NASA Technical Memorandum 87565

NASA Oceanic Processes Program

Annual Report—Fiscal Year 1984

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Edited by
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PREFACE

At the present time we are proceeding with implementation activities which were approved in NASA's FY-85 budget: the NASA Scatterometer (NSCAT) scheduled for flight aboard the Navy's NROSS satellite in September 1990, and the Alaskan Ground Facility for the direct reception of Synthetic Aperture Radar (SAR) observations of sea ice. For the latter, negotiations are underway with the European Space Agency for coverage by the SAR aboard their ERS-1 satellite.

Although not successful in the FY-86 budget, NASA's Ocean Topography Experiment (TOPEX) -- as a collaborative project with the French Space Agency (CNES) -- is currently the highest priority new start within the FY-87 budget of the Office of Space Science and Applications. Earliest launch date is April 1991.

Unfortunately, the Ocean Color Imager (OCI) has such a low priority in the FY-87 budget that its chances for approval are not favorable; this quite likely will preclude consideration of the OCI as a candidate passenger for CNES's SPOT-3 satellite. As an alternative, NOAA has a candidate FY-87 initiative for flight of an OCI aboard one of their polar-orbiting meteorological satellites. Otherwise, the next opportunity for an OCI initiative is in the FY 88 budget.

This, the fifth annual report for NASA's Oceanic Processes Program, provides an outline of our recent accomplishments, present activities, and future plans. Although the report was prepared for fiscal year 1984 (October 1, 1983 to September 30, 1984), the period covered by the introduction extends into May 1985. 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 four components; they and their respective program managers are: (1) Physical Oceanography -- Dr. William C. Patzert; (2) Ocean Productivity -- Dr. Curtiss O. Davis; (3) Polar Oceans -- Dr. Robert H. Thomas; and (4) Oceanic Flight Projects -- Mr. William F. Townsend and Mr. James R. Greaves.

Funds available to the Oceanic Processes Program in FY-84 amounted to approximately $18 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 89 specific research activities. The distribution of funding according to institutions was roughly as follows:

Jet Propulsion Laboratory	$4,800
Goddard Space Flight Center	4,700
Academic Institutions, etc.	4,800
Industry	3,400
Other Government Agencies	150
Miscellaneous	150
Total	$18,000

Funds available for Oceanic Processes in Fiscal Year 1985 will rise to the $19M level. An increase to $20M is anticipated for Fiscal Year 1986.

As approved in the FY-85 budget as submitted, the NASA Scatterometer (NSCAT) planned for flight on N-ROSS received an additional $12M 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.

Baker, D. J. (ed.) 1984. Oceanography from space: a research strategy for the decade 1985-1995, executive summary (part I) and proposed measurements and missions (part II, in press). Joint Oceanographic Institutions Inc. Special Reports. 52 pp.

Bernstein, R. L. (ed.) 1982. Seasat special issue I: geophysical evaluation. J. Geophysical Research 87 (C5) 3173-3438.

Born, G. H. (ed.) 1984. Theme issue: satellite altimetry. Marine Geodesy 8 (1-4) 1-402.

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

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

Kirwan, A. D., T. J. Ahrens, and G. H. Born (eds.) 1983. Seasat special issue II: scientific results. J. Geophysical Research 88 (C3) 1529-1952.

Maul, G. A. 1985. Introduction to satellite oceanography. Martinus Nijhoff Publishers. 599 pp.

Stewart, R. H. 1985. Methods of satellite oceanography. U. of California Press. 360 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.

Wilson, W. S. (ed.) 1984. Recent advances in civil space remote sensing. Proceedings of a Special Session, Society of Photo-Optical Instrumentation Engineers 481, 141-220.

PHYSICAL OCEANOGRAPHY PROGRAM

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

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

Significant accomplishments during FY-84 include: analysis of the Seasat altimeter data to demonstrate the large-scale, temporal variability in the Antarctic Circumpolar Current; further refinements in the global geoid models necessary to compute the mean general circulation of the oceans; refinement of global and regional tide models; and the 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.

As the Physical Oceanography Program concentrates more of its resources on the analysis of satellite data and plans for future space missions, we will be phasing out the development of in situ instrumentation. Our intent was development and now that many of these new instruments are commercially available, we are looking to NOAA, NSF, and ONR to fund their use in the traditional research mode. When we invested in these instrument development tasks, we intended that over the next few decades they would be used to provide near- and sub-surface data, as well as accumulate large amounts of statistical information, to aid our understanding of upper ocean current variability. These data will be crucial for validating the data from NASA's satellite missions planned for the next decade.

The thrusts of the Ocean Circulation studies will continue to be the analysis of historical altimeter data and the development of models that will utilize and assimilate TOPEX topography data. In mid-1985 NASA will release an Announcement of Opportunity (AO) solicting science investigations that utilize TOPEX/POSEIDON data. The investigations will be coordinated with the large, international oceanographic experiments planned for the early 1990's -- the World Ocean Circulation Experiment (WOCE) and the Tropical Oceans Global Atmosphere (TOGA) program. An update of the Seasat altimeter data set is planned and analysis of these data will continue. 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 studies is to determine the winds over the world's oceans with an accuracy sufficient to advance our understanding of the physical processes occurring in the layers of the oceans and atmosphere close to the sea surface. Specific objectives are to determine surface wind stress, ocean surface waves, air-sea fluxes of momentum and heat, and wind-driven ocean currents. The NASA Scatterometer (NSCAT), planned for flight aboard the U.S. Navy's Remote Ocean Sensing System (N-ROSS), scheduled for launch in late-1989, forms the basis for this program.

During the past year, accomplishments include: publication of the In Situ Science Working Group Report, including ARGOS II recommendations; development of techniques to estimate low-frequency latent heat flux over the global oceans; studies of ocean wave spectra using aircraft surface contour and short pulse radar tecniques; model refinements in assimilation of oceanic surface wind data into atmospheric and oceanic models; and application of both model and data analysis to understanding El Nino events. Our program has sponsored limited research in the application of Synthetic Aperture Radar (SAR) data to oceanographic problems. SAR research includes: a study of internal waves in the Gulf of California using Seasat SAR and a study of "rogue waves" in the Southern Ocean through analysis of SIR-B data collected from the NASA Shuttle. We will continue to make room for some SAR research, but will concentrate most of our future resources on scatterometry and altimetry.

The new thrusts of the Air-Sea Interaction studies will be concentrated in two areas. First, we will expand the 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 has been initiated and includes the participation of NASA investigators in the ONR-sponsored FASINEX field experiment planned for early-1986. Second, NASA has appointed the Ocean Energy Flux Science Working Group to assess the useful ocean parameters that can be obtained from GEOSAT and SSM/I data (both to be launched in 1985), and to review the scientific problems that can be addressed using these data. Based on their recommendations, we anticipate initiating a program to study various components of the global ocean's heat budget through analysis of satellite data.

In January, 1985, NASA released the NSCAT AO soliciting science investigations that will utilize the NSCAT wind data. We look forward to these proposals and expect to announce the selection of the NSCAT Science Investigators in late-1985. 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 Program. Looking to the future, research will be expanded to include the joint utilization of these data.

OCEAN PRODUCTIVITY PROGRAM

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

In the last three years, major advances have been made in techniques used to determine chlorophyll pigment concentrations from the CZCS ocean color measurements. Among these improvements are the refinement of sensor degredation and calibration corrections, understanding the effects of enhanced scattering by particulates, and understanding the effects of absorbance by dissolved organic material on in-water algorithms. Processing capability for CZCS data has increased substantially with improved image processing techniques, software, and additional processing facilities. The availability of data is also rapidly improving with the establishment of a dial-up catalog and microfilm browse file search capability.

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

An empirical model for estimating the vertical profile of ocean productivity from CZCS data has been developed using large *in situ* data sets. Several existing analytic productivity models are being investigated to see if they will work with only satellite data as the input. Finally, a third modeling effort focuses on how you simulate intermittent time series of CZCS data in areas such as New York bight where there is frequent cloud cover. This model uses *in situ* data from moorings to supplement satellite ocean temperature and color data. The model simulates the circulation and productivity between passes and then resets the model with each subsequent CZCS pass.

Satellite ocean color and sea surface temperature distributions are now regularly used to guide seagoing oceanographic studies and to help put shipboard measurements in a larger oceanographic context. Beyond this the processing and analysis of time series of temperature and pigment concentrations on a regional basis has been initiated. A 5 year color and temperature time series for the West Coast of the U.S., and shorter time series for the 1979 spring bloom for the Northeast U.S., the Southeast U.S. bight region, and the Gulf Stream Warm Core Ring region are underway.

The third Sea Surface Temperature Workshop was held in February 1984 at the Jet Propulsion Laboratory (JPL). Workshop participants assessed the relative accuracies of various techniques used to derive mean sea surface temperatures and identified some systematic inconsistencies between observations. The results of this workshop are being incorporated into climatological and oceanographic studies and will establish a basis for future research objectives. A follow-on International Sea Surface Temperature workshop is planned for May 1985 in conjunction with the Spring American Geophysical Union meeting in Baltimore, Maryland.

The development of airborne techniques to aid in oceanographic process studies, satellite ocean color algorithm development, and satellite data validation continues at the Wallops Island Flight Facility. The Wallops P-3 is equipped with an Airborne Oceanographic Lidar (AOL) which measures passive spectral radiance and laser stimulated flourescence emission spectra. This unique instrument is supported by a PRT-5 for surface temperature measurements, and AXBT for temperature profiles, and ship to 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 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. In addition, we have been investigating research applications of altimetry data over the ice sheets of Greenland and Antarctica.

During the past year, we have made considerable progress in all three areas: passive microwave, SAR and radar altimetry.

In situ and airborne experiments in the Greenland sea with the MIZEX program, together with intensive analysis of SMMR data and results from earlier field studies have yielded continued improvements in our ability to distinguish different ice types using passive microwave data, and a better understanding of the effect on the data of environmental conditions, such as snowcover, surface temperature and surface melting. A major achievement has been development of a technique for estimating the amount and, to a first order, the thickness of new, thin ice using SMMR data. As we gain more experience with these improved techniques and more confidence in their capability, we expect to incorporate them within a set of algorithms for routine processing of SSMI data. Meanwhile, our intercomparison of existing algorithms has resulted in approval of an algorithm for initial use by the processing system currently under development by the Pilot Ocean Data System at JPL. SSMI data will start to become available early in 1986, and we plan to transfer processing, archival and distribution responsibilities to the National Snow and Ice Center in Boulder, Colorado later that year.

In February, 1985, we shall publish a report on "Passive microwave remote sensing for sea ice research", which provides the data requirements used by the PODS groups to develop the SSMI data-processing system. The report also summarizes the research potential of these data. In our program, this is represented by continued investigation of Antarctic polynyas, and an analysis of large-scale ice drift in the Arctic. In the future, we look for an increase in such research and a corresponding reduction in algorithm-improvement activities.

NASA's FY-85 budget included provision for establishing a receiving station in Alaska to acquire SAR data from ERS-1. The station will be at the University of Alaska, and we expect the level of activity on this project to increase during 1985 and 1986. Meanwhile, we are having some success in developing automated techniques for extracting sea-ice velocity vectors from sequential SAR imagery. This and similar work will continue in the years prior to ERS-1, to ensure that we are in a position to analyse SAR data as fast as they are acquired.

Late in 1984, the SIR-B mission succeeded in obtaining some SAR data over the northern fringe of Antarctica sea ice. These show many interesting features which await thorough analysis and explanation. We expect the SIR-B to be reflown, in polar orbit, during late 1986 or early 1987. This will provide an excellent opportunity for obtaining unique data over both sea ice and the continental ice sheets.

In radar altimetry, we have had considerable success in developing an automated technique for mapping ice-cliff coastlines from Seasat data. This work will continue to produce a map of ice-cliff positions around Antarctica, north of 72°S. In addition, we have asked a science working group to investigate potential ice-sheet research applications of GEOSAT data, and we shall be publishing their report during 1985. We expect to acquire the over-ice data from GEOSAT, and we are developing plans to process these to a form suitable for research purposes.

Within the Polar Program, our first priority is to ensure that relevant high-latitude data from existing and upcoming satellite missions are processed to a form suitable for research and archived in appropriate data centers for easy and timely distribution to interested scientists. To this end our work on interpretation of passive microwave SAR and altimetry data is targeted on algorithm improvement. And the cooperation between PODS and NSIDC is aimed to facilitate distribution of passive microwave data and their derived products. With the imminent launch of SSMI and GEOSAT we expect algorithm development and improvement to peak in both passive microwave and altimetry. Thereafter, we shall focus on routine processing and archival of these data, with reduced emphasis on algorithm-related studies. This should allow us to increase our support for geophysical research using the satellite-derived data. This has necessarily taken a back place in our program in the past, but now our ability to extract useful geophysical parameters from the remotely sensed data has advanced sufficiently to justify use of these parameters for research. We intend to encourage such research, but ultimately, full scientific exploitation of satellite data will require support also from the other funding agencies.

In the SAR area, our first priority is to acquire over-ice data from future satellite missions. In addition, we shall continue to develop techniques for automatic analysis of SAR images. As SAR data becomes available, we shall shift our focus towards geophysical research. In preparation for this, we are working closely with a group of U.S., Canadian and European scientists in the preparation of a Plan for International Polar Ocean Research. A report from this group will be published during 1985, and we shall look to it to provide long-term guidance for our research program.

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 N-ROSS, 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-84, the joint Phase B study of TOPEX/POSEIDON initiated with CNES during FY-83 was successfully completed. Under this arrangement, 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. In late FY-84, for the first time after almost five years of study, TOPEX/POSEIDON was proposed by NASA to OMB as a candidate FY-86 new start for earliest launch in late 1990. While ultimately deleted by OMB from the President's budget submitted to the Congress, this was done "without prejudice," TOPEX being a victim of the Administration's attempts to slow down the rate of increase of the Nation's rapidly growing budget deficit.

Also during FY-84, Phase B Satellite Definition studies were initiated with industry (Fairchild, RCA, and Rockwell); a geopotential model improvement effort was initiated collaboratively between GSFC and the University of Texas; the development of a brassboard model of the TOPEX Radar Altimeter was continued; a Non-Advocate Definition Review of TOPEX/POSEIDON was successfully conducted; retrievability by Shuttle was added as a TOPEX capability; an experimental GPS receiver was added to the TOPEX sensor complement; and a New Start Review was held with the NASA Administrator.

Areas of emphasis for FY-85 will center around preparing to submit TOPEX/POSEIDON as a candidate New Start in the agency's FY-87 budget request. More specifically, joint studies with CNES will be continued; Phase B Satellite Definition studies with industry will be completed: the RFP leading to the selection of a single satellite contractor for

TOPEX is planned to be released; the brassboard Altimeter will be completed; etc. We are optimistic that the work done in FY-85 and prior years will lead to TOPEX's approval as an FY-87 New Start, which would permit earliest launch of TOPEX in 1991, possibly just months after the currently planned launch of N-ROSS, with NASA's Scatterometer (see below) on board, in September 1990. Such a schedule would, for the first time, permit extended intercomparisons of the ocean's response (topography, as measured by TOPEX) to its fundamental driving force (winds, as measured by NSCAT).

NASA Scatterometer (NSCAT)

During FY-84, NSCAT was approved for initiation in FY-85; similarly Navy obtained New Start approval for N-ROSS. Thus NSCAT became the first New Start in the post-SEASAT era for NASA's Oceanic Processes Program. Under this arrangement, the NSCAT instrument will be developed by NASA and flown on the U.S. Navy's Remote Ocean Sensing System (N-ROSS), currently planned for earliest launch in September 1990. Additionally, NASA will receive raw Scatterometer data from Navy for processing in a NASA developed research data system. These geophysical data products will then be distributed to the Principal Investigators selected via the Announcement of Opportunity released in January 1985.

