acoustic energy which is reflected back to the ship by drifting plankton. By time gating the echo,we can determine the relative velocity as a funciton of depth. By adding the velocity of the ship over the earth to the relative velocity,we produce a vertical profile of currents measured relative to the earth.

We are identifying those factors which limit the accuracy and spatial resolution of this system. High frequency motions of the ship caused by waves introduce noise in the current measurements; these motions are easily compensated by making inertial observations of the ship motions. At present, the horizontal resolution is limited by noise in the navigational systems used to obtain the ground speed of the ship. When GPS-NAVSTAR becomes operational, the performance will be limited by the processing of the Doppler-shifted acoustic signal and by errors in the ship's gyrocompass.

The research consists of theoretical and field studies. The system has been used under a wide range of oceanic conditions using TRANSIT,GPS, and LORAN-C to determine ship ground speed. Most observations have simultaneous inertial measurements of ship motion.

An error model has been formulated based on our experiences. A paper describing the model and the ultimate limitations of the method is in preparation. Performance and scientific analyses are continuing on data taken during the FRONTS'80, FRONTS'82, CODE I and II, and MILDEX experiments.

LOCAL DEFORMATION OF SEA ICE FROM SAR IMAGES

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Our work is directed towards improving the understanding of the mass and heat balance of sea ice and of the interaction of sea ice with the ocean and atmosphere. In this field, which has always been data limited, enormous progress will be made by learning to make good use of remotely sensed data. Our work addresses the interpretation of remotely sensed data, and its application to specific scientific questions.

The objective of the present research is to characterize the spatial structure of the ice velocity field, taking into account its discontinuous, piece-like nature. The spatial autocorrelation function is a statistical tool for this task. Another is identifying pieces of ice, observing their size and rigid body motion. The central objective is to relate the formation of open water and the ridging of thin ice to the mean deformation of areas containing many rigid pieces.

Our approach has been to measure the field of motion at high spatial resolution by identifying hundreds of ice features common to a pair of sequential SEASAT synthetic aperture radar (SAR) images. In the image field of 100 x 100 km, the motion is resolved on a 4 km square grid. From this kinematic data alone, one can identify rigid pieces tens of kilometers across. Changes of open water and thin ice areas can be estimated both from the extreme deformations of the grid cells in between the pieces, and from automated or manual measurement of these areas which appear dark in the images.

The deformation field has been measured and rigid pieces identified in two pairs of images. The distribution of piece sizes has been compared to summertime floe size distributions. The pieces are several times larger than summer floes. Piece motions and rotations are similar to the motion and rotation of the whole area. The hypothesis is being tested that these pieces behave as if responding to the wind stress and its curl. The estimation of changes in areas of open water and thin ice is next on the agenda.

CALCULATION OF OCEAN TIDES

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Long Term Objectives: To develop and test an interpolation technique to extrapolate tidal height fields (amplitudes and phases) in ocean basins from data obtained from satellite altimetry and/or conventional tide guage measurements.

Specific Objectives: To test the technique initially on a small water body such as Lake Superior in order to evaluate it's performance and then to extend the technique to ocean basins.

Approach: The method is based on computing the normal mode functions for the height and velocity fields taking into account the earth's rotation, the topography, and the shape of an ocean basin. The normal mode functions are then used to compute the forced solution for a chosen tidal constituent. An examination of the forced solution yields the most dominant noraml modes in the spectrum. These normal modes are then used to represent the available data in a spectral expansion and the expansion coefficients are determined in a least square sense.

Current Status: The technique was successfully demonstrated in Lake Superior for the M2 tidal component. A paper entitled "An objective analysis technique for extrapolating tidal fields in a closed basin "by Sanchez, Rao, and Wolfson was submitted to the Marine Geodesy journal and was accepted for publication. The computations are now extended to the Atlantic-Indian ocean basin and a report will be written up.

ANALYSIS OF A SEASAT-IMAGED EVOLVING OCEAN WAVE FIELD

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Objective: To study the spatial variation of the dominant wavelength and direction of an evolving gravity field in the offshore regions of Cape Hatteras, N.C., as imaged by the Seasat SAR, and to compare the SAR-derived spectral estimates with oceanographic wave/current and wave/topographic interaction theory.

Approach: The approach utilized in this study is to examine the spatial variation of the gravity wave spectral estimates using fast Fourier transforms of digitally processed Seasat SAR data and then identify the oceanographic cause of the variations. Included as part of this year's analysis is a determination of the precision and accuracy of the SAR-derived spectral estimates.