The emphasis in FY-85 will be on awarding contracts to industry for key Scatterometer subsystem development; conducting system tradeoff studies; working with Navy to finalize N-ROSS/NSCAT interfaces; initiating key data system procurements; selecting Principal Investigators from those who responded to the AO to form a Science Working Team to advise the Project during the pre-launch years and to begin to plan the details of their proposed research investigations; etc.

OCEAN COLOR IMAGER (OCI)

An Ocean Color Imager (OCI) is one of the three instruments identified by the Joint Oceanographic Institutions as essential for the major oceanographic studies planned over the next decade. In particular the Global Ocean Flux Study outlined at a recent National Academy of Sciences Workshop requires an OCI. NASA is considering building an OCI with a 1987 new start to fly in 1990. Possible flight opportunities are:

1. To fly on the NOAA-NEXT series of polar orbiting satellites. Studies have been completed which show that it is feasible to stretch the standard NOAA bus to accommodate both the Advanced Microwave Sounding Unit (AMSU) planned for NOAA satellites beginning with NOAA K in 1989 and an OCI. Both agencies are considering proposing a FY-87 new start to put an OCI on NOAA-2 to be launched in 1990.

2. To fly on the French SPOT-3 satellite also scheduled for a 1990 launch. A phase A feasiblility study and cost estimates have been completed. This option is also being considered for an FY-87 new start.

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).

PODS has 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.

A review has been held to aid in formulating the direction that the transition to an ocean science support center 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. Plans to develop a processing and archival system for SSMI are being completed and 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 have begun.

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 1: Solid Earth and Oceans," which was published two years ago, the companion report, "Part II: Atmosphere and Interactions with the Solid Earth, Oceans, and Biota," has been published. 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 have been 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. The first part of a two-part report, "Oceanography from Space, A Research Strategy for the Decade 1985-1995" has been published; the second part is currently in press.

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

Table 2 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
West Coast Chlorophyll-Temperature Time Series Science Working Group	Mark Abbott, SIO/JPL	June 1984	June 1985
Ice Sheet Science Working Group	Robert Thomas, NASA HQ	April 1984	December 1984
Ocean Surface Energy Fluxes Science Working Group	Peter Niiler, SIO	March 1984	June 1985
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	1985	APPROVED
DMSP	USAF	MR	1985	APPROVED
	NASA	MR DATA RECEIVING/PROCESSING FACILITY		APPROVED
MOS-1	JAPAN	CS,IR,MR	1986	APPROVED
ERS-1	ESA	ALT, SAR, SCAT, IR	1989	APPROVED
	NASA	SAR DATA RECEIVING/PROCESSING FACILITY		APPROVED
NROSS	USN	ALT, MR	1990	APPROVED
	NASA	CONTRIBUTE SCAT		APPROVED
TOPEX	NASA	ALT	1990	PROPOSED
ERS-1	JAPAN	SAR	1990	PROPOSED
	NASA	UTILIZE SAR DATA FACILITY		PROPOSED
SPOT-3	CNES	PIGGYBACK ALT	1990	PROPOSED
	NASA	PIGGYBACK CS	1990	PROPOSED
RADARSAT	CANADA	SAR	1991	PROPOSED
	NASA	CONTRIBUTE LAUNCH		PROPOSED
	NOAA	CONTRIBUTE SCAT		PROPOSED
	UK	CONTRIBUTE BUS		PROPOSED
GRM	NASA	SATELLITE-TO-SATELLITE TRACKING	1992	PROPOSED

GEOSAT This is a U.S. Navy-sponsored mission to provide the Defense Mapping Agency with a larger quantity of altimeter data of Seasat quality. 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 to proceed with full implementation of the ERS-1 mission and have begun Phase C studies. ERS-2 is being considered as a tentative follow-on and would utilize spares from ERS-1.

NROSS This is a U.S. Navy mission with NASA and NOAA participation. The NASA (provision of a scatterometer) and Navy components have been approved in the FY-85 budget. The Navy currently plans to use the DMSP 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 establish SAR technology for Earth observations and to carry out observations of the Earth, primarily focused on terrestrial applications. It will be in a sun-synchronous orbit and will have an L-band SAR with a two-year design life. Preliminary design and definition studies are underway.

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 one of two options being considered. Satellite design studies have been completed, and according to present schedules, TOPEX could be launched to provide a 20-month overlap with the NROSS mission.

POSEIDON This is a CNES program to develop and utilize satellite altimetry and an associated tracking system (DORIS) for ocean and ice studies. One of two options being considered is 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 The other option being considered for TOPEX and POSEIDON is to conduct a joint mission between NASA and CNES. Joint implementation studies have been completed whereby NASA will provide the satellite and TOPEX sensors and CNES will provide an Ariane launch and the POSEIDON sensors.

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. Two spacecraft are being considered for flight of the OCI: the NOAA-K operational meteorological and French SPOT-3 satellites.

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 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 by providing a Shuttle launch and NOAA by providing a scatterometer.

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 POSEIDON and OCI.

ACRONYMS

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
SAR	SYNTHETIC APERTURE RADAR
SCAT	SCATTEROMETER
TOPEX	OCEAN TOPOGRAPHY EXPERIMENT

SPACEBORNE OCEAN-SENSING TECHNIQUES

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 equilibrium 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 sixth year of operation.

COASTAL ZONE COLOR SCANNER (CZCS)

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

Nimbus Project personnel are working with GSFC ocean scientists to define a new open ocean chlorophyll product which would be much more widely useful to the ocean science community. As a first step, a pilot project was recently completed in which CZCS data was used to produce chlorophyll concentration maps of the open ocean areas off the coast of the Eastern U. S. Users of this mapped data have strongly confirmed the value, indeed the requirement, of extending this work to produce such maps of ocean parameters on a global scale.

The Nimbus Project is proposing to develop a processing system with the capacity and efficiency to process the large quantities of CZCS observations that will be required to produce a global scale data set, while possessing the image processing capability to allow scientific analysts to validate the data by applying calibration and atmospheric corrections, and comparing results with in situ observations.

SCANNING MULTICHANNEL MICROWAVE RADIOMETER (SMMR)

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

Four years of data have been processed, validated and archived at the NSSDC. By the end of FY 85, two more years of data will be available. The archived data are: (a) calibrated antenna temperature tape (TCT): calibrated brightness temperature for each pixel, (b) TCT half degree map: TCT data mapped into half degree by half degree grid system, (c) TCT quarter degree map: 37 GHz data from TCT, mapped into quarter degree by quarter degree grid system, (d) CELL data tape: calibrated brightness temperature averaged into "cell grid," (e) PARM tape: extracted geophysical parameters, i.e., sea surface temperature, sea ice concentration, multi-year ice fraction, atmospheric total water vapor and near surface wind speed, in "cell grid" and (f) MAP tape: PARM tape data mapped into Mercator or polar stereo projection. All data are in the form of computer magnetic tape and available from the NSSDC. In addition to the tape specification for each of the aforementioned data tapes, three user's guides are available at the present time: (a) CELL Data User's Guide, (b) PARM Tape User's Guide and (c) MAP Tape User's Guide. All documentations can be obtained from the NSSDC or Dr. Paul H. Hwang, GSFC, Code 636.

TIROS-N/NOAA SERIES

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Project Objectives: 1) To provide spectral radiometric information for accurate sea and land temperature mapping, determination of global atmospheric temperature humidity profiles, day-night cloud cover information, and monitoring of total ozone burden and outgoing longwave and shortwave radiation. 2) To provide a remote platform location and data collection capability over the oceans.

Instrumentation:

1) Advanced Very High Resolution Radiometer (AVHRR)
This scanning radiometer (4-channel on NOAA-8 and 5-channel on NOAA-7, NOAA-9) provides stored and direct readout of radiometric data. The fifth channel was added to NOAA-7 to account for boundary layer water vapor and thereby increase the accuracy of sea surface temperature measurement in the tropics. Future satellites will carry the 5-channel AVHRR.
2) TIROS Operation Vertical Sounder (TOVS)
This sounder consists of three instruments: a High Resolution Infrared Radiation Sounder (HIRS/2), a Stratospheric Sounding Unit (SSU), and a Microwave Sounding Unit (MSU). These instruments provide better temperature and humidity soundings than previous sounders especially in the presence of clouds. In addition, other parameters such as sea/land surface temperature, sea ice extent, and cloud cover can be determined from these sounders.
3) ARGOS/Data Collection System (ARGOS/DCS)
This system, provided by France, is designed to locate, collect and relay data from free-floating balloons, buoys, floating ice platforms, remote weather stations, etc.
4) Space Environment Monitor (SEM)
The objectives of the SEM are to determine the energy deposited by solar particles in the upper atmosphere and to provide a solar warning system.
5) Search and Rescue (SAR)
SAR was launched on NOAA 8 and is also on NOAA 9 and all future satellites. Its purpose is to receive and locate distress signals from ships and planes.
6) Solar Backscatter Ultra Violet Spectrometer (SBUV/2).
This nadir viewing radiometer measures vertical ozone distribution and total ozone. Its main purpose is to determine the long term trends in global total ozone burden. Soundings are produced only during the day on the afternoon satellites.
7) Earth Radiation Budget Experiment (ERBE)
This is a NASA experiment, flying on NOAA 9 and scheduled to fly on NOAA G, to collect global data on the radiation processes of the Earth's Surface and Atmosphere.

Current Status: The current system is a two satellite system with a morning satellite in a 0730 LST descending orbit and an afternoon satellite in a 1430 LST ascending orbit at the equator. Both are in sun synchronous orbits at an average altitude of approximately 830 km with orbital periods or 102 minutes. Each satellite provides essentially global coverage twice daily. NOAA 9, launched in December 1984, is the current afternoon satellite, replacing NOAA launched in 1981, and TIROS N launched in 1979. NOAA 9 contains the 5 channel AVHRR and is the first satellite containing SBUV and ERBE. NOAA 8, launched in 1984 to replace NOAA 6, launched in 1979, failed shortly after launch. It is scheduled to be replaced by NOAA G in November 1985. NOAA G will contain the 5 channel AVHRR and ERBE but will not contain SBUV2 because it is a morning satellite.

Data Availability: Data from the AVHRR are available in 4 modes: 1) Direct readout to APT ground stations, 2) Direct readout to HRPT ground stations, 3) Global onboard recording readout to NOAA-NESDIS at Suitland, MD, and 4) Readout of onboard recording selected highest resolution (LAC) data. AVHRR and TOVS data are archived at NOAA/SDSD, World Weather Building, Camp Springs, MD. The data are available in two forms: level Ib calibrated radiance data, and level II retrieval products data, from February 1979 to present. Both tapes and picture imagery are available on request. SBUV and ERBE products are not yet available.

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. In its preferred form, it will be combined with the French POSEIDON mission in a joint TOPEX/POSEIDON mission, optimized for altimetric use in geophysics and oceanography. The baseline mission would be of three years duration with sufficient expendables for an additional two years. The spacecraft would be in an orbit repeating its groundtrack within 1 km. for the full mission lifetime. Instruments carried would be nominal mission altimeter and tracking system, plus several experimental tracking systems and an experimental (French-built) solid-state altimeter to be operated 5% of the time. Instrumentation for making the important water vapor and ionospheric corrections would also be carried.

TOPEX is currently scheduled for launch in late 1990; Phase B has been completed and we are awaiting approaval of Phase C/D to move toward launch.

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 NROSS satellite scatterometer which would be flown at the same time. This scatterometer will 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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Understanding the impact of changes in the global cycles of carbon and nitrogen requires specification of the present and future role of the marine biosphere in accelerating fluxes of these elements among their atmospheric, terrestrial, and oceanic reservoirs. Experience with the present Coastal Zone Color Scanner (CZCS) aboard the NIMBUS-7 satellite has shown that the biomass of marine phytoplankton within the upper 1-10 m of the water column can be measured from space to within ±30% of the *in situ* value in waters of little sediment or humic matter. Extension in depth and time of the spatially synoptic estimate of phytoplankton biomass within surface water during one satellite overflight of the CZCS will provide an index of the algal population growth responsible for extraction of CO_2 from the atmosphere and of nitrogen from the water. Composites of local CZCS scenes in time and over the ocean basins in space represent the necessary data base to examine decadal changes in global carbon and nitrogen fluxes, between the CZCS images of the 1970's and 1980's and the follow-on data from an Ocean Color Imager (OCI) of the 1990's.

The relationship of sub-surface algal biomass distribution and daily primary production (carbon and nitrogen fluxes) to the surface data sensed by the CZCS is now being examined from a number of field experiments. Off the east coast of the United States, for example, concurrent shipboard and moored instrument measurements have been made during overpasses of the CZCS within slope (Warm Core Rings Program) and shelf (Shelf Edge Exchange Processes Program) waters. Similar data sets have been collected off Vancouver Island, northern California (Coastal Ocean Dynamics Experiment Program), the Gulf of California, and within the Southern California Bight. At the same time, two joint meetings of the NASA Ocean Color Science Working Group and CNES Ocean Color Science Team were held in Paris and Fort Lauderdale to discuss the scientific requirements of an OCI launched aboard the French SPOT-3 spacecraft in 1990. A similar launch date of 1990 appears to be feasible for an OCI aboard the NOAA-K/L/M satellites, providing sufficient lead time for development of multidisciplinary experiments involving an altimeter, scatterometer, and the OCI.

OCEAN SURFACE ENERGY FLUXES

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In Spring 1985 the U.S. Navy will launch GEOSAT which will orbit an altimeter for a three-years mission and, in Fall 1985, DMSP will launch the Special Sensor Microwave Imager (SSM/I), a first in a series of many missions. Similar sensors were flown in SEASAT and subsequent data analysis has shown that a number of parameters useful in the study of fluxes of energy between the ocean and atmosphere can be determined from these sensors.

The Ocean Surface Energy Fluxes Science Working Group was established 1) to review the requirements of scientific studies of exchange of moisture, heat and turbulent energy between the ocean and atmosphere, 2) to examine the use of satellite-born microwave radiometers and altimeters in making estimates of the parameters used in estimating these exchanges and 3) to recommend how SSM/I and GEOSAT data should be processed and stored to ensure scientific utilization for energy flux studies.

The SSM/I data have the potential for determining ocean surface wind speed, total column humidity above the surface and rain rate to scientifically useful levels of accuracy. The GEOSAT altimeter data can be used to sense scientifically useful measures of wind speed, significant wave height, and changes of large-scale sea level. These data can be used to study local exchange processes and to compute global exchange rates of moisture, fresh water, and latent heat between the ocean and the atmosphere. GEOSAT altimeter data can be utilized to map the movement of strong, mid-latitude eddies and basin-wide changes of tropical sea level. The principal *in situ* verification problems in SSM/I are wind speed and rain rate and, in GEOSAT, the classification of orbit parameters can potentially limit the scope of scientific use of the data for sea level studies outside the DOD laboratory environments. The principal recommendations are that i) SSM/I brightness temperatures be made accessible in a user-friendly fashion in PODS, ii) complete documentation of the orbital errors and geoid errors in GEOSAT be provided at NOAA/GDS, iii) suite of geophysical algorithms for both missions be available, documented and verified, and iv) close relationships of the geophysical algorithm teams with FASINEX, OCEAN STORMS and TROPIC HEAT/EPOCS should be established to obtain ground truth.