Status: Digitally processed Seasat SAR imagery from Revolution 974 has been obtained from the Jet Propulsion Laboratory. FFTs of 30 shallow water and 50 deep water regions have been obtained and used to measure variations of the surface gravity wave field as detected by the Seasat SAR. The variations in the wave field have been found to be due to the source of gravity waves (Hurricane Ella), a wave/current interaction with the Gulf Stream, and refraction of the gravity wave field as it entered shallow, coastal waters. The analysis of the wave/current interaction has been extended to include dynamical considerations, and the results are currently being incorporated into a doctoral dissertation at the University of Michigan.

ADVANCED SAR SYSTEMS FOR OCEANOGRAPHIC REMOTE SENSING

Co-Principal Investigators: Dr. Robert A. Shuchman
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Objective: The objective of this task is to explore the feasibility of applying advanced SAR system concepts such as angle diversity, frequency diversity, and multiple antenna systems to oceanographic remote sensing.

Approach: This study is being approached from a theoretical as well as empirical standpoint. A comprehensive theoretical understanding of the principles of operation of each proposed system is being developed and utilized to predict the performance of these systems. Whenever possible, existing data from prototype sensors or from conventional SAR systems are being processed to simulate the operation of the proposed sensors.

Status: Preliminary theoretical analyses of the effects of scatterer motions on angle diversity or spotlight SAR data have been carried out. These analyses are being used to evaluate the image degradation for ocean surfaces on the one hand, and the possibility of extracting ocean current information on the other hand. An analysis of the feasibility of applying frequency diversity processing methods to SAR data has also begun, and an experiment involving existing large-bandwidth aircraft SAR data has been performed. The results of this experiment indicate that SAR systems can be configured to operate in a Δk mode in order to produce an output which is sensitive to a selectable surface wavelength component. The range of wavelengths that can be selected is limited by the existing SAR bandwidth but could be expanded by system design modifications.

SAR OCEAN WAVE IMAGING STUDIES

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Objective: To advance our understanding of the SAR imaging mechanisms for ocean waves and to apply this understanding to the inverse problem of estimating two-dimensional wave height spectra from SAR data. Topics include: investigation of possible biases in the SAR estimates of the dominant wavelength and direction; the effects of processor focus settings on wave imagery; and exploitation of complex SAR data (amplitude and phase) for estimation of ocean wave parameters.

Approach: Experimental and theoretical studies are being carried out using ERIM's data base of SAR ocean wave data in conjunction with numerical and analytical imaging models. Measurements using this SAR data are being compared with predictions of the SAR imaging models. The understanding obtained from these experimental and theoretical results is being used to update the ERIM SAR spectral estimation algorithm.

Status: A numerical SAR image simulation model has been implemented and simulated images have been compared with actual SAR data collected during the Marineland and GOASEX experiments. Initial results of this activity were presented at the AGU Ocean Sciences meeting in January 1984. A complementary analytical modeling effort is also being carried out with Dr. C. Rufenach of NOAA/ERL, some results of which are scheduled for presentation at the URSI Meeting in Israel in May, 1984.

LARGE SCALE AIR-SEA INTERACTION

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Long Term Interest: To investigate the mechanisms of air-sea interaction, to document space and time scales of SST variability and to provide theoretical basis for accuracy and resolution requirments for space observations of SST.

Specific Task Objectives: 1) To analyse the historical data sets of SST and surface wind. 2) To determine their long term trends and interannual variability for different space and time scales. 3) To investigate the influence of SST on climate. 4) To provide quantitative specifications for accuracy and resolution requirments of SST measurements from space.

Current Status: Thirty-three tapes were received from the National Climate Center (NCC) containing surface marine data. (Atlantic Ocean, 1855-1971, 15 x 10^6 records; Pacific Ocean, 1940-1977, 10 x 10^6 records; Indian Ocean, 1854-1979, 7 x 10^6 records;). Five new data tapes were made retaining location to unit degrees, data to day, wind speed in m/sec, air temperature and SST to tenths of a degree. Incomplete NCC records were rejected, as were those records showing wind speed as variable or greater than 80 knots, SST less than -5°C or greater than 35°C, or air temperature less than -50°C or greather than 50°C. This editing procedure resulted in rejection of less than 1% of the total data. Two degree by two degree means and standard deviations for SST air temperature, u wind and v wind were calculated. The original records were then reexamined and records were discarded whose SST differed from the two degree by two degree mean by more than four standard deviations.

Tapes containing only monthly mean SST air temperature were prepared from the new tapes.