SAR STUDIES OF SEA ICE IN THE ARCTIC

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The objectives of this study are to examine the benefits of establishing an Alaskan receiving station for SAR data from the ESA ERS-1 and other planned radar satellites, and to assess its potential in helping to solve scientific and operational problems. The first phase of this study identified sea ice problems (NASA, 1983) as briefly summarized below:

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, break-out of ice through the Bering Strait, and a conveyor-belt type circulation in the Northern Bering Sea which advects ice out to the ice edge.

Studies of these various ice regimes 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 its heat, mass and momentum balances? 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?

Another set of questions deals with engineering studies and operational forecasting. What is the distribution of annual and multi-year ice, pressure ridges and rubble fields? How may these ice types interact with offshore drilling platforms? Where can one route tankers through pack ice? When and where would invading ice threaten drillships operating in open water?

It is clear that there are numerous critical scientific and operational sea ice problems that could be addresses if a SAR station were established in Alaska. SAR is also a useful tool in terrestrial applications in geology, glaciology and botany. In the second phase of this study a workshop is planned to address terrestrial uses of SAR in the Arctic.

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 (S^3 SWG) has engaged in activities aimed at: (1) Identifying oceanographic, meteorological, air-sea interaction, and instrument science studies that could benefit from vector wind measurements obtained by future satellite scatterometers; (2) Establishing measurement accuracy, coverage, and resolution requirements for the NASA Scatterometer (NSCAT) to fly on N-ROSS; (3) Evaluating the performance and accuracy of the Seasat SASS instrument and associated ground data processing techniques; (4) Identifying future areas of research that must be addressed in order to interpret accurately backscatter measurements in terms of wind stress and other geophysical quantities; (5) Advising and guiding the NSCAT Project in its Phase A and B instrument and data processing design studies.

Basic and applied research studies, as well as operational uses of satellite scatterometer data, have been enumerated in O'Brien (1982) and Freilich (1985). The inadequate spatial and temporal coverage and resolution or conventional (mostly ship-based) oceanic wind observations has severely hampered past efforts to test and refine oceanographic and air-sea interaction models. Satellite scatterometer data can be applied to studies as diverse as surface wave and mixed-layer modelling and prediction, studies of the dynamics of tropical and mid-latitude current systems, tropical ocean-atmosphere interactions and climate fluctuations, atmospheric general circulation, numerical weather prediction, and investigations of the dynamics of many important meteorological phenomena.

Requirements on measurement accuracy and coverage were presented in O'Brien (1982), and reviewed at several meetings in 1983 and 1984. In addition to measurement accuracy, the S^3 SWG believes that timely access to processed scatterometer wind data is necessary for the measurements to be fully and efficiently utilized by the research community.

Several members of the S^3 SWG have conducted scientific studies to evaluate and refine the accuracy of wind measurements from SASS. While SASS convincingly demonstrated the capabilities of active microwave scatterometers to measure oceanic surface vector winds, the short duration of the Seasat mission and the difficulty in calculating unique wind directions from SASS backscatter data have limited the use of the data for geophysical research studies. Comparisons of SASS measurements with in-situ and climatological wind data, examinations of the internal consistency of the SASS data set, and detailed investigations of the numerical algorithms used to calculate vector winds from the SASS data have revealed several areas in which data processing for future scatterometers could be improved. The addition of a third antenna on each side of the NSCAT instrument will greatly ease the task of determining unique wind vectors from NSCAT measurements.

Future research activities must be conducted both to increase the global accuracy of scatterometer wind velocity measurements, and to aid the calculation of horizontal surface stress and other fundamental geophysical quantities from scatterometer data. The effects of long surface waves, surface tension, viscosity, and stability must be quantified in order to allow the ultimate accuracy of scatterometer systems to be ascertained.

The work of the S^3 SWG has been completed. The committee was formally disbanded in January, 1985. The NSCAT Announcement of Opportunity was issued in February, 1985.

Research Applications of Satellite Data Over the Polar Ice Sheets

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During the next decade there will be several satellite missions overflying the polar regions and collecting data potentially useful for ice research. In most cases these missions have goals that are unrelated to polar research, and data from them may not be readily accessible to the polar community. In order to ensure that these data are fully utilized, NASA has formed a small Science Working Group to assess potential research applications of satellite-derived data over polar regions.

The needs of the sea-ice research community have been addressed by working groups considering applications of passive-microwave data from sensors aboard Defense Meteorological Satellites, and Synthetic Aperture Radar (SAR) data from the European Space Agency's ERS-1 mission. The purpose of this SWG is to assess potential applications of satellite data over the large continental ice sheets and ice shelves.

Results from Seasat have clearly demonstrated some of these applications, and they have highlighted the need for special data processing in order to obtain useful geophysical parameters. Relevant future missions include: U.S. Navy's Geosat (carrying an altimeter; launch date 1985); Air Force weather satellites (microwave radiometers, 1985-1992); U.S. Navy/NASA/NOAA N-ROSS (altimeter, microwave radiometers, scatterometer; 1989); ESA's ERS-1 (altimeter, scatterometer, SAR; 1989); Japan's ERS-1 (SAR; 1990); Canada's Radarsat (SAR; 1991).

A strong case has already been made in the literature for the research potential of satellite altimetry over ice sheets, and this is the first priority of the SWG.

In general terms, these issues are being addressed:

- What aspects of ice-sheet research can benefit from satellite data, and how do such data complement information from key existing and planned research in Greenland and Antarctica.

- Which data from the planned missions can be usefully applied to ice-sheet investigations, and what are the required data characteristics (accuracy, spatial and temporal resolutions, areal coverage, etc.).

- Formulation of a long-term plan for applying satellite measurements to ice-sheet research, identifying _in situ_ measurements required for calibration and verification.

- Recommendations for:

  - modifications to sensor characteristics to optimize data over ice.

  - data that could, potentially, be obtained from space but which will not be provided by planned missions.

We expect to publish the report of this SWG during the summer of 1985.

WEST COAST SATELLITE TIME SERIES

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In view of the increasing availability of high quality SST and pigment images from several areas of the California Current System, a West Coast Satellite Time Series Advisory Group was established to consider the following issues: 1) Is there a scientific rationale for extending current CZCS-AVHRR time series to a larger spatial and temporal domain on the west coast of North America? 2) What are the scientific and data processing requirements for such time series? 3) How will this work relate to other oceanographic programs, both within and outside of NASA? 4) What are the implications for acquisition, production, validation, archival, distribution, and analysis of such time series? 5) What further action should be taken to address the above issues? 6) Who should be responsible for this work (and exactly what work should be done)? The Advisory Group has prepared its report, "Towards a Study of Synoptic-Scale Variability and Dynamics of the California Current System." This report will be available through the Jet Propulsion Laboratory.

Satellite imagery of near-surface phytoplankton pigment concentrations and sea surface temperature is extremely useful in the study of mesoscale variability in the ocean. The development of time series of this imagery spanning the entire California Current System is essential for the study of many compelling scientific questions. These questions involve the synoptic-scale dynamics of biological and physical processes that cannot be adequately examined using only ship and other in situ measurements. Satellites can provide the repeated, synoptic, high-resolution data necessary to observe the high degree of temporal and spatial variability in the California Current System. The first use of such time series would be to characterize descriptively and statistically the patterns of synoptic-scale variability. These results will then be combined with in situ data and modeling efforts to help understand the synoptic-scale dynamics of the California Current System.

Development of these time series will be coordinated through a project established at the Jet Propulsion Laboratory. The ultimate goal is to produce complete time series (from approximately 20°N to 60°N and 105°W to 120°W, encompassing the lifetime of the Coastal Zone Color Scanner). The project will acquire the raw digital data (level 1) and develop a browse file and catalog. Production of the remapped, pigment and temperature data (level 3) will take place at several locations and will be coordinated through the JPL time series project. Most of this level 3 processing will take place at JPL. The JPL time series project will provide high-resolution mesoscale data (1km resolution in a 5°x5° "tile") and reduced-resolution large-scale (10km resolution encompassing the entire California Current domain) data mosaics to the JPL Pilot Ocean Data System for archiving and distribution.

Currently, the time series project at JPL has installed procedures to cope with large volumes of data. A prototype series is being produced. The project is copying about 25 tapes per week from the Scripps Satellite Oceanography Facility. A data base management system is in place to keep track of the processing history of every swath. About 8 swaths per week can be converted to level 3 mosaics. For validation, the resulting level 3 products will be checked for data quality by examining areal means and other lower order statistics. The satellite-derived estimates will be compared with any available in situ measurements. This will ensure that most of the variations between successive scenes in the time series result from geophysical variations rather than processing variations (e.g. changing aerosol types, variations in viewing geometry). Suspect data will be flagged. Processing may need to be repeated as algorithms improve and comparisons with in situ data identify problem areas. Eventually, 750 full swaths of AVHRR and CZCS imagery will be processed per year at JPL and made available through PODS.

Such time series will prove extremely useful for a global Ocean Color Imager program from both a scientific and practical standpoint. Scientifically, a CZCS time series will extend the length of any future OCI time series. It will also focus scientific attention on synoptic-scale processes as well as provide large amounts of fully processed satellite imagery to oceanographers who previously only had limited access to such data. This project will also address issues of data base management and distributed processing, as well as the production of a consistently processed data set over a long time period. Such abilities will be essential for any future global missions as well.

OCEAN TOPOGRAPHY EXPERIMENT (TOPEX)

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Program Science Objectives: The primary objective of the Ocean Topography Experiment is to increase our understanding of ocean dynamics by making precise and accurate observations of oceanic topography over entire ocean basins for a period of several years. These measurements, when integrated with subsurface measurements and models of ocean circulation, will contribute towards: a) a determination of the general circulation of the oceans and its variability; b) studies of the nature of ocean dynamics; c) tests of our ability to compute the wind-driven circulation; d) calculation of the transport of heat, mass, nutrients, and salt by the ocean; e) the determination of geocentric ocean tides; and f) investigations of the interaction of currents with waves.

Instrumentation: The objectives of TOPEX require that accurate measurements of the satellite height above the sea surface be combined with accurate measurements of the height of the satellite's orbit in geocentric coordinates. 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 influence of free electrons in the ionosphere. 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 based on differences in the GPS signal measured by a receiver on TOPEX relative to the signal received at ground stations will be carried as an engineering demonstration. 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 1983. 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.

In FY84, CNES and NASA conducted 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. As a result of the study, the agencies concluded that a joint mission was feasible. NASA would provide the satellite bus and the full TOPEX sensor complement; CNES would provide a POSEIDON altimeter, a DORIS tracking system receiver, and an Ariane launch of the satellite to the desired orbit. Both the TOPEX and POSEIDON altimeters would share a common antenna and the French altimeter would operate 1 day out of 20 (for 5% of the time) while the TOPEX altimeter is turned off.

In FY84, the Jet Propulsion Laboraotry also issued contracts to Rockwell International, RCA and Fairchild to investigate the usefulness of existing satellite designs for the TOPEX or TOPEX/POSEIDON mission. Each contractor has a satellite complete with major subsystems that could be used with minor modifications for either the TOPEX mission or TOPEX/POSEIDON mission. As a result of discussions with NASA, each is now studying the modifications required to enable the Shuttle to retrieve the satellite due to failure early in the mission.

TOPEX is currently a primary candidate for a new start in FY'87, with a planned launch in October 1990.

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. Data from the French payload will be processed by CNES and distributed through a French data system. A coordinated Announcement of Opportunity to pick Science Investigators to analyse TOPEX/POSEIDON data will be issued by NASA and CNES in FY85.

PROPOSED OCEAN COLOR INSTRUMENT (OCI) ON SPOT-3

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The OCI mission objectives are governed by the scientific requirements established by the U.S./French Joint Ocean Science Working Team, the MAREX report, and experience with the Coastal Zone Color Scanner (CZCS).

OCI mission objectives may be summarized as follows:

- Mapping world-wide chlorophyll distribution means in correlation with sea surface temperature (SST), and spatial and temporal variances.
- Determining important aspects of the role of biological physical coupling in phytoplankton dynamics in an oceanic system.
- Verifying laboratory derived models for determining the instantaneous rate of marine primary production.
- Enabling plankton biology to be studied within a Lagrangian reference frame.

These objectives will be realized by making observations with the OCI instrument from the SPOT-3 orbit. The orbit is circular, sun-synchronous 10:30 A.M., at an altitude of 832 km, and 98.7 degree inclination. This results in approximately 14 orbits per day. The swath width provides three-day repeat coverage at the equator.

The OCI proposed for flight on SPOT-3 is an improved version of the CZCS. It will have eight channels, six visible and two IR; a 100% duty cycle over the sunlit ocean; and will employ active calibration. To simplify the OCI/SPOT-3 interface, satisfy the mission requirements, and maintain some OCI autonomy, the OCI system will be provided as one unit for mounting on the outside of the spacecraft. The OCI system (unit) will contain the instrument, experiment computer for programming and data handling, three tape recorders, a power regulator, two transmitters for realtime and recorded data dump (S-Band), an antenna, a cross-strap unit for switching these components, and bus couplers to provide the interface with the SPOT-3 spacecraft. The SPOT-3 spacecraft supplies the Earth oriented platform, unregulated power, and a command link. Data transmission will be continuous realtime during the daylight portion of the orbit. Recorded data will be dumped to ground stations; one French station (probably Lannion), and between one and three American stations (Wallops, Goldstone, and Canberra). The basic payload for the French SPOT-3 spacecraft is two HRV instruments for land observation in the visible spectrum at 10 to 20 meter resolution. The inclusion of the OCI on the SPOT-3 completes it as very effective global observation satellite having land and ocean capability.

All Level 0 and 4 data shall be exchanged between CNES and NASA; a limited amount of these data shall be near realtime (exchanged within 24 hours). The French and Americans will have the same definition of data levels but shall independently develop their own software. The science of the mission shall be coordinated by a joint Ocean Color Science Working Group. NASA and CNES shall issue Announcements of Opportunity.

The SPOT-3 is scheduled for launch in late 1990. The OCI system can be executed in three years and must be provided one year prior to launch for integrating with the SPOT-3.

Current Status: Phase A has been completed. NASA's decision to proceed with the program is expected in July.

ERS-1/SAR

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The ESA Remote Sensing Satellite (ERS-1) is being prepared by the European Space Agency (ESA) for a 1989 launch in a near-polar orbit at an 800 km altitude. On board will be a C-Band SAR to be operated at 21 degree look angle and capable of yielding SAR images with 30 m resolution covering a 80 km swath. With no on-board SAR data recording capability planned, one of the objectives of the ERS-1/SAR project is to acquire a dedicated data receiving station at the University of Alaska in Fairbanks. This will allow SAR data taken in real-time over Alaska and the surrounding oceans to be acquired when the satellite is in view. The second objective is to develop appropriate SAR data processing capabilities to support science study goals.

ERS-1 data acquired over the Alaska region will allow researchers to investigate the dynamic behavior of polar ice through at least one full year and to provide insights 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.

The main project goal for FY'85 is to prepare and present to NASA in August 1985 a formal project proposal that includes science, ground receiving station and ground data processor plans. Frank Carsey of the Geology and Planetology Section is assigned to co-ordinate the science team. An European-Canadian-American science team PIPOR (Program for International Polar Oceans Research) was founded to develop user requirements through meetings in November 1984, January 1985 and March 1985. A Fairbanks SAR User's Group meeting in May 1985 is scheduled to firm up the overall project requirements. John Ovnick of the Radio Frequency and Microwave Subsystems Section is responsible for the ground receiving station systems study. That includes station design, site selection and potential station vendors identification. Site survey trips to Alaska have been planned for April during which environmental conditions including EMI (electromagnetic interference) will be assessed. Station vendors will be approached in April and May for timely evaluations. Kon Leung of the Radar Science and Engineering Section is overseeing the proposal effort in addition to the ground data processor study. As a candidate for data processing, the IDP (Interim Digital SAR Processor) satisfies all worst case ERS-1 processing requirements except for throughput. The throughput requirement will be decided in the May Fairbanks meeting and is expected to be in the range of 3 to 10 minutes of data per day. In addition to the ADSP (Advanced Digital SAR Processor) which is capable of near real-time processing, a wide range of dedicated mini-computer/array processor combination systems in conjunction with various system architecture and algorithm options are also under evaluation as data processor candidates. A set of data processor alternatives satisfying the range of throughput requirements will be included in the proposal.