We propose to prepare a final report containing monthly and seasonal global maps of mean and standard deviation of SST, air temperature, U, V etc. at 2° x 2° resolution, time series of SST and air temperature averaged over 10° x 10° boxes, correlation coefficient between SST and air temperature, monthly and seasonal climatologies for 1° x 1° and 2° x 2° resolution and interannual variability of ocean surface properties.

We have conducted several sensitivity studies to determine the influence of SST on climate. The most remarkable result is the significant influence of tropical SST anomalies on global atmospheric circulation.

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 during this past funding period 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; the ecological and evolutionary significance of this variability; and the relationship of this variability to the distributions of organisms at higher trophic levels.

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 equipments; the development of data handling procedures for the merging of contemporaneous ship and remotely sensed data, plus other various ancilliary data sets; the development of models with which to link chlorophyll concentrations and the subsequent optical properties (Smith and Baker, 1982).

Status

For the SCB we have developed techniques for assessing regional phytoplankton biomass and primary productivity (Smith and Baker, 1982; Smith, Eppley and Baker, 1982; Smith and Baker, 1983), and are working toward the assessment of these on a seasonal basis (Smith *et al.*, 1983). A parallel effort is being made for the region of Gulf Stream WCR's, and data reports for the WCR program have been and are being prepared (Smith and Baker, 1983). Collaborative data analysis and publication of ship, aircraft and satellite data with several universities and NASA research groups is 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 scattered 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 am working with the University of California Press to complete publication of a book on the Methods of Satellite Oceanography. I am also investigating the accuracy of scatterometer observations of the sea and am helping plan future experiments for improving our understanding of errors of scatterometer measurements of wind. In particular, I wish to determine the influence of regional variations in sea surface temperature and oceanic productivity on the accuracy of the observations of wind speed. Temperature influences viscosity, productivity influences surface films, and both then influence the small waves from which radar signals are scattered.

(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, is measuring rain noise in a laboratory tank, in a lake, and in the ocean. He finds a useful correlation between noise and rain rate, and has begun to test proposed methods for separating rain noise from wind noise.

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

MICROWAVE REMOTE SENSING MEASUREMENTS OF OCEANS AND ICE

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The long term interest of this research is to develop algorithms to quantify geophysical parameters relating to oceanic and ice processes using active and passive microwave sensors. One example of specific objectives accomplished is the analysis of airborne remote sensing data collected over Greenland in 1979. In this experiment both active and passive microwave sensors were used to probe beneath the surface of glacial ice sheets. During this mission, anisotropies in the radiometric and radar signatures were observed for the first time. This effect was attributed to the preferred orientation of subsurface volume scatterers, which may relate to run-off patterns occurring during summer melt, and perhaps to glacial flow. A paper describing this research has been written and submitted to the refereed literature. The development of a SMMR two-frequency algorithm that quantifies percentages of first-year and multi-year sea ice was reported last year. The algorithm success has been strengthened by further comparisons with surface observations, and a paper is in the final stages of preparation. This work will be extended to include weather corrections to further reduce retrieval errors.

In the oceans area, we have resolved errors in the calibration of the C-Band Stepped Frequency Microwave Radiometer (SFMR) that was used to measure rain rate and ocean surface wind speed in connection with the 1980 overflights of Hurricane Allen. In collaboration with Dr. Peter Black of NOAA, a new realtionship between excess brightness temperature and wind speed was developed which may result in future measurements of wind stress.

Work has progressed for the past two years to develop new airborne sensors, indpendent of Federal funding. To this end, a modified C-Band SFMR has been developed, and was installed on the NASA P-3 aircraft to participate in the Arctic Cyclone Experiment. In March, 1984, activity will be underway to install the SFMR on a NOAA aircraft for future remote sensing of hurricanes from safe altitudes. In addition, a C-Band scatterometer is under development for future oceanic underflights of the C-Band scatterometer to be flown on the European Satellite ERS-1.

SATELLITE ALTIMETRY IN THE GULF OF MEXICO

Principal Investigator:

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(joint project with Dr. George Born, UT
Dr. George Maul, AOML)

Long-Term Interests: (1) To understand the dynamics of the Gulf Stream system. (2) To develop optimum techniques for utilizing satellite remote sensors in understanding ocean dynamics. Satellite altimetry is particularly important since it is an all-weather, synoptic instrument providing ocean information over depth.

Objectives: (1) To develop methods for using altimetric data to initialize and update numerical ocean models for studying ocean dynamics and ocean forecasting. (2) To use models of the Gulf of Mexico and the Gulf Stream as test beds for evaluating these techniques.