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

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Program Science Objectives

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

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

- Extract SSM/I cryospheric data from the orbital input data stream.
- Create mapped data sets.
- Distribute data to the user community (foreign and domestic)
- Provide an interactive data catalog.
- Provide facilities for visiting scientists.
- Incorporate other non-SSM/I cryospheric data.
- Implement revised microwave algorithms.
- Provide special products upon user request.
- Anticipate future data requirements and develop guidlines for data collection/management.
- Hold workshops to promote interaction within the user community.

Equipment

The computer system which will be utilized on this project consists of a Digital Equipment Corporation VAX-750. The data management software is being developed by the Jet Propulsion Laboratory, Pilot Ocean Data System (JPL/PODS), and will be delivered to the WDC-A for Glaciology over the next eighteen months. Laser optical read-write disks will be used to store the SSM/I data.

Current Status

The two tasks proposed in the first year of this three year project have been completed. These are: (1) Ordering and installation of a VAX 11/750 computer and (2) planning for transfer of the Pilot Ocean Data System (PODS) software to NSIDC. In addition, NSIDC staff provided input to the SSM/I Sea Ice

Science Working Group and initiated discussion on how data will be transferred from NOAA to NSIDC.

The VAX computer was ordered in late summer 1984 and arrived on November 12. The system was installed in mid-December, however routine operation did not begin until late February 1985 due to delays in completion of the computer machine room.

In mid-November a draft Implementation Plan was completed which outlines the responsibilities of JPL-PODS and NSIDC for completion of the development of the SSM/I processing software by PODS and the transfer of the system to NSIDC. This Implementation Plan has been signed by all interested parties.

Data Distribution Plan

Exact dates for data distribution are indefinite because the SSM/I launch date has not yet been precisely determined. JPL/PODS has begun work on software revisions permiting incorporation of SSM/I data into the PODS data management system. It is expected that limited data distribution will commence witnin 4-8 months after SSM/I launch. Timetables for implementation of the system are defined in the Implementation Plan.

PILOT OCEAN DATA SYSTEM

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In response 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 distribution 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 data browse 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 PODS via a 1200 bit/second commercial communications network (TELENET) or 4800 bit/second dial up modems. Monochrome or color graphic displays are available at the user's terminal; while magnetic tapes, tabular listings and hard-copy graphic products produced at the PODS facility are shipped to investigators within 24 hours of generation via an express shipping service.

In the future, it is expected that PODS will evolve into the NASA Ocean Data System (NODS). NODS will be a distributed network of data archive facilities. These facilities will collectively be the custodian of NASA's satellite observations of the oceans. The services provided by NODS are related to the archiving and distribution of data sets from spaceborne ocean viewing sensors and to a limited extent, data sets from _in situ_ measurement systems. Data sets being considered for inclusion in NODS are:

(1) Geos-3 Altimeter;

(2) Seasat Altimeter, Microwave Radiometer, and Scatterometer;

(3) Limited TIROS Advanced Very High Resolution Radiometer and Nimbus Coastal Zone Color Scanner (support West Coast Color and Temperature Time Series);

(4) Geosat Altimeter;

(5) DMSP Special Sensor Microwave Imager (SSM/I);

(6) TOPEX Altimeter;

(7) Poseidon Altimeter (French sensor to fly on TOPEX bus);

(8) NASA Scatterometer (to fly on NROSS);

(9) Ocean Color Imager (OCI);

(10) NROSS Altimeter;

(11) ERS-1 Altimeter, Scatterometer and Microwave Radiometer.

NODS will archive data at various processing levels, ranging from level 0, 1, and 2 swath-oriented data to level 3 and 4 gridded data. NODS will produce and archive browse files which are designed to provide rapid response to users wishing to browse through data interactively. Users will be able to interactively select data by time, region, project, platform, sensor, data level, and parameter measured. Selected data can then be displayed at the user's terminal, written to temporary disk files for later display or transmission, or written to magnetic tape or optical media for shipment to the requester.

The first two NODS nodes, JPL and the National Snow and Ice Data Center, will become operational in 1986 and 1987, respectively. A node at the Goddard Space Flight Center would be added in the early 1990's when OCI is expected to be launched. Other nodes would be added as NASA needs and research community interest grows.

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 1985 are also included. The activities are listed alphabetically by senior principal investigator.

STUDIES OF OCEAN PRODUCTIVITY

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and

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

Specific Objectives: To 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. Preliminary studies of imagery covering the entire California Current System have begun. These studies are focusing on the seasonal variation of the observed patterns. With R. W. Eppley, I have been studying the relationships between near-surface chlorophyll concentration and water column chlorophyll from several regions.

Current Status: Studies of satellite imagery and field data from Lake Tahoe, Calif.-Nev. have been completed, and results have been published. Comparisons of productivity and surface chlorphyll are well underway, and the first results have been published. 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. A study of an upwelling event during CODE-1 using CZCS and AVHRR imagery has been published. Analysis of the dominant modes of variability has begun.

Relationships Between Phycoerythrin Fluorescence And Productivity in Marine *Synechococcus* spp.

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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 photosynthetic and metabolic parameters, and to detail the adpative mechanisms that ensure ecological success of marine plants. These efforts are directed towards defining and predicting phytoplankton distribution, biomass and productivity in natural waters. It is felt that laboratory studies that simulate natural conditions provide a powerful means by which process level events can be defined and integrated into ecological descriptions.

Specific Objectives: The principal objectives of the current investigations are to describe in detail the influence of variable light and nitrogen regimes on photosynthesis, physiological state and biomass of the marine, phycoerythrin-containing *Synechococcus* spp., and to related these responses to whole cell absorption and fluorescence properties which can be assessed by remote sensing. These studies have shown that there exist highly significant correlations between photosynthesis, specific growth rate, and photosynthetic adaptive strategy and the yield of whole cell phycoerythrin fluorescence relative to chlorophyll *a* fluorescence.

Approaches Used: Laboratory cultures of the two dominant forms of the marine *Synechococcus* spp., and several species representing the other major phytoplankton groups have been grown under defined conditions of light, temperature and nutrient levels. The photosynthetic performance, photosynthetic unit features, growth rates, and whole cell fluorescence and absorption properties have been assessed. These data have been used to construct artifical assemblages to assess the optical properties that would result in natural mixed assemblages.

Current Status: We have completed a detailed description of the influences of light and nitrogen environment on photosynthesis, fluorescence, growth and optical properties of the two dominant clonal forms of *Synechococcus* spp. and compared these features to diatoms, chrysophytes, chlorophytes and cryptomonads. We have also completed a comparative study of the relationships between fluorescence excitation and absorption properties of all the phytoplankton groups to demonstrate that cellular absorption due to chlorophyll *a* underestimates biomass and photosynthesis, while fluorescence excitation spectra present a more representative picture of these physiological features. Further, we have shown that phycoerythrin fluorescence accurately tracks losses in the cellular content of this pigment under nitrogen starvation conditions, and measures recovery when nitrogen becomes available. Lastly, we have delineated the time course responses to the onset and recovery from photoinhibition of photosynthesis in *Synechococcus*. These studies demonstrate that photoinhibition occurs rapidly and that recovery is equally rapid, that response times for onset and recovery are within the same time scale as vertical and Langmuir mixing, that the site of photoinhibition is photosystem I, and that phycoerythrin fluorescence from whole cells is a reliable means of monitoring these events.

Scatterometer Applications to Ocean Surface Analysis and Numerical Weather Prediction

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Long term interest: To utilize scatterometer wind data to (a) produce global surface analyses of wind, wind stress and fluxes of heat and moisture and (b) to improve 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 generate global fields of surface wind and surface fluxes.

Approach: a) Use of a 4-dimensional Seasat analysis/forecast system to dealias and assimilate SASS winds and generate surface fluxes; b) Evaluation of objective and subjective dealiasing schemes; c) Comparison of forecasts made from analyses with and without SASS data: d) Utilization of data generated from a simulated "nature" model to assess future 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 was developed. With this system, SASS data were objectively dealiased for September 1978. Global fields of surface wind stress, wind stress curl, and surface fluxes were derived from the GLAS analysis forecast system using subjectively and objectively dealiased SASS winds. The instantaneous GLAS wind analyses were found to be in excellent agreement with subjective analyses. 10-day averaged GLAS stress fields were found to be in good agreement with published fields. Two global SASS forecast impact studies were completed using the GLAS and NPRF analysis/forecast systems. Preliminary simulation experiments were conducted to assess the model sensitivity to low level wind specification. 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 cyclongensis in this case.

The entire 90 days of global SASS data are being dealiased using the objective dealiasing schemes described by Baker et al. (1984) and Hoffman et al. (1983) The different dealiasing schemes are being compared. Global surface wind and flux fields are being generated for the 90 days. Detailed simulation studies of NSCAT data and the capabilities of objective dealiasing schemes for such data are being initiated.

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 to 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 in conjuction with A. Henderson-Sellers and K.P. Shine, University of Liverpool).

Approach: The approach utilized the US Air Force's DMSP (Defense Meteorological Satellite Program) 4 km resolution visible and IR imagery satellite data, supplemented 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 sclae 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 collabration with K. Shine 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.

The project has been completed and reports and publications are available.

This research was jointly sponsored by National Science Foundation, grant ATM-80-18898.

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.

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.

Approach: SMMR sea ice test products were prepared, based on a survey of potential needs of the snow and ice community. Computer software developed to manage the data were used to generate sea-ice data products which are available to the snow and ice community. To check the SMMR data, independent sea ice information from charts have been compared with the SMMR data.

Current Status: Graphical and digital SMMR products were obtained from software designed to read selected (spatial and temporal portions of the orbital (PARM-SS) and gridded (MAP-SS) SMMR data. The work has been mainly concerned with sea ice parameters, although snow parameters could also be derived from the software products that have been developed. Areal ice statistics were not produced because of spurious regions of sea ice concentration and multiyear ice fraction identified on the data tapes. The data would have to be reprocessed in order to obtain meaningful statistics; this was not within the scope of the project.

User difficulties were relayed to NASA and changes made in the documentation accompanying the data tapes. Two case studies were conducted to verify the SMMR derived sea ice concentrations and multiyear ice fractions with other data sets available at the WDC-A. One study investigated a lobe of ice in the Greenland Sea during early May 1979 and the second examined sea ice breakup in the Sea of Okhotsk during May 1979.

The project is completed and reports and publications are available.

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

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

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

Status: In the past year, we have successfully conducted a comprehensive field experiment off the coast of Chile, obtaining estimates of the directional wave spectrum using three independent methods (Shuttle SAR, Surface Contour Radar, and Radar Ocean wave Spectrometer). We are now heavily involved in the analysis and intercomparison of the spectra, and expect to be in the interpretation phase at least through FY86. We also have a hurricane data set, a number of passes in the Agulhas region, and several in the South Atlantic that have yet to be examined. A number of interagency workshops are planned, and several joint papers are envisioned during FY86.

Related work is sponsored by the Office of Naval Research, and by internal R&D funds.

VALIDATION AND SCIENTIFIC APPLICATION OF NIMBUS-7 SMMR SEA SURFACE TEMPERATURE DATA

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Long-Term Interests: the upper ocean and its coupling with the atmosphere, on scales from 10's to 1000's of kilometers, with particular emphasis on the development and application of remote sensing techniques to advance the study and understanding of ocean variability.

Specific Objectives: the principal objectives of this investigation are to first validate, and then apply the Nimbus-7 SMMR sea surface temperature data to a study of equatorial Pacific and Southern Ocean air-sea interaction.

Approach: Nimbus-7 SMMR sea surface temperature data obtained from the Nimbus project at Goddard Space Flight Center, will be mapped and otherwise intercompared with in situ measurements collected in 1979, from the NORPAX Hawaii-Tahiti shuttle program and the FGGE drifting buoy program. Systematic errors in the SMMR data will be identified and corrected for to the extent possible. Time-sequences of objectively analyzed SMMR sea surface temperature maps will be produced and used to examine variability over a broad range of time scales. In the Southern Ocean, the emphasis will be on synoptic meteorological forcing scales, while in the tropical Pacific, emphasis will be on annual and interannual scales.

Current Status: Since the start date of this project was 1 August 1984, only modest progress has occurred to date. The data and a variety of analysis tools have been assembled. The P.I. is working in close collaboration with Dr. Andrew Milman of Hughes Aircraft, who had played a key role in the production of the Nimbus-7 SMMR data while.

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. With the successful launch of GEOSAT into an orbit with nearly the same inclination as Seasat, the possibility of an unclassified extended exact-repeat mission for GEOSAT is greatly enhanced. A paper has been submitted to the 1985 AAS/AIAA Astrodynamics Conference which describes how 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.

NASA SPACE AND EARTH SCIENCES COMPUTING CENTER (NSESCC)

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Long Term Goals:

- To provide first class computational support for NASA-sponsored research
- To provide easy access to computational tools appropriate for research
- To simplify complexities of supercomputer use

Current Status: The NSESCC was formed in August, 1984, by combining the Science and Applications Computing Center and the NASA High Speed Computing Facility. The two facilities are currently in two separate buildings, but the plan is to physically merge them by the end of the calendar year 1985.

The consolidated computing center is organized within the Space Data and Computing Division at Goddard and operates a locally connected complex of large-scale computers including an IBM 3081 mainframe and a CYBER 205 supercomputer. A very broad range of user support services is also provided, including graphics and data management tools, user consultation, training, and documentation.

Highlights of the consolidation effort to date include:

o Management

- Day-to-day operations of both facilities consolidated under one head
- Steering Committee established and active in reviewing/advising plans
- Integrated Program Plan and Budget developed and submitted to Headquarters
- Contractor support management consolidated under one head for both facilities
- Cross training of system programmers, operators, and user support

o System Improvements

- Main memory increased on both Amdahls, significantly improving user responsiveness
- Successful installation and integration of very high speed laser printer
- Communications front-end subsystem upgraded to improve responsiveness
- Plans finalized for April, 1985, installation of additional megaword of memory on CYBER, relieving major bottleneck for CYBER performance
- Plans completed for additional memory and channels on IBM 3081
- Remote dial-up access provided through Telenet public packet-switched network, enabling more reliable connections and eliminating long-distance phone charges
- Preliminary configuration planning completed for merged facility

o Workload Sharing

- Low-speed links established between facilities enabling interactive sessions, job submissions, and output to be routed from any system to any system
- Successful offloading of subset of VM users for Amdahl to IBM 3081

The emphasis for the remainer of FY85 and FY86 will be the physical merger and stabilization, along with continued improvement of input/output capabilities to enhance overall CYBER performance.

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

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

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

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

Current Status: The project began January 1, 1985 and the semi-objective analysis scheme is now 50% complete. The stratification dependent PBL model has been inverted to relate surface pressure fields to input surface stress (or winds).

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 this research was to study the relation between the scatterometer (SCATT) backscatter coefficient and the wind and sea state. We used data taken from the NASA CV 990 airborne laboratory by L. Jones during the Storms Transfer and Response Experiment (STREX) in conjunction with geophysical data taken from the NOAA P-3 and the NCAR Electra. We also intercompared Seasat SASS, JASIN, and MARSEN data sets.

Approach: We worked 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 (JASIN and MARSEN).

Current Status: Work on this project finished in 1984. Most objectives were satisfied; however the comparison between the airborne scatterometer and stress extrapolated to the surface produced only a thesis delineating the accuracies in these measurements and the marginal correlation in high winds due to inadequacies in both sets of data. We obtained an evaluation of the scatterometer as an anemometer for mesoscale applications. We found that satellite scatterometer data were valuable in defining frontal location and possibly shapes. This capability is a result of sharply different sea-states before and behind frontal passages as identified in the Storm Transfer and Response Experiment (STREX). The SASS algorithm is inadequate in the vicinity of fronts, due mainly to three effects: very high winds behond the calibration range of the SASS; large changes in boundary layer stratification causing significant variation in wind versus surface momentum flux; and non-equilibrium in the sea-state behind a front. Nevertheless, the SASS signatures clearly responded quickly to these sharp discontinuities in ocean character (and air-sea interaction). Data from SASS in number of events and surface data were inadequate to establish new parameterizations. We also did preliminary investigations of the large fluxes through the PBL in cases leading to very rapid oceanic storm development in STREX and in the Arctic Cyclones Experiment (ACE). These data will be carried into a future thesis work.

ANALYSES OF THE WIND-DRIVEN RESPONSE OF TROPICAL OCEANS

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

Objectives: There are two primary objectives to the present research. The first is to study the wind-driven interannual variability of the tropical Atlantic. Of particular interest is how the interannual solution relates to the seasonal response. The other major thrust pursues factors which influence calculations of the response in the tropical Pacific. Examples of which include the amplitude and phase dependencies of a solution as a function of vertical normal modes, the influence of zonal changes in the density field, differences in the nature of the wind field variability among several wind events and different analyses of the same wind event, and general changes to the mass and heat budgets.

Approach: A combination of numerical and analytical models is invoked to carry out this research. Linear, multi-baroclinic mode numerical models are used in studies of the wind-driven variability of the tropical Atlantic and Pacific Oceans. The influence of zonal changes in the equatorial density field is analyzed with an analytical multiple reflection/transmission approach. The nonlinear hydro- and thermodynamic model of Schopf and Cane (1983) will be used to study the mass and heat budgets of the eastern tropical Pacific in response to seasonal and interannual forcing.

Current Status: Monthly fields of wind stress and sea surface temperature for the tropical Atlantic have been prepared for January 1964 to December 1979. Simple statistical measures of the seasonal and interannual variability have been obtained. The gridded wind data was subsequently used to force the first three baroclinic modes in a linear numerical model. The sea level signature for the onset of the 1982-83 El Nino was hindcasted using a linear wind driven model that consisted of four vertical modes. The hindcast solution was compared with sea level time series from 18 Pacific island and coastal stations. In order to obtain a solution that accounted for a significant portion of both the amplitude and phase of the observed sea level it was necessary to sum the first and second baroclinic modes. The comparisons with observed sea level were best in the eastern tropical Pacific along the equator and South American coast where the solutions were a function of integrals of the zonal wind field to the west. The skill of the hindcast was notably less away from the equator where a derivative of the forcing determined the response. In modelling studies such as these the influence of zonal structure in the density field on equatorial wave phenomena is not well known. Thus a formalism has been developed with which to study the propagation of equatorial waves in a stratified ocean with a Brunt-Vaisalla frequency $N=f(x,z)$. The behavior of reflected and tranmitted Kelvin and Rossby waves for idealized and observed stratifications is of interest.

APPLICATION OF REMOTE SENSING TO STATISTICAL STUDIES OF OCEANIC PROCESSES

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Long-term interests of the investigator

Development of algorithms for estimating phytoplankton biomass and primary production on regional, basin or global oceanic scales, and for studying processes that govern biological systems in the ocean. 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 investigate the distribution of phytoplankton in a highly dynamic, tidally mixed ecosystem using aircraft remote sensing data together with conventional oceanographic sampling methods. This was the objective of the experiment entitled "Dynamics of Phytoplankton on Nantucket Shoals," that began in 1981. This year's goal was to complete the documentation on that experiment.

Approach utilized for this task

Data collected during a field experiment in May 1981 were analyzed by a variety of methods. On the basis of cruises in 1978-79, it had been hypothesized that phytoplankton patches occur downstream of areas of deep tidal mixing along the northern and eastern boundaries of the Shoals. This concept was tested in all our analyses. Methods included variance and covariance analyses, spectral analysis, and a simple transport model for predicting the displacement of phytoplankton patches from cold surface manifestations of vertical mixing.

Status and progress

Maximum correlations between chlorophyll, temperature and depth occurred at nonzero lags, suggesting westward movement of water over the Shoals and a time lag in phytoplankton growth. Covariance patterns in data taken at the same time of day and tidal phase were notably similar (Campbell and Esaias, 1985, in press). Local phytoplankton maxima were physically displaced from cold frontal areas, but the latter exhibited considerable variability in intensity and location whereas phytoplankton distributions were somewhat stable (Campbell et al., 1985, accepted for publication).

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 (ENSO) cycle, while specifying as little as possible.

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

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

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

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

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

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

Approach: We are developing a laboratory breadboard version. An *in situ* prototype will follow. Spectral transmissivity measurements are being made with the optical breadboard, and 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 version and the signal processing circuits. Integration of the optics and electronics is underway 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 algae and other color groups. These models were further tested on cruises in 1984 in the Gulf of Mexico where optical breadboard components were used to study relationships between chlorophyll and other ocean color constituents. These relationships resulted in an analytical remote sensing reflectance model for the Gulf of Mexico that was heavily dependent upon the size of the chlorophyll-bearing particles. This model can be fine tuned for seasonal and geographic variations in the color constituents. Fluorescence quantum efficiencies have been calculated from field reflectance data which appear to detect populations stressed due to nutrient limitation/photo-inhibition.

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ACTIVE-PASIVE 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.

Objective 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 observation of ice motion, type and surface albedo.

Approach: The approach is to examine the Seasat data set and data from SIR-B, Nimbus, Landsat, other satellites, and platforms, notably buoys. The types of analysis in use 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 satellite instruments, 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 1984, papers were published from a field study at Mould Bay NWT undertaken to improve satellite observations of sea ice. More such work is in planning for 1986 for the summer to fall transition. Work was continued on the efficient tracking of ice floes in sequential SAR images and on scene classification methods for SAR ice images. Case studies wer performed of ice kinetics in the ice margin of the Beaufort and Chukchi seas in Seasat data. A method for inferring ice surface albedo was tried, but good emissivity values for summer remain a research problem.

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 dual-polarized, multi-frequency data can be used to remove ambiguities in distinguishing among various ice types thereby overcoming current limitations in determining sea ice concentration.

Objective: The primary objective is to assess the potential of and use the dual-polarized, multi-frequency data acquired during the Bering Sea Marginal Ice Zone Experiment (MIZEX-West) for determining the distribution of ice type and ice compaction. Other objectives are to assess the extent to which poor weather conditions limit the usefulness of the high frequency data and to obtain a passive microwave classification of first-year sea ice types.

Approach: The approach is to analyze the coordinated surface, aircraft and satellite observations made during MIZEX-West. The principal sensors on the NASA CV-990 aircraft are the passive microwave radiometers which span a frequency range from 10.7 to 183 GHz. Visible, photographic, and thermal infrared surface observations also made from the aircraft are used to complement the microwave measurements. Nimbus-7 SMMR and NOAA-7 AVHRR satellite observations are used to provide a coherent description of the entire Bering Sea region.

Status: Preliminary analysis of the aircraft and Nimbus 7 SMMR data has been completed and published in the Proceedings of the IGARSS'84 Symposium. Results show the 92 GHz microwave imager to be very effective in mapping the characteristics of the Bering Sea MIZ including regions of open water, ice compactness, and ice-edge structure. Limitations at this frequency include a 10-20 K loss in ice-water contrast imposed by heavy cloud cover and a drop in brightness temperature of 25 K relative to lower frequencies in shear zones with heavy snow accumulation. Analysis also shows that the 18 and 37 GHz polarization obtained from the NASA aircraft radiometers discriminates among new, young, and first-year sea ice types, a result confirmed by surface radiometric measurements. Work has begun on developing an algorithm for mapping regions of new, young, and first-year sea ice types in the Bering Sea.

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 had planned 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 can supply relative current velocities, providing a means for field calibrating the Lagrangian response of the drifter.

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

FACILITIES FOR OCEANOGRAPHIC REMOTE SENSING APPLICATION

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Many questions relating to meso- and large-scale ocean circulation might better be addressed with an observing system, closely akin to that which is available to the meteorological community. A long term interest includes developing a 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 are created for specific oceanographic experiments in which these facilities are used for analysis of both in situ and remote sensing data.

This project was initiated in September 1982. The hardware/software system was selected (the ESL, Inc. VAX/IDIMS), installed, and the Oceanographic specific software from Scripps Institution of Oceanography has been implemented. We are actively working on communications links with URI, NMFS, and NEARSS. We anticipate installing a digital APT system from NUSC during the coming year. The system is now being used to support analyses of data from the California Current, Agulhas Current, East China Sea and several smaller experiments. Numerical modelling and tomographic inversions are also being run on the system.

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

TEMPORAL AND SPATIAL VARIABILITY OF SEA SURFACE WINDS

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Long-Term Interests: To utilize satellite measurements for the study of large-scale low frequency variability of the ocean through statistical and numerical models. Primary emphasis is on winds. However, sea surface temperature (SST), water vapor and atmospheric liquid water are also of interest as they relate to heat flux which is an important component of near surface ocean dynamics.

Specific Objectives: There are two primary objectives of the present work. The first is to evaluate the usefulness of passive microwave measurements from the NIMBUS-7 SMMR and, assuming anticipated problems with calibration drifts and biases can be resolved, use measurements during 1982 and 1983 to study the development of El Nino in the tropical Pacific. The second objective is to explore methods for spatially interpolating vector winds to improve the usefulness of scatterometer data for studies of wind-forced ocean circulation.

Approach: The approach for determining the usefulness of the SMMR data is to examine the brightness temperatures measured as a function of frequency, incidence angle and time and search for evidence of calibration drifts or cross-scan biases. These problems will then be removed to develop internally consistent data sets which will then be used to construct monthly average fields of SST, wind speed, water vapor and atmospheric liquid water. The approach for extending the usefulness of scatterometer data is to develop Gandin-type objective analysis techniques to spatially interpolate vector winds across the 400 km gap centered on the satellite ground track.

Current Status: The proposed SMMR work is new and analysis is in a very early stage. The SMMR data tapes have been obtained from Goddard and processed through brightness temperatures. Preliminary examination shows evidence for El Nino in the SST fields. The proposed SASS work is also new. A simple objective analysis model has been developed and the results are encouraging. The maximum errors in interpolated wind speeds at satellite nadir are within the 2 m/s rms error requirement set by the Satellite Surface Stress Working Group.

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.

Objectives: The objective of this research is to develop *in situ* instrumentation capable of examining 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.

Approach: The approach is to develop instrumentation to measure the vertical distribution of fluorescence and spectral reflectance from chlorophyll and other pigments. Instrumentation has also been developed to 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 permits the range-gated measurement of the vertical distribution of zooplankton species in the euphotic zone.

Status: A collaborative effort with D. Kiefer and J. SooHoo to examine spectral signatures from phytoplankton and certain aspects of phytoplankton physiology has led to the development of a model for the spectral distribution of the quantum yield for phytoplankton fluorescence, and an understanding of the nonlinear processes involved in the generation of fluorescence signatures. A chirp sonar instrument has been constructed to study the small scale temporal and spatial variability of zooplankton size class distributions in Saanich Inlet in collaboration with R. Pieper, D. Mackas, and K. Denman. These studies have yielded data for the estimation of the vertical distribution of zooplankton size classes and of the small scale spatial and temporal scales of those distributions. Studies of the use of Raman and Brillouin scattering for the study of the distribution of temperature and salinity in the ocean have been completed and the results reported in *Ocean Optics VII*.

SPECTRAL STUDIES OF MARINE PHYTOPLANKTON

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

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

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

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

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

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Long-term Interest: An optimal utilization of satellite multichannel microwave data in the characterization of the sea ice cover and a better understanding of some ice/ocean/atmophere phenomena.

Specific Objectives: (1) To improve our understanding of the time variability of the microwave emission from the different types of sea ice, (2) To develop or improve current techniques for retrieving sea ice parameters, and (3) to use retrieved sea ice parameters to quantify the size and persistence of polynyas, and the variability of the marginal ice zone and relate these results to various oceanographic and/or atmospheric processes.

Approach: Orbital data from the different channels of the multispectral sensor are mapped to a common polar stereographic grid for effective analysis of the frequency and polarization dependence of the sea ice microwave signature. Physical temperatures retrieved from an infrared sensor are also mapped to the same grid and used to calculate emissivities which are more directly associated with the physical and radiative characteristics of the emitting material. Cluster and statistical analysis are employed to determine which of the different ice types can be unambiguously identified during different times of the year. To retrieve ice concentration, the two polarization channels at 37 GHz are utilized for Central Arctic data while an 18 GHz channel is used in conjunction with a 37 GHz channel in the seasonal ice region to minimize ambiquity due to snow cover. Retrievals are compared with available in-situ data including those from the Ameriez cruise, MIZEX, submarine sonar, Canadian Arctic measurements, and also with measurements from an experimentally controlled artificial sea ice at CRREL.

Status: A detailed and comprehensive analysis of the emissivity clusters of the Arctic winter sea ice is near completion. A new technique for retrieving sea ice concentration has also been developed and implemented for some winter months. A paper (with H.J. Zwally and A.L. Gordon) about off-shore polynyas and oceanographic effects has recently been accepted for publication. This study is currently being extended to deep ocean winter polynyas and will include both Nimbus-5 ESMR and Nimbus-7 SMMR data for longer time coverage. Correlation analysis using the spring Ameriez cruise data and SMMR data is in progress. A method to determine the optimum ice edge concentration that can be inferred from the SMMR data has been developed.

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 wind 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 at many depths.

System development is subcontracted to RD Instruments which has experience in bottom-mounted and shipboard acoustic profilers. Primary emphasis is development of highly directional acoustic transducers so that observations can be made near mooring lines and the surface. Polyvinylidene fluoride (PVFD) piezoelectric films have been tested and abandoned because of their low power efficiency. Acoustic lenses have been abandoned for mechanical reasons. Amplitude shaded single-piece ceramic transducers have been fashioned using multiple electrodes to provide excitation which varies radially. This modulates the thickness mode to form a narrow beam but additional radial modes degrade this beam. Segmenting the transducer and special materials bonded to the transducer edge both reduce the radial mode but the best approach is yet to be selected.

Aside from the transducer, the subsystems for a self-contained profiler are developed. Unmodified 3M cartridge recorders with low-power CMOS drivers provide 67 Mbyte storage with 10% of the energy per byte needed for conventional cassette recorders. Combining a flux gate compass, pendulous tilt meters, and a microprocessor provides conversion of velocity components to earth coordinates for vector averaging. Acoustic processing permits measurement of the Doppler spectrum centroid frequency (which determines the velocity) plus spectral width and signal strength which help characterize the quality of the velocity determination.