Approach: (1) Use actual altimeter data, ground truth information, and model-generated sea surface heights to describe the circulation in the Gulf of Mexico. (2) Use "perfect" sea height data from the dynamic ocean model to investigate the problem of using altimetric data to produce near-synoptic objectively-analyzed fields. Contaminate the perfect data with likely errors from the geoid, orbit determination, and other sources to study the problem of initializing and updating the dynamic ocean model with noisy data.

Progress: (Refer to Bibliography for complete references). Thompson, Born, and Maul have published a paper on SEASAT repeat-track altimetry in the Gulf of Mexico in JGR. Three papers have been accepted for publication in a special issue of MARINE GEODESY. Maul and Herman have calculated the mean dynamic height and its variability from historical data for the Gulf of Mexico. Born, Lame, and Mitchell have completed a detailed survey of altimetric satellites useful for oceanography. Hurlburt has examined the potential for altimetric satellites in ocean forecasting. Also, Kindle has shown that nearly circular eddies can be adequately resolved by 3-4 ascending or descending passes from a single nadir-beam altimeter and Mitchell has developed a strategy for studying the circulation in the Gulf of Mexico using GEOSAT altimetric data, in-situ observations, and inverse methods. Finally, a link to the Goddard CYBER 205 has been established at NORDA through a VAX 780.

Primary support for Hurlburt, Kindle, Mitchell and Thompson in this work at NORDA has been through the Office of Naval Research Special Focus Program "Ocean Dynamics from GEOSAT."

A RADIATIVE TRANSFER MODEL FOR REMOTE SENSING OF LASER INDUCED FLUORESCENCE IN NON-HOMOGENEOUS TURBID WATERS

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Long Term Interest: Our interests are to utilize computer simulations to characterize the validility of airborne fluorosensor systems and to determine how effectively simulations can be utilized to enhance the development of new and improved instruments. In addition, our interest are to aid experimentalists in interpreting the results of measurements made with such systems.

Objective: The specific objective of this past year's research was to expand the semianalytical radiative transfer model SALMON to include variable concentration profiles of media constituents. In addition, the model was to be expanded to investigate range and depth gating. Finally, we were to begin incorporating the effects of ocean waves on the lidar signal.

Approach: The SALMON code was implemented on the Hampton Institute VAX 11/780 computer. The code was modified to allow for stratifed media. Simulation results were obtained for both homogeneous media and linearly varying vertical distributions of the media constituents. Laser excitation wavelengths of 480 and 532 nm were considered. Results were obtained for surface concentrations of chlorophyll a ranging from 0.01 to 20 micrograms/liter and for gradients from -20% to 20% per meter in steps of 5% per meter. Geometrical constraints involved with the incorporation of waves were determined and a statistical approach was selected to handle these effects.

Current Status: The results of this years efforts indicate that statistically significant differences can be seen, under certain conditions, in the water Raman normalized fluorescence signals between nonhomogeneous and homogeneous cases. This suggests that generally, remote sensor users must exercise care when making empirical calibrations of airborne fluorosensors. The SALMON model has been used to show that fluorosensor measurements are sensitive to certain ranges of surface concentrations when the chlorophyll concentrations vary linearly with depth in the water medium. Results for range gating and depth gating have been completed and a paper on these results is being prepaired. Two reports were presented at professional meetings and one paper was accepted for publication during the year.

INTERPRETATION OF SEASAT SAR IMAGES IN TERMS OF OCEAN SURFACE PARAMETERS USING SPECIALLY PROCESSED DATA FROM THE JASIN AND GOASEX EXPERIMENTS

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Long-Term Scientific Interests: Synthetic aperture radar (SAR) images collected by aircraft or satellite contain information regarding ocean surface phenomena on spatial scales from about 10 m to 1,000's of km. SAR image brightness responds to changes in small scale (about 30 cm) surface roughness, to larger scale surface dynamics which modulate the small scale roughness and to surface motion via Doppler effects. Our objective is to interpret brightness variations in terms of ocean phenomena, such as gravity waves, winds, internal waves, current gradients, sea surface temperature gradients, surface films, ship and wakes.

Research Task Objective: Our research objectives are two-fold. First, we want to assess the ability of the SEASAT SAR to measure ocean waves using the best images and surface data available. Second, we want to take some steps in understanding the physical processes by which ocean surface phenomena, such as surface and internal waves, manifest themselves in SAR images. In particular we want to put SAR measurement of the directional waveheight spectrum on a quantitative footing. Since digitally imaged SAR data are more consistent and superior in quality relative to optically imaged data, we now use digitally imaged data.