ASSESSING OCEAN PRODUCTIVITY FROM SATELLITE MEASUREMENTS

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

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

Approach. Using existing data on ocean primary production, collected in the past by ships, we compare depth-integrated primary production (mg C m^{-2} day^{-1}) with near-surface chlorophyll-like pigments (mg m^{-3}), determining the proportionality between the two. 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 esitmated using regional mean values of the proportionality between production and chlorophyll than a global mean value. Data for the Southern California Bight indicate that within a region, the proportionality between production and chlorophyll is related to climatological data, reducing the error in estimating production by about one-half. In the eastern tropical Pacific, variation in the production-chlorophyll relation depends upon the character of the photosynthesis-light curve. Evidence of shade adaptation was seen in the nutrient-rich South Equatorial Current where the relation varied with stratification/mixing parameters. Collaborators are Dr. Mark Abbott (JPL and SIO), Dr. Ulf Heyman (1984 visitor from Uppsala), and Dr. Robert Owen, Southwest Fisheries Laboratory, NMFS, NOAA.

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

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

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

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

Over the past two years, our studies suggest that we can determine light saturated photosynthetic rates (Pmax) and I_k values using this technique. We have demonstrated the functional relationship between photosynthesis and fluorescence in several species of phytoplankton and discovered some differences with the predicted relationship at low irradiance levels. Our initial results are published (Falkowski et al., 1984) and two additional manuscripts are submitted. These studies have encouraged us to begin development in FY85 of a prototype double flash fluorometer which can be mounted on a CTD water column profiler.

SCATTEROMETRY STUDIES

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

Specific Objectives: (1) Model the interactions between centimetric ocean waves and both the wind and the long wave field. Specific emphasis is placed on determining the directional distribution of the centimetric waves relative to the mean wind (collaboration with G. T. Csanady of Woods Hole). (2) Calculation of the 2-d wavenumber spectrum of surface winds on scales from 200-2200 km, using the SASS unambiguous vector wind data set of Woiceshyn et al. (collaboration with D. B. Chelton of Oregon State).

Approach: (1) A realistic model for direct momentum and energy input from winds to short waves is being developed (Csanady) based on recent laboratory measurements of vorticity and water velocity under growing and decaying wind waves. The theory for 3-d instability of short gravity waves is being extended, both to determine the rate of energy transfers due to wave-wave interactions and to determine the directional distributions of centimetric waves associated with 3-d crescentic gravity waves. (2) The initial study of wavenumber spectra of winds concentrates on four regions in the Pacific. Within SASS swaths, vector winds are decomposed into zonal and meridional components, interpolated onto a fixed grid, and Fourier-transformed in the along-track direction. Two-dimensional turbulence models, if valid, can be used to infer properties of 2-d isotropic spectra from 1-d spectral results. Certain 1-d results can also be used to test the validity of the turbulence models.

Status: (1) A model for wind input to short waves, including details of airflow separation and reattachment, is being prepared for publication (Csanady). (2) Results of the wavenumber study in the Pacific have been submitted for publication. 1-d spectra have $k^{-2.2}$ dependence in midlatitudes, $k^{-1.9}$ dependence in tropical regions. Analysis of 1-d cross-spectra indicates that assumptions of 2-d turbulence theories are not uniformly valid for near-surface winds. Significant divergence was found in the northern hemisphere, and tropical winds on these scales are probably anisotropic.

OCEAN CIRCULATION FROM SATELLITE ALTIMETRY

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

Specific Objectives: (1) Application of Seasat altimeter data to the detection of large-scale temporal variability of the Antarctic Circumpolar Current (ACC). (2) Comparison of sea level observations made by the Seasat altimeter with tide and bottom-pressure gauges in the tropic Pacific. (3) Detection of the seasonal and interannual variations of the Gulf Stream using Geos-3 altimeter data.

Approach: Arrays of sea level time series are constructed at locations where the satellite ground track intersections (crossovers) are clustered. The procedure involves least-squares optimization for both orbit error reduction and time series estimation.

Status: (1) The results of the Seasat ACC studies are described in Fu and Chelton (1984, 1985). (2) Sea level data in the tropic Pacific have been acquired from Doug Luther (co-investigator) of the Scripps Institution of Oceanography. Comparison with Seasat altimetry is in progress. (3) Jorge Vazquez has been working with me on the Geos-3 data, whose relatively poor quality requires more effort to reduce the data.

MASS, HEAT, AND SALT FLUXES IN THE OCEAN

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

Specific Objectives: Estimation of the meridional mass, heat, and salt fluxes in the South Indian Ocean and the North Pacific Ocean using existing hydrographic sections.

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

Status: Six hydrographic sections in the South Indian Ocean has been acquired and processed for inverse calculations. One of them is in the Timor Sea, allowing an assessment of the effects of the Pacific-Indian Ocean through flow rate on the circulation and property budgets of the Indian Ocean, a problem of considerable recent interests. A manuscript on this study is in preparation. A single section along 35°N in the Pacific will be used to study the meridional fluxes there.

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

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

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

Approach: Acquire multispectral microwave radiometric data from airborne and spacecraft-based instruments during a major international field experiment in the Fram Stait/East Greenland Sea.

Current Status: During the past year, we served as Mission Scientist and Principal Investigator, respectively, for the NASA CV-990 Airborne Laboratory on its June/July mission to overfly the Fram Strait/East Greenland Sea MIZ during MIZEX'84. The data flights were coordinated with overpasses of the Nimbus-7 satellite, and with measurement of sea ice properties at the surface. There were also coordinated flights with the NRL P3, NOAA P3, Canadian CV580, and the French B-17 during the overlap portions of their respective missions. Processing to produce calibrated microwave radiance data tapes from the raw data acquired on board the CV-990 is presently underway. Analysis of the real-time data acquired during the mission and uncalibrated data stored on tape has served to indicate the mission was over 90% successful. These results have been submitted to the MIZEX Executive Committee in the Platform Data Report, published in a recent MIZEX Bulletin, and presented in a paper at the IGARSS'84 meeting at Strasbourg.

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

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

Specific Investigation Objectives: (a) study the seasonal variability of the phytoplankton pigment concentration; and (b) attempt to compute the net sources of phytoplankton pigments from observations of color and thermal imagery on successive 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: To assemble seasonal time series, several problems have had to be overcome. These include development of a good sensor calibration history, incorporation of more complex physics in the atmospheric correction procedures, and of course, acquisition of the data in question. Sufficient progress has been made on these problems to produce a time series of temperature and phytoplankton for the WCRE study area covering the period 14 April to 8 May 1982. This series clearly delineates the seasonal warming and the "spring bloom," revealing comparable flowering in the Shelf and Slope waters. Attempts to generalize this short time series to a longer interval are underway.

RADAR SCATTERING FROM THE OCEAN SURFACE: A VARIATIONAL APPROACH

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

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

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

Current Status: A paper has been accepted for publication describing a test-model analysis of Kirchhoffean trial functions. Improved trial functions have subsequently been developed. Using the latter, the variational solution has been completed for the horizontally polarized e.m. field scattered by a perfectly conducting, single-sinusoid surface, and preparation of a paper is in progress. The variational result has been shown analytically to agree with exact values for a variety of known limiting cases, including low-frequency and high-frequency limits. Numerical studies are in progress to evaluate the results for intermediate regimes of the scattering parameters.

MICROWAVE EMISSION FROM POLAR SURFACES

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Long Term Interests: Passive microwave remote sensing imagery has demonstrated its ability to provide time dependent sea ice concentrations and ice type distributions to useful levels of accuracy for many situations. Our long-term interest is to determine how these images can be used most effectively to investigate the large scale structure of sea ice.

Objectives & Approach: Our present objective is to see how well multifrequency data can distinguish among sea ice types and variations in surface conditions throughout the year in different parts of the Arctic Basin. For this purpose we make surface based measurements of emissivity at 5 frequencies fom 6.7 to 90 GHz together with concurrent determinations of the important physical properties of the upper layers of the ice.

Current Status: Our principal activities during the past year include participation in the first stage of the CRREL ice tank experiment (Dec 83 through March 84) and in the Greenland Sea MIZEX (May through July 84). We added the final radiometer to our set (a C-Band instrument at 6.7 GHz). We also constructed a simple apparatus to measure the free water content of snow and ice which was used successfully during MIZEX 84.

At CRREL, we studied in detail a full growth cycle from initial formation through to final melting stages. During MIZEX, we operated from the drifting ship and covered the end of the cold season through the onset of summer melting. Special effort was made to compare emissivities over the full range of free water content and ice types encountered.

The results from our experiment at Tuktoyaktuk over first-year ice have been analyzed and submitted for publication. We found a pronounced dependence of T_B on snow thickness which varied with frequency as well as a correlation between brightness temperature and most of near surface salinity. These effects appear to explain most of the spatial variations in T_B for the ice conditions under study. This work is sponsored jointly with the Office of Naval Research under 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: Using the JPL ATMOS library of spectral line parameters and an empirical model of the water vapor absorption continuum, line by line atmospheric transmission calculations in the 8-13 micron waveband have been made for a wide range of water vapor and temperature conditions. The calculations have shown that a major source of uncertainty in satellite SST retrievals relates to the non-linear extinction of the water vapor absorption continuum. Models of the attenuation of the surface radiance due primarily to the absorption by water vapor will be tested with a set of experimental measurements that are based on the use of a new downward-looking infrared radiometer. Aircraft observations will yield synoptic vertical profiles of the outgoing radiance, water vapor and air and sea temperatures. The incorporation of these data into the model response is intended to lead to more effective evaluations and testing of atmospheric correction techniques, such as the multiple-wavelength and multiple- angle methods.

Current Status: A new high-precision radiometer, which is based on the use of an objective star wheel chopper, has been built and calibrated. The conceptual aircraft measurement plan will be tried in the spring of 1985.

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) 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;

(ii) a paper on the effects of episodes of equatorial westerly wind (lasting a few days) in the central Pacific on SST in the eastern Pacific is in preparation; the "bursts" appear to be involved in the onset of El Nino events in the ocean. Other typical modeling studies are under way;

(iii) a paper on the character of the thermocline and deep mean circulation in eddy-resolving ocean models has been submitted for publication;

(iv) a paper on the apparent mid-latitude origin of the winds that triggered off the '82-'83 El Nino in the ocean has appeared in "Science";

(v) a paper on the parameterization of the net long wave radiation at the ocean surface appeared.

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 and from the National Oceanic and Atmospheric Administration.

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 (separately and in combination with passive ocean color systems) to advance the development and 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 (such as phycoerythrin) by measuring integrated laser induced fluorescence (LIF) with a calibrated airborne laser fluorosensor. Data have been obtained during four separate overflights of the multi-institutional Shelf Edge Exchange Processes (SEEP) experiment in the New York Bight, as well as the previous Warm Core Ring (WCR) flights. This year (FY 85), additional LIF and passive ocean color data will be obtained with the AOL in the cooperative Spring Recovery Experiment (SPREX), a Department of Energy sponsored program involving Skidaway Institute of Oceanography, University of Miami, University of Georgia, and Brookhaven National Laboratory. Analysis is aimed at the quantification of results from these missions, and the production of synoptic contour plots of LIF 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 goals of this task will be achieved through ongoing corroboration with participating scientists in the SPREX, SEEP, and WCR experiments. 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 deconvolution 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: An important recent result is the finding that the effect of wind on surface gravity waves changes their nonlinear behavior. The evolution of a nonlinear wave field is governed by a nonlinear Schrodinger equation, which predicts wave modulations and the generation of wave groups and side bands. Laboratory experiments in the wind-wave tank at the Wallops Flight Facility have revealed that wind stress inhibits wave packet formation. This result established that the importance of wind in wave studies is not limited to the generating stage. Further theoretical and experimental work on sea surface fluxes and wave progagation is planned for the next year.

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

Current status: As the funding prospects for a Shuttle experiment are bleak (so this investigator has been advised), no work toward the end of defining such an experiment has been done this year. Instead, work has concentrated on tasks b) and c) and the publication of scientific results. The Fall '78 mission validation results have been published in two papers appearing in the J. Geophys. Res. (Jan., 1985). The hindcast study with V. Cardone is complete and a paper is being prepared for journal publication. The results, based on ROWS and buoy data and three hindcast runs, indicate that the wave models perform well for the integrated properties of the spectrum but may contain serious directional errors. Particularly, the directional response in rapidly varying wind fields is too rapid, and the models tend to place too much energy into the local wind direction. The MASEX fetch-limited data and SCR intercomparison data obtained in MASEX are processed; these results are in the queue for publishing. The MASEX altimeter mode mean square slope (MSS) data have been integrated with existing aircraft and satellite data sets. A consistent picture of the Ku-band MSS behavior emerges showing the MSS to be approximately linear on u-star and manifestly related to the drag coefficient. We expect to build on this data set in the FASINEX experiment. The Chile SIR-B underflight mission with the SCR and other NASA P-3 instruments in October, 1984 was successful. Good agreement has been found between the ROWS and SCR and basically, also, with SIR-B for the spectra of swell systems of 300-400 m wavelength.

Other funding: The Office of Naval Research funded the NASA-P3 underflights of SIR-B.

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 euphotic 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/or 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, and statistically analyzed using polynominal 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, all NODC ocean areas have been analyzed. Refined tables of all statistical analyses are stored on computer disk. World maps of selected variables including r^2 values for the cubic regressions and contour world maps of the temperature and sigma-t values at which nitrate, phosphate and silicic acid are no longer measureable have been generated.

AIR-SEA INTERACTION STUDIES

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Long term interests: Our aim is to provide statistically dependable information on the intrinsic properties of gravity-capillary waves in the presence of gravity waves and a wind field. Implications of the results will be investigated from points of view of air-sea interaction studies and microwave remote sensing.

Objectives of this specific research: Our objectives were to develop the techniques for obtaining the wavenumber spectrum of short water waves from temporal measurements of the wave heights; evaluating the modulation of short-wave amplitude by long waves and wind speed (stress); and to apply them to data collected in a natural environment. Breaking waves were studied separately.

Approach: Surface roughness can best be described by wave number spectrum of short waves. For this purpose, we measured wave heights and calculated frequency spectra of short waves. These can be converted to wavenumber spectra by accounting for the Doppler frequency shift that short waves experience. By calculating spectra from segments of data, much shorter than the long-wave period, a time series of spectra can be constructed. The variations in short wave amplitude along the long-wave phase yield the modulation transfer function. Surface roughness, obtained by averaging the results over a long period of time, can be correlated with measured friction velocity to study its dependence on wind speed (stress). The breaking waves also contribute to the surface roughness. However, since breaking results in turbulent patches rather than freely moving waves, they are excluded from these analyses by using a technique we have developed earlier.

Current status: The initial project is completed. The analysis techniques were developed and applied to a limited range of data (covering wind speeds from 2.7 to 6.1 m/s). It was found that in this range of wind speeds spectral amplitudes of short waves increase by a factor of 10. The short-wave amplitudes are modulated by underlying long waves. Maximum modulation occurs in the crest region and decreases with increasing wind speed.

This project was jointly sponsored by the Office of Naval Research.

STUDIES OF MIDLATITUDE CYCLONE STRUCTURE WITH SEASAT SCANNING MULTICHANNEL MICROWAVE RADIOMETER

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Long Term Interest. Our aim is to investigate mesoscale structure and dynamics of midlatitude oceanic cyclones using satellite derived atmospheric water parameters.

Objectives. Our objectives were to examine the Scanning Multichannel Microwave Radiometer (SMMR) derived atmospheric water parameters for many storms that formed in different oceans, and to develop methods to use SMMR products to calculate dynamical parameters.

Approach. The parameters obtained from SMMR are integrated water vapor, integrated liquid water and rain rate. With these we have compared storms that formed in different seasons and oceans to find similarities and differences in water vapor and rain structure. Then, with the Seasat Scatterometer, which measures wind speed and direction at the ocean surface, and SMMR we are developing several methods to calculate vertical velocity and moisture convergence. We are currently concentrating on the storm that damaged the ocean liner, Queen Elizabeth II (the "QEII" storm).