Research Approach: Our approach to understanding how waves are imaged by SAR is to: i) obtain digitally imaged SEASAT SAR data relevant to the JASIN, GOASEX and hurricane IVA experiments, ii) calculate 2-D wavenumber (Fourier) spectra of the images correcting for instrument response, iii) compare SAR spectra with surface buoy spectra to determine experimentally the relationship between these two quantities, iv) use these comparisons to assess the ability of SAR to measure ocean waves, and v) compare experimentally determined relationships with predictions of relevant theoretical models. This research is done in collaboration with Dr. Werner Alpers, Mr. Brian Barber and Dr. Steve Peteherych.

Current Status: Analysis of the JASIN experiment images so far obtained from DFVLR and RAE have been completed. Software to read the digital image tapes, compute spectra, correct for instrument response and display spectra in both x,y and contour plot form is complete. Analysis of the JASIN experiment images so far delivered from Europe has been completed. The digital images produce a much larger signal to background ratio and thus allow one to observe a larger portion the spectrum (in terms of wavemumber). Results thus far show better agreement between SAR and surface wave measurements than do the same comparisons using using optically imaged data. We are now beginning work on the GOASEX and hurricane IVA data sets.

APPLICATION OF SURFACE CONTOUR RADAR TO OCEANGRAPHIC STUDIES

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Long Term Interests: To use perfectly registered maps of topography and radar backscatter derived from the Surface Contour Radar (SCR) to: (1) measure oceanographic parameters directly; and, (2) evaluate the ability of satellite systems to measure these parameters remotely.

Specific Objectives: (1) To acquire additional comparative data sets with the wave spectrometer during the fetch-limited wave conditions of the MASEX experiment; (2) to analyze the characteristics of the fetch-limited wave spectrum in detail; (3) to analyze the signal fluctuations statistics in detail and determine the extent to which elevation measurement noise corrupts the spectral measurements; and, (4) to analyze the backscattering characteristics as a function of angle of incidence, local slope, deviation from mean sea level, and azimuth angle relative to the local wind.

Approach: SCR data will be compared with in-situ sensors, other remote sensors, and the results of simulations and models.

Progress: A paper has been prepared for the Journal of Physical Oceanography which documents intercomparisons of the SCR with both the XERB and ENDECO pitch-and-roll buoys and establishes the noise levels in the elevation measurements and the spectrum. It demonstrates the angular resolution of the system, the number of Fourier coefficients it can produce, and its high spatial resolution for wave diffraction and refraction studies. A paper was presented at the 1983 International Geoscience and Remote Sensing Symposium (Walsh, E. J., D. W. Hancock, III, D. E. Hines, and R. N. Swift, "Contamination of the fetch-limited directional wave spectrum by waves emanating from an embayment," IGARSS '83, Vol. II, TP-3, pp. 4.1-4.6, Aug. 31-Sept. 2, 1983) demonstrating the dominance of waves from the Delaware Bay during fetch-limited conditions and indicating a faster than linear growth in the downwind wave field in the first 30 km from shore. Another paper was given at the American Meteorological Society Fifth Conference on Ocean-Atmosphere Interaction (Walsh, E. J., D. W. Hancock, III, D. E. Hines, and R. N. Swift, "The variation of the directional wave spectrum during MASEX," Jan. 10-13, 1984), which plotted the absolute growth of the directional wave spectrum off the New Jersey and New York coasts and demonstrated its severe contamination due to the irregular coastlines. SCR spectra from the MASEX data set were in good agreement with spectra from Fred Jackson's wave spectrometer. An article characterizing the fetch-limited spectra off the mid-Atlantic states is in preparation for submission to the Journal of Physical Oceanography.

INVESTIGATION: STUDIES RELATED TO THE REMOTE SENSING OF SEA ICE

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Long-Term Interest: My primary interest is in the geophysics of sea ice and in how satellite-borne remote sensing techniques can be utilized in advancing our knowledge of this subject. My particular speciality is the structure and crystal growth aspects of the ice itself. However I have, in the past, studied a wide variety of varied problems related to the formation and presence of sea ice. I am particularly interested in improving satellite-borne remote sensing of the Polar Regions in that I believe that the only hope of resolving many sea ice and ice sheet problems lies through such an approach.

Objectives: My specific objective at present is to obtain data sets that will allow improved verification of ice estimates made by satellite-borne passive microwave imagery. I am also attempting to develop an up-to-date documentation for the need for improved satellite-borne remote sensing in both Polar Regions.