Current Status. The results from comparing storms in different regions are as follows: 1) Generally, integrated water vapor and rain rate patterns are similar to and support conclusions found in previous studies. 2) Absolute values of integrated water vapor have been found to be higher in regions of western boundary currents than in other regions (i.e. the Gulf Stream vs. the North Pacific). 3) Rain rates greater than 4 mm hr^{-1} affected water vapor retrievals in two overpasses causing the water vapor to be either much greater or much less than the surrounding values.

The results from the "QEII" storm are as follows: 1) Regions of convergence derived from the scatterometer are spatially correlated with regions of rainfall and higher integrated water vapor content. 2) Calculations of vertical velocity at 550 mb using an assumed vertical velocity profile and the scatterometer data are consistent with rainfall patterns from SMMR and results from other studies. Other methods of calculating vertical velocity and boundary layer moisture convergence are being explored.

STUDIES OF ATMOSPHERIC WATER CONTENT WITH THE NIMBUS 7 SCANNING MULTICHANNEL MICROWAVE RADIOMETER

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Long Term Interests: Exploration of the possibilities inherent in the distributions of atmospheric and oceanic parameters that a Scanning Multichannel Microwave Radiometer (SMMR) can provide.

Objectives: To use SMMR data to study structure of mid-latitude weather systems as they approach the Washington coast.

Approach: This project takes 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 was therefore possible.

Current Status: We examine the spatial relationship between the atmospheric water parameters obtained from SMMR and fronts in cyclones. Cold fronts are consistently located at the leading edge of the strongest gradient in integrated atmospheric water vapor. Using only 37 GHz brightness temperature in horizontal polarization for calculating rain rates, we can study mesoscale undulations in a front. We found no contamination by land, just one footprint, 30 km away from the coast. Rain rates are in reasonable agreement with raingauge measurements on the coast. Onset of rain agrees with timing found by advection of SMMR rain areas. The Nimbus 7 SMMR derived region of rain is also a very good indicator of frontal location.

Cloud liquid water content, which unfortunately has received very little *in situ* verification, exhibits patterns which are consistent with the patterns of frontal clouds and with the clouds in a shortwave trough.

FLUORESCENCE OF PHYTOPLANKTON PIGMENTS: KINETIC AND SPECTRAL STUDIES IN SUPPORT OF REMOTE SENSING

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This research includes both spectral and kinetic studies of the fluorescence of marine phytoplankton and their relationship to primary productivity required to interpret remotely-sensed data obtained from the phytoplankton community in the ocean.

A theoretical model was developed to describe the spectral shift of fluorescence emission expected as a result of internal reabsorption of primary excitation and the emitted light by the chloroplast and surrounding medium. Predicted emission spectra were compared to spectra measured from several species of phytoplankton grown at varying light levels. Assessment of the photoadaptive state of the algae based on the behavior of the efficiency factor for absorption is possible and reflects the sensitivity of the spectral shift of fluorescence with increasing reabsorption in the chloroplast.

We have also investigated the relationship of *in vivo* absorption and fluorescence excitation spectra to photoadaptive state. At low growth irradiances, the excitation of chlorophyll fluorescence by accessory pigments increased relative to the excitation by chlorophyll *a* itself. The effect of photoadaptation on the fluorescence excitation spectra can be as great or greater than taxonomic influence. Results indicate that the utility of compositional indices based on fluorescence properties to characterize field populations may be restricted -- especially when interpreting vertical profiles where the light gradient may be quite large.

During 1985, we will concentrate on development of an algorithm to relate remotely-sensed patterns of near-surface concentrations of chlorophyll *a* and sea-surface temperature to the primary production of the upper mixed layer. We will pursue our research on the contributions of detrital material to optical variability and the relationship between photosynthesis, photoadaptation, and spectral fluorescence.

REMOTE SENSING OF AIR-SEA EXCHANGES IN HEAT AND MOMENTUM

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

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

Approach: (1) To examine the distribution of water vapor in the atmosphere over oceans. (2) Using radiosonde reports from ocean stations, to seek a universal relation between the columnar water vapor measured by space-borne sensors and the surface level humidity required for calculation of ocean evaporation. (3) Using this relation, geophysical parameters measured by the SEASAT microwave radiometer (surface wind speed, sea surface temperature and columnar water vapor) will be combined to determine global distribution of latent heat flux. The accuracy of this technique will be evaluated with data from ship reports. (4) This technique will be applied to NIMBUS-SMMR observations to study the 1982 warming event in equatorial Pacific. (5) The possibility of relating latent heat flux directly to the radiance observed by microwave radiometers will be explored.

Current Status: In FY'84, the relation between columnar water vapor and surface level humidity was demonstrated in refereed publications and presented in a number of NATO and WCRP workshops. The proposed technique of measuring latent heat flux has been the main topic of discussion of the NASA Ocean Surface Energy Flux Science Working Group formed in FY'84. Historical radiosonde data from all ocean stations reported to WWW have been collected and the determination of a universal relation is in progress. Geophysical parameters determined from SEASAT and NIMBUS SMMR observations with different algorithms are being evaluated. The establishment of TOGAPAC Surface Energy Flux data Center to consolidate data required to study the interannual variability of tropical oceans and global atmosphere is being pursued.

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 10cm 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

Precision orbit computation techniques provide an important contribution to the development of accurate mean sea surface topography data. The results of recent NASA Geodynamics investigations in the area of the earth's gravity model, tracking station coordinates, and the reference coordinate system have been incorporated into the ocean topography analyses. Refined techniques for the computation of regional and global mean sea surfaces are being developed. Image processing techniques are being developed and applied for the interpretation of the mean sea surfaces.

Status

The global Seasat and Geos-3 altimeter data set have been analyzed for the computation of a global mean sea surface on a 0.25° grid. Our best estimates indicate that a precision of about 10-20 cm. has been achieved for wavelengths of a few thousand kilometers. A global, illuminated colored map of the mean sea surface has been produced using image processing techniques. Analyses of the mean sea surfaces in conjunction with the most accurate geoids available have produced dynamic topography maps which are in good agreement with the Levitus data.

STUDY ON GLOBAL OBSERVATIONS AND UNDERSTANDING OF THE GENERAL CIRCULATION OF THE OCEANS

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Study on Global Observations and Understanding of the General Circulation of the Oceans. The objectives of this study were (1) to determine whether we do indeed have the ability to obtain ocean data on a global scale that could profoundly change our understanding of the circulation; (2) to identify the primary and secondary elements needed to conduct a world ocean circulation experiment (WOCE); (3) if the ability is achievable, to determine what the U.S. role in such an experiment should be; and (4) to outline the steps necessary to assure that an appropriate program is conducted. To achieve the objectives of the study, a Steering Committee was appointed consisting of Carl I. Wunsch, Chairman, D. James Baker, Francis P. Bretherton, Wallace Broecker, James C. McWilliams, Worth D. Nowlin, Jr. and Ferris Webster. The Steering Committee organized a workshop held August 8-12, 1983 at the Woods Hole Study Center of the National Academy of Sciences, Woods Hole, Massachusetts. At the workshop, three working groups were organized to consider specific technical issues and present their findings at plenary sessions. The workshop participants agreed on this overall goal of the contribution to a World Ocean Circulation Experiment (WOCE): To understand the general circulation of the global ocean well enough to be able to predict ocean response and feedback to long-term changes in the atmosphere. (The three groups were (1) Water Masses and Their Exchanges; (2) Atmospheric-Ocean Exchange; and (3) Velocity Field. Each working group prepared a report of its findings.)

In order to meet that goal, a number of specific objectives were identified by the workshop. These specific objectives are as follows:

1. To complete a basic description of the present physical state of the ocean.
2. To improve the description of the atmospheric boundary conditions on the global ocean and to establish their uncertainties.
3. To describe the upper boundary layer of the ocean adequately for quantitative estimates of water mass tranformation.
4. To determine the role of interbasis exchanges in the global ocean circulation.
5. To determine the role of ocean heat transport and storage in the heat budget of the Earth.
6. To determine seasonal and interannual oceanic variability on a global scale and to estimate its consequences.

The report of the workshop <u>Global Observations and Understanding of the General Circulation of the Oceans: Proceedings of a Workshop</u>, was published in April 1984.

This study was jointly sponsored by the National Science Foundation and the National Aeronautics and Space Administration.

THE GLOBAL OCEAN FLUX STUDY

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The Board on Ocean Science and Policy of the National Research Council has designed a study to assess biogeochemical cycles of reactive elements, particularly as they relate to major climate trends and global ocean circulation. As part of this planning process, the Board sponsored a major workshop from September 10-14, 1984, at the National Academy of Sciences Study Center in Woods Hole, Massachusetts. The report "Global Ocean Flux Study - Proceedings of a Workshop" presents the results of that workshop.

The workshop focused on the following questions related to a Global Ocean Flux Study: (1) Do we have the potential to obtain ocean data on a global scale that could advance, in a major way, our understanding of the flux of critical chemical constituents? (2) What are the immediate and long-term objectives needed to achieve a Global Ocean Flux Study? (3) If these objectives are achievable, what is the U.S. role in such an international program? (4) What are the immediate steps necessary to ensure that an appropriate program can be conducted within the next decade?

By the end of the workshop, a consensus was reached that, indeed, a Global Ocean Flux study is not only feasible, but also valuable and timely. The overall objective of the study is to identify and quantify the physical, chemical, and biological processes controlling biogeochemical cycling in the ocean, and their interaction with the global atmosphere. The goal is to understand the processes governing the production and fate of biogenic materials in the sea well enough to predict their influences on, and responses to, global-scale perturbations.

This study was jointly sponsored by the National Science Foundation and the National Aeronautics and Space Administration.

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The Board on Ocean Science and Policy of the National Research Council addresses and reports on major ocean science and policy issues. The terms of reference of the Board are:

1. To contribute to the advancement of the scientific understanding of the ocean by the maintenance of a continuing oversight of the health of the ocean sciences and the stimulation of their progress.
2. To foster the application of scientific knowledge of the wise use of the ocean and its resources.
3. To provide leadership for the formulation of national and international marine policy and to clarify scientific issues that affect ocean policy; and,
4. To address marine science issues involved in cooperative international oceanographic research and to improve technical assistance.

The Board serves as the NRC focal point for the consideration of ocean issues and identifies, considers, and conducts studies on appropriate science and policy issues as well as respond to specific requests from federal agencies and private foundations. To perform specific tasks and to respond to requests, ad hoc or standing committees are established. In addition, the Board serves as the U.S. National Committee to the Scientific Committee on Oceanic Research (SCOR) of the International Council of Scientific Unions.

In 1984, the Board produced the following reports:

<u>Case Studies for the Workshop on the Effects of Human Activity on the Coastal Ocean</u>, Board on Ocean Science and Policy, (January) 1984

<u>Global Observations and Understanding of the General Circulation of the Oceans, Proceedings of a Workshop</u>, National Academy Press, (March) 1984

<u>Deep Seabed Stable Reference Areas</u>, National Academy Press, Washington, D.C., (June) 1984

<u>Disposal of Industrial and Domestic Wastes: Land and Sea Alternatives</u>, National Academy Press, Washington, D.C., (August) 1984.

<u>An Assessment of the Oceanographic Program of the Department of Energy</u>, National Academy Press, Washington, D.C., (August) 1984.

<u>Global Ocean Flux Study - Proceedings of a Workshop</u>, National Academy Press, Washington, D.C., (December) 1984.

The Board is sponsored by the National Oceanic and Atmospheric Administration, the National Science Foundation, the Office of Naval Research, the U.S. Geological Survey, the Minerals Management Service of the Department of Interior, the U.S. Coast Guard, the Department of State, the Department of Energy, the Environmental Protection Agency, and the National Aeronautics and Space Administration.

INVESTIGATIONS OF MESOSCALE PHYSICAL AND BIOLOGICAL OCEANIC PROCESSES

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

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

APPROACH: In order to study a number of oceanic systems, collaborations with ongoing multidisciplinary field programs have been initiated. These include studies in the South Atlantic and Middle Atlantic Bights of the eastern U. S. continental shelf, the Gulf of Mexico, N. W. Spain*, the eastern tropical Pacific Ocean and the Adriatic Sea. Whenever possible, CZCS and AVHRR data are collected during cruises in order to tie the imagery to high quality *in situ* measurements for interpretation. In order to understand variability on seasonal and interannual time scales, time series of images are selected from the archive, processed and composited into seasonal mean and variance fields.

CURRENT STATUS: Some initial studies have been published (McClain, *et al.*, 1984 and Feldman, *et al.*, 1984) which describe the biological response to individual forcing events. The processing and interpretation of time series for the South Atlantic Bight, the Adriatic Sea and the eastern tropical Pacific Ocean are in various stages of completion. The eastern tropical Pacific Ocean data set was processed by G. Feldman (SUNY/Stony Brook) for his dissertation research under the NASA Graduate Student Researcher Program. The Adriatic Sea time series is being analyzed by V. Barale who is currently a graduate student at Scripps Institute of Oceanography.

*Partially supported by the Department of State.

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

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

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

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

Status and Progress: Eight island stations are installed and operating: Christmas, Ponape, Tarawa, Majuro, Nauru, Honiara, Rabaul, and a test system in Honolulu. Sea level, temperature and system parameters are monitored. Hardware and software was developed (in-house and in conjunction with manufacturers) to sense and encode the data, up-link to satellite, access and record the returned data and distribute it to users. Techniques, personnel and procedures were developed for installing and maintaining these stations at remote island sites. An FM link has been developed, field tested and is now ready to take measurements at sensing sub-stations and telemeter them to a central up-link. Dr. Wyrtki's tide gauges have been interfaced at each site, providing data routinely. The Pacific Marine Environmental Laboratory has contracted to utilize our capabilities, and the Pacific Tsunami Warning center is receiving information from two of our stations in a combined effort.

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

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During the past year, the Microwave Remote Sensing Laboratory (MIRSL) at the University of Massachusetts continued studying the feasibility of ocean surface current measurements using multifrequency, coherent radars. The long term objective of this study is to determine if multifrequency radars mounted on a geostationary satellite platform can accurately determine ocean surface currents over large areas of ocean.

We have recently published results that show that radar systems can be developed to measure ocean currents if the cross product power spectrum formed by scattered signals at different wavelengths consistently displays a resonant peak that provides the necessary Doppler frequency-shift information. Although recent field-test measurements made at the Naval Research Laboratory are encouraging, additional measurements made for a wider variety of surface conditions are needed before the prognosis for this technique is clear.

During the coming months, the MIRSL will complete development of a multifrequency C-Band radar, which will be used to make land-based measurements. Preliminary measurements will be made during the fall at either North Truro, Cape Cod, MA or Camden, ME. The field tests will allow us to determine the consistancy of the radar to measure surface currents over a wide variety of weather conditions.

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 a meeting on future developments and uses of deep drifters in the ocean, the initiation of the design of the FLUX Drifter System with K. Prada and K. Peal of WHOI, the continuing coordination of Lagrangian, thermistor, and meteorological buoy systems developments, and the further development of scientific plans for the use of various drifters in WOCE, TOGA, and the Ocean STORMS experiments.

This work is jointly sponsored with NOAA and ONR.

ADVANCED RADIO TRACKING SYSTEM (ARTS)

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Long-Term Interest: To develop a GPS-based (Global Positioning System) tracking system for high precision earth orbiter navigation applications.

Specific Objectives: To conduct systems analyses and definition studies of the GPS-based tracking system concept, to design and build two prototype high precision GPS receivers, and to conduct a limited technology validation demonstration of the concept through a series of baseline recovery experiments.