Approach: Mr. Tucker and I have completed arrangements with the Naval Underwater Systems Center to allow us to analyze the results of the upward looking sonar profiles of the underside of the arctic pack ice made during two recent cruises by U.S. Navy submarines. The results of this analyses will, of course, provide useful information on the mass balance of the arctic pack. In addition we also plan (through the assistance of Dr. Comiso) to make a comparitive study of ice conditions as seen by the submarine as contrasted with ice conditions as estimated by the SSMR system on board Nimbus-7.

I have (or am currently) also involved in the preparation of planning documents that discuss (a) the usefulness of NASA establishing a SAR receiving station in Alaska (Weller et al., 1983); (b) a 10 to 15 year program for earth science from space with particular emphasis on the atmosphere and its interactions with the solid earth, oceans, and biota (Prinn et al., 1984); (c) an overall, integrated program of earth observations from space (the Earth Systems Science Committee); and (d) a general NASA approach for remote-sensing research focused on the earth (the Space Applications Advisory Committee).

Status: We have just obtained the sonar data from the first of the two submarine cruises and are in the process of initial data reduction and analysis.

MICROWAVE REMOTE SENSING OF THE OCEAN AND ATMOSPHERE USING SEASAT

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Long Term Interest: My principal interest is to assist in the design and development of satellite microwave sensors and the associated computer processing systems. Also, by studying the sensors' data, I hope to better understand the physical processes that govern microwave backscattering and emission from the ocean.

Objective: 1) To reprocess the SEASAT SASS and SMMR data sets using improved sensor and geophysical algorithms. 2) To compare the wind sensing performance of SASS versus SMMR. 3) To apply the knowledge gained from this research to future sensors such as SSM/I and NROSS.

Approach: This investigation is being accomplished in three steps. First, the three months of SASS and SMMR sensor data are compressed and merged onto 20 6250-BPI tapes (16 for SASS and 4 for SMMR). Corrections are applied to the SASS σ^0's (a more accurate volts-to-signal-power algorithm) and the SMMR T_B's (crosstrack and temporal T_B biases are added). Next, improved model functions are developed for the SASS and SMMR. No *in situ* anemometer or SST measurements are used to derived the models. Rather, the model derivations are based on the statistics of the σ^0's and T_B's in conjunction with well-accepted microwave theory. The third step is to process the three month σ^0 and T_B data sets using new retrieval algorithms to estimate geophysical parameters. The new algorithms are deterministic retrieval techniques that are applied to the model functions coming from step II.

Status: Steps I and II above have been completed, and step III will be performed in FY 84. We expect to have the new SEASAT SMMR and SASS geophysical data sets available October, 1984.

This investigation is jointly sponsored by NASA and the Atmospheric Environment Service, Toronto, Canada.

RADAR MEASUREMENTS OF OCEAN SURFACE WAVES USING THE TWO FREQUENCY SCATTEROMETER

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Long Term Interests: To advance the ability of microwave radar to measure the directional spectrum of ocean surface waves, their modulation transfer functions, and the wind vector at the air-sea interface. The modeling of the combined effects of these quantities and other environmental parameters on the remote observation of the two frequency resonance and the surface radar cross section is being developed with comprehensive data sets and empirical techniques.

Specific Objectives: To measure the modulation transfer function for a wide set of ocean wavelengths from an aircraft and to determine how these functions depend on ocean wavenumber, the incidence angle of the radar wave and environmental conditions at the interface. The application of these results to the operational problem of remote sensing of waves from aircraft and spacecraft using the two frequency scatterometer and imaging radars will be considered.

Approach: Experimental data acquired during the ARSLOE Experiment in November 1980 by the NASA Langley two frequency scatterometer, supported by the surface contour radar, a single frequency AM-FM modulation measurement and buoy measurements have been fully analyzed to yield new and significant information about the modulation function. This data was used to validate the theoretical formula relating the two frequency resonance intensity to the wave spectrum and modulation function. These complementary data sets were used in this theoretical model to alternately infer the modulation of the waves (at a variety of incidence angles, flight directions, and winds) and the directional spectrum of the surface waves. Comparisons have also been made with modulation measurements made from towers by the Naval Research Laboratory to study the similarities and differences between these two different radar platforms.

Current Status: These results demonstrate that the microwave modulation transfer function and the directional spectrum can be measured with the airborne two frequency scatterometer. These quantitative results have been assembled into a manuscript for the Proceedings of the URSI Symposium on "Frontiers of Remote Sensing of the Oceans and Troposphere from Air and Space Platforms" to be held in Isreal, May 1984. Also a Journal article is in preparation. In addition, this data set will be combined with data acquired by NRL to develop improved algorithms for inferring surface winds and wave parameters from hypothetical simultaneous radar cross section and two frequency measurements.

SMMR ALGORITHM REFINEMENT TASK

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

Specific Objective: The purpose of this task is to refine the algorithms used for retrieving the temperature and wind speed at the ocean surface, to improve their accuracy, to understand their limitations, and, where possible, to reduce those limitations. Participation in the series of SST intercomparison workshops held at JPL is explicitly contained within this specific objective.

Approach: The tuning approach to improving the SST algorithm has been continued. It has been found that the tuning must be broken into multiple time periods to compensate for the changes in the SMMR instrument and for consistency with the SST workshop ground rules. It has been found that using the time rate of change of various instrument temperatures was useful in reducing errors in SST retrievals. The primary impact of the tuning has been to reduce large-scale systematic errors with only a minor reduction of the RMS error.

Current Status: The tuned algorithm has been tested in three different workshops. The data sets compared were ships, xbt's, AVHRR, HIRS, VAS and SMMR. The net result was that all SST approaches had significant problems. The AVHRR performed best overall but had difficulties in some areas, most notably the tropics, where the SMMR performed better.

Although the tuning can probably absorb any problems with the ocean surface emissivity model, it is desirable to have a better model to explain the tuning results and to serve as a basis for planning and performance simulation of future microwave radiometers. To this end, the first year of SMMR data have been combined with observations of surface temperature and wind where radiosonde data were available to give precipitable water measurements. Preliminary analysis of this data set indicates that the increase in emissivity caused by the wind is proportional to the square of the wind speed at all SMMR frequencies and for both polarizations.

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

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Objective: 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) Determination, with the TOPEX Science Working Group, of an optimum set of scientific requirements for a future altimetric satellite mission and its relationship to international general circulation programs. (2) Construction of optimum gravimetric surfaces by use of the known components of the ocean circulation, satellite and surface gravity measurements, and of regional geophysics. (3) Estimating the global, long-wavelength components of the sea surface relative to the geoid by SEASAT altimetry. (4) Simulation of the impact of altimetry and scatterometry on knowledge of the ocean circulation through models combining these fields with existing observations.

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

Status: (1) The PI continues as Chairman of the Science Working Group for TOPEX and as U.S. Chairman for the World Ocean Circulation Experiment (WOCE). (2) Dr. Victor Zlotnicki is continuing his work on the optimum procedures for combining gravimetric, altimetric and ocean circulation observations. (3) Tai and Wunsch have produced a global chart of absolute dynamic topography at long wave-lengths from the SEASAT data, through a procedure described by Tai (1983). (4) Wunsch, Dr. H. Mercier, and Dr. J. Schröter are working with a variety of ocean circulation models and inversion methods to combine altimetry and scatterometry information into statements about the ocean circulation, and regional gravity and geophysics.*

* 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 long term interest of the investigator is to understand how physical and biochemical systems affect the distribution of light-absorbing and light-emitting microorganisms in oceanic waters.

Objectives of this Research Task: We are attempting to characterize hydrographic regions throughout a Warm Core Ring by using optical signatures. This requires the measurement of fluorescence excitation and emission spectra as well as the diffuse attenuation of spectra of visible light. Specifically, we have concentrated on the high velocity region of the eddy and the region that is warm center.

Approach: We pump water throughout the water column to a depth of 200 m. This water is passed through fluorometers which are fitted with filters for measuring specific excitation and emission fluorescence. In conjunction, we take specific water samples for measuring the spectral characteristics of fluorescence and excitation as well as the spectrophotometric measurement of diffuse attenuation spectra. In addition to the discrete samples, we extract the pigments and count the principal species.

Current Status: At the onset, we hypothesized that a pattern of phytoplankton distribution in time and space in a Warm Core Ring would be the result of variations in the bouyancy of the water masses associated with the eddy. Shipboard and satellite optical observations confirmed this and also showed that the convective overturn is an important mechanism in regulation the distribution of phytoplankton. The central core of the warm core eddy experiences two bursts of phytoplankton growth and they are out of phase with the seasonal changes observed in slope and shelf water at the same latitude.

This work has been jointly sponsored by NOAA, NASA, NSF and the State of Maine.

MESOSCALE ICE DYNAMICS AND PROCESSES/OBSERVATIONAL

Principal Investigators: H. Jay Zwally and J. C. Comiso
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Long Term Interest: (1) To investigate the general characteristics of the sea ice cover and how they relate to oceanic and atmospheric processes, (2) To investigate sea ice dynamics and processes near the marginal ice zone and short and long term variability of the sea ice extent, and (3) To investigate the seasonal variability of the multiyear ice cover in the Arctic Region.

Specific Objectives: (1) To quantify the variability of the amount of open water inside the ice pack including the opening and closing of offshore polynyas and correlate results with processes including katabatic winds and the salinity and circulation of underlying ocean, (2) To investigate the gradient of ice concentration in the marginal ice zone and the rate of advance and retreat of the ice edge and quantify the variability of the areal sea ice extent, and (3) To quantify the areal extent and fraction of multiyear ice cover.

Approach: Daily and 3-day averages of Nimbus-5 ESMR and Nimbus-7 SMMR brightness temperature data are used to investigate short term and long term openings and closings of leads and polynyas in the Antarctic Region. The amount of salt production from the freezing of leads and polynyas are calculated and compared with measured salinity profiles around Antarctica. Available data on katabatic winds are also correlated. The 3-day and monthly averages of ESMR brightness temperature data are also used to quantify the gradient of concentration at and variability of the position of the marginal ice edge, as well as the areal extent of sea ice. Using a current algorithm for classifying first year and multiyear ice, polar maps of multiyear ice cover are generated for each month during an annual cycle. Monthly distortions in size and shape of the inferred multiyear ice maps are analyzed and compared with ice velocities determined from buoy data.

Status: A paper on the "Variability of Antarctic sea ice and changes in Carbon Dioxide" has been published in the June 1983 issue of Science and a book on "Antarctic sea ice 1973-1976: Satellite passive microwave observations" has been publised as a NASA SP in 1983. A paper on "Ice concentration gradient and growth and decay characteristics of the seasonal ice cover" has been submitted to JGR for publication. A paper presenting preliminary results of the polynya and open water analysis was presented in the 1984 AGU Ocean Sciences Meeting. Multiyear ice maps for the 1978 to 1979 period have been generated for some months and are currently being analyzed.

MESOSCALE ICE DYNAMICS AND PROCESSES/REMOTE SENSING

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Long Term Interest: (1) To investigate the physics of the microwave radiative property of sea ice and understand why and how it varies with age, thickness, roughness, and surface characteristics, and (2) To develop or improve current techniques for extracting geophysical sea ice parameters from passive microwave data.

Specific Objectives: (1) To investigate the temporal and spatial variability of the microwave emissivity of sea ice at various frequencies and polarizations, (2) To study the feasibility of consistently identifying the different ice types on a year round basis, and (3) To develop numerical and statistical methods for automatically classifying the various ice types on a global basis.

Approach: Near simultaneous images of the Scanning Multichannel Microwave Radiometer (SMMR) and the Temperature Humidity Infrared Radiometer (THIR), both on board the Nimbus-7 satellite, are used to obtain large scale measurements of sea ice emissivities in the polar regions. Multispectral cluster analysis is used to study the ability to separate the various ice types and to investigate the effects of different surface or subsurface characteristics, especially the varying nature of the snow cover over the ice. Comparative analysis with surface ice observations like those from the OctoberNovember 1981 US/USSR Weddell polynya expedition (WEPOLEX) are conducted. Similar analysis with the November-December 1983 ice observations, also in the Weddell Sea, will also be made in collaboration with Dr. C. W. Sullivan of the University of Southern California. Correlation analysis of sea ice emissivities with 1979 and 1982 submarine data in the Arctic region will be conducted to understand the sensitivity of thickness, age, and other parameters to the microwave radiation emitted by the ice. The submarine correlation will be done in collaboration with Dr. W. Weeks of CRREL. To understand the effects of snow cover at various times of the year, station data of snow cover over land will be utilized. Since the emissivity of soil is approximately the same as that of first year ice, the snow over soil should have very similar radiative characteristics as snow over first year ice.

Status: Two papers, one on sea ice microwave emissivities in the Arctic and another on the correlation studies with the WEPOLEX data have been published in the September 1983 and January 1984 issues of JGR, respectively. A paper presenting preliminary results on microwave signatures of snow cover over sea ice, has been presented in the 1984 AGU Ocean Sciences Meeting. Correlation studies using submarine data and observed sea ice data in the Weddell Sea are in progress.

SECTION IV - BIBLIOGRAPHY

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15. Supplementary Notes
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16. Abstract

This, the fourth 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 1983 (October 1, 1982 to September 30, 1983), the period covered by the Introduction includes March 1984. 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.

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