Approach: The tracking system concept entails the concurrent tracking of all visible GPS satellites by a global network of GPS receivers and by a receiver aboard the user spacecraft (e.g., TOPEX).. The data streams are transported to a central ground site where high accuracy positions (e.g., subdecimeter in altitude) of the user satellite are obtained. In FY'82 we began the development of two high precision GPS receivers known as SERIES-X. Construction was completed in FY'83 and a geodetic meaurement campaign was begun in May 1983 and completed in March 1984. A series of experiments was conducted in which the baseline vector between the phase centers of the antennas was determined from observations of the GPS constellation. These vectors were compared with independent determinations obtained from ground surveys and VLBI. The campaign included five regimes of baseline lengths: zero length (one antenna, two receivers), 15m, 150m, 22km, and 171km. These experiments tested different critical system elements as a function of length. The short baseline tests were used to debug and evaluate receiver performance, e.g., SNR, multipath, phase integrity, precision and accuracy. The longer baselines provided performance data where environmental factors are dominant, e.g., differential tropospheric and ionospheric effects. The longest baselines showed the effects of GPS ephemeris errors.

Status: The SERIES-X campaign was highly successful. The 150m tests demonstrated repeatability of the baseline determinations at the 2mm level and agreement with a ground survey at the 5mm level. The physical location of the phase centers within the antennas is unknown to about 5mm. On the 22km baseline the repeatability was subcentimeter and the agreement with the VLBI/survey was 4cm. On the 171km baseline the length determination agreed with a series of VLBI determinations to 2cm with an RMS of 4cm. The transverse components differed by 1-2 decimeters because of incompatibilities between the GPS and VLBI coordinate frames. At the conclusion of these tests it was proposed that (1) a GPS receiver be developed for flight on the planned TOPEX mission, (2) a ground network be concommitantly developed and deployed and (3) a demonstration of the performance of this tracking system be mounted during the TOPEX mission as a flight experiment. This experiment is currently included in the baseline TOPEX mission plan.

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 were to study the effects of iron and manganese on fluorescence excitation spectra of phytoplankters from various taxonomic groups and environments of the open ocean and to predict trace metal effects on natural communities, especially as these effects account for differences in eutrophic and oligotrophic waters, and to determine the effects of these metals on spectra as perceived by remote sensing.

The approach has been to evaluate the role of the trace metal nutrients, iron and manganese, on photosynthesis, fluorescence excitation spectra, growth rates, and trace metal quotas. The correlation of specific spectral changes with specific physiological changes should provide insight into factors governing distribution, biomass and spectral properties of phytoplankton. The comparison of physiological spectral alterations with taxonomic spectral alterations should be useful in interpreting remotely-sensed chlorophyll data.

The three-year study has been completed. It is clear that manganese and iron can limit phytoplankton distributions. The relationship between chlorophyll content and chlorophyll fluorescence is a function of trace metal nutrition in all major phytoplankton taxa. 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. The magnitude of the effect of iron or manganese starvation on fluorescence intensity is similar to that observed by others for nitrogen starvation and less than the magnitude of the "taxonomic" effect, the differences in intensity attributable to taxonomic affinity. Thus, a remotely-sensed increase in fluorescence could be due to any combination of 1) and increase in biomass, with or without a concomitant increase in primary productivity, 2) the presence of a stress such as nutritional deficiency causing an increase in fluorescence per unit pigment, with or without a decrease in primary productivity, or 3) a change in the taxonomic makeup of the community, which may not be accompanied by a change in primary productivity.

MICROWAVE REMOTE SENSING OF OCEANOGRAPHIC PARAMETERS

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

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

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

Current Status: Analysis of the tropical Pacific SMMR data sets has shown the ability of the SMMR to observe interrelated changes in sea surface temperature, wind speed, water vapor, and cloud liquid water during a major geophysical event such as the 1982 El Nino. Analysis is underway to determine if the accuracies are sufficient for air-sea interaction modeling studies. Three workshops have been held to involve remote sensing scientists and oceanographers in planning future research and instrumentation for sea surface temperature measurements. A further workshop is planned for May 1985. The findings have been documented in a series of workshop reports.

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 have been 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 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. Steepening and strengthening of vortices is provided by the nonlinear terms. Ms. Sirpa Hakkinen completed her Ph.D. and will join NASA Goddard.

INVESTIGATION OF THE PROPERTIES OF RADAR BACKSCATTER FROM SEA 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 best parameters for radar remote sensors and develop techniques to facilitate automatic analysis of ice images. 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: Current work has concentrated on ice and ocean in the East Greenland Marginal Ice Zone (MIZ) under early and middle summer melt conditions, as well as a controlled study of the microwave properties of artificial sea ice. This work will improve our knowledge of the relation of radar signatures to ice and ocean properties such as ice concentration, ice type distributions, ice floe roughness, state of the ice sheet and snowpack, and presence of ocean eddies and fronts. During MIZEX, radar backscatter and physical property measurements were coordinated with the active-and-passive microwave aircraft and surface measurement programs. Data were acquired, using the University of Kansas helicopter-borne scatterometer (a calibrated radar) at 5.2, 9.6, 13.6 and 16.6 GHz, at multiple angles from 0° to 70°, with VV, HH and HV transmit-receive polarizations. In addition, a calibrated radar operating at 1.5 GHz and HH-polarization installed on the icebreaker "Polarstern" used viewing angles ranging from 17° to 50°. Sites investigated included small-to-vast first-year, thick first-year and multiyear sea ice floes which were visually representative of ice types in the MIZ and pack ice region. Ice thicknesses ranged from 30 to well over 300 cm, with up to 60 cm of snow on multiyear ice floes. During the experiment the snowpack and ice sheets underwent a transition from early-summer to summer-melt conditions. Auxiliary measurements, to assist in the study of the radar altimeter response to sea ice and ocean, were made with a vertical look angle at 5.2 and 13.6 GHz. Transects were flown to study the relationship between radar response and ocean phenomena such as fronts at the leading ice edge and eddies, as well as the relation between the radar response and ice concentration. General ice condition descriptions, oblique photography and detailed descriptions of snowpack were made in support of near-surface and aircraft observations.

Saline ice grown under somewhat controlled conditions at the U.S. Army Cold Regions Research and Engineering Laboratory has also been under study. This is a program which also involves the Universities of Massachusetts and Washington, MIT and CRREL. Backscatter measurements have been made on ice ranging in thickness from 0 to 30 cm for angles from vertical to 50° at 5.2, 9.6, 13.6 and 16.6 GHz. Antenna polarizations include VV, HH and cross. In addition, penetration depth measurements were made.

STATUS: This year's field- and lab-operations have successfully been completed. We are in the midst of considerable data processing and analysis. A summary of recent MIZ (1983) results is given in the Proceedings of the IGARSS'84 Symposium, Strassbourg, France, 27-30 August 1984. In succeeding years, additional observations will be needed in the MIZ at other seasons, as well as additional late-summer and early-fall measurements in all regions.

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

TIME DEPENDENT ALTIMETER STUDIES

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

Specific Objectives:

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

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

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

(4) 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. The Somalia eddy off Somalia is being studied. Also the Gulf Stream recirculation using a combination of Seasat and Geos data.

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. Global crossover data show an essentially equal improvement regardless of which of the above models is included.

The University of Texas doppler orbit has been recieved for the locked orbit period of Seasat, and included in an altimeter data set. If the accuracy is as thought, simple analysis of this data should show the largest variations of the deep water tide.

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. Unfortunately, this does not seem to be the answer.

Northern Hemisphere Sea Ice from Passive Microwave Observations

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

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

Approach: The basic approach consists of three steps--data reduction, data compilation and plotting, and data analysis. (1) Data gaps, if small, are eliminated by spatial and temporal interpolation; an apparent 1976 calibration shift in the ESMR instrument is being adjusted for; and the satellite brightness temperatures are being normalized and converted to sea ice concentrations. (2) The data are being compiled and plotted into various data products, such as mapped monthly average ice concentrations and time sequence plots of ice area. The plots are produced for both the full north polar region and for each of eight subregions. (3) The images and plots from #2 are used to analyze the Northern Hemisphere sea ice cover, on a regional and hemispheric basis, after which the images, plots, and analysis will be combined into an Arctic sea ice atlas.

Current Status: Techniques have been devised and implemented to account for missing data and land contaminated pixels; regions for analysis have been determined and mapped; the ESMR data have been accumulated into the desired averages; and most of the color-coded images have been generated, including monthly and yearly average brightness temperatures and ice concentrations, monthly ice concentration differences, and four-year monthly averages. About half the desired time sequence plots have been created, including, for each of the eight regions and for the Northern Hemisphere as a whole, the ocean area covered by ice of concentration exceeding 15%, 35%, 50%, 65%, and 85%, plus the integrated ice area; and the ocean area covered by ice in various concentration classes. All the images and plots still have to be drafted into final form. An introduction (Chapter 1) to the planned volume has been written, as has a preliminary draft of Chapter 2 describing aspects of the relevant oceanography and meteorology. The detailed analysis of the mapped images and time sequence plots is beginning.

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 use of these microwave observations.

Specific Objectives: (1) Complete the development of an end-to-end altimeter simulator system in support of the ongoing altimeter program. (2) Continue studies of new microwave techniques for application to long range program needs. (3) Continue the development and use of microwave sensing systems in the research wave tank facility.

Approach: To use existing altimeter data and error budget information as bases for the development of new system concepts; long range program needs will be used for setting priorities when choosing between competing techniques. The key elements of this comprehensive instrument development activity are theoretical study, computer simulations, wavetank investigations, laboratory breadboard systems, aircraft system testing and experimentation, and eventually Shuttle experimentation. The approach of establishing a sound theoretical basis, then simulating and laboratory testing, and finally field or flight testing is most economical.

Current Status: In FY 1984, the altimeter simulator was completed and documented. It is expected to provide an invaluable analysis capability for TOPEX and GEOSAT work in the future. A study of the backscattering cross-section of wind-roughened water surfaces at 13.9 and 5.3 GHz was finished. The C-band results were needed in the link equations for the TOPEX C-band channel, and the Ku-band data were in good agreement with published results in the literature. The development of a solid-state transmitter at Ku-band suitable for space flight use was began. A single transmitter module will be manufactured and evaluated. Finally, after several years of study, the decision was made to develop multi-beam altimetry as the next significant altimetry design improvement. A study with NASA Langley Research Center (LaRC) in FY 1984 proved that an interfer-ometric multiple beam concept can work on Shuttle using the LaRC 15m deployable hoop/column antenna. Other studies have shown that an even larger antenna could be erected in space for use with a real-aperture multibeam altimeter. A plan towards the eventual flight of one of these concepts is being prepared in FY 1985.

OCEANOGRAPHIC AND METEOROLOGICAL RESEARCH BASED ON THE DATA PRODUCTS OF SEASAT

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Long Term Interests: (1) To contribute toward improved numerical computer- based weather, ocean circulation and ocean wave predictions and toward an improved scatterometer design for N-ROSS using the SASS data. (2) To show that the viscosity of sea water, which depends on water temperature, needs to be considered in an improved model function. (3) To demonstrate that niether u_* nor $\bar{U}(19.5)$ is the best parameter to define the physics associated with backscatter and derive an improved model function from first principles starting with properties of the waves. And (4) to study the errors of conventional wind measurements.

Objectives of Present Research: (1) To revise and extend the work of Donelan and Pierson so as to obtain a new model function and to verify it against SASS data. (2) To discover inconsistancies in the SASS-1 model function not explainable by the use of the incorrect SOS algorithm. (3) To compare two new recently proposed model functions with each other and with SASS-1. (Completed report in preparation).

Approach: For (1), to work closely with M. Donelan in refining a first effort, (distributed as a C.C.I.W. report). For (2), to develop new ways to study the SASS backscatter data independently of the model function. For (3), the study is well along as supported mostly by NOAA.

Current Status: Three Contractor's Reports, rather too long and too expensive to publish in a journal, were completed by W. Sylvester (NASA CR 3799), who studied the errors introduced by a ± 3 hour data window in tracking cyclones with the SASS, by Pierson, et al. (NASA CR 3810) who extended the concept of a superobservation so as to include sampling variability and derive wind stress, wind stress curl and vertical velocity fields (with error estimates), and by Pierson (NASA CR 3839) who showed that, if the power law assumption was correct, much better winds could have been recovered if a correct theory for the PDF of the backscatter measurements had been used. Copies are available from the above address.

COMMITTEE ON CLIMATIC CHANGES AND THE OCEAN

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The Committee on Climatic Changes and the Ocean (CCCO) is sponsored jointly by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the Scientific Committee on Oceanic Research (SCOR) of the International Council of Scientific Unions, (ICSU). It works in cooperation with the Joint Scientific Committee (JSC) of the World Meteorological Organization (WMO) and ICSU. Together with JSC, the CCCO is responsible for planning oceanic aspects of the World Climate Research Program. Because of their great heat capacity and sluggish motions, the oceans respond slowly to changes in environmental conditions. Consequently the possibility of prediction of climatic variation from season to season and from year to year may depend on measurements of ocean properties and motions. On a longer time scale, climatic changes over decades and centuries are profoundly affected by the concentrations of carbon dioxide in the atmosphere, and these in turn depend in part on carbon dioxide exchange processes between the ocean and the atmosphere and within the ocean itself.

The CCCO has initiated two major ocean studies--TOGA AND WOCE. TOGA is concerned with the effects on the global atmosphere of variability in the tropical oceans, as manifested in the Southern Oscillation of air pressures over the Pacific Ocean, the phenomena of El Nino, and variations in the monsoon over the Indian Ocean. WOCE, (World Ocean Circulation Experiment) is concerned with the global ocean circulation and the transformation of water masses. In both programs ocean-observing satellites will play an essential role. The satellite observations must be supplemented and calibrated by ocean surface and subsurface measurements from research vessels, drifting and anchored buoys, ships of opportunity, and fixed observatories for measuring sea level on islands and coasts. The CCCO is also investigating a program for measuring dissolved carbon dioxide and particulate organic carbon in ocean waters.

Climatic prediction will depend upon the development of interactive ocean-atmosphere models which simulate the circulation and properties of the two great earth fluids. These models must be based on global synoptic observation of the kind being taken under TOGA and WOCE. The CCCO does its work through a series of international panels for its different projects in addition to panels for each of the three major oceans and panels on ocean-atmosphere modeling, paleoclimatology, and impacts of climate on ocean biology. It has held a series of international workshops on special problems such as ocean time series, satellite oceanography, and ocean observing systems.

CCCO held its sixth session in Washington, 27 November to 4 December 1984. It sponsored an international scientific conference on TOGA in Paris in September 1984, attended by representatives of 35 countries. An office for the TOGA program has been set up in Boulder, Colorado, and an office for WOCE in Great Britain. The CCCO also encourages and monitors national and multilateral programs in climatic research such as the "Sections" program of the Soviet Union, East Germany and Poland. This work is jointly supported by the National Science Foundation and the National Ocean and Atmospheric Administration, as well as the National Aeronautics and Space Administration, IOC and SCOR.

INVESTIGATION OF THE DYNAMICS OF THE NORTHERN ADRIATIC SEA THROUGH CZCS SATELLITE IMAGERY

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Long-Term Interests relevant to the project are: i) To analyze an extensive series of CZCS images of the Northern Adriatic Sea; ii) to carry out advection-diffusion experiments with an available numerical model of the Northern Adriatic circulation; iii) to use the relevant satellite fields for initialization-assimilation studies with the model.

Objectives of this Research Task. i) To understand the dynamical differences in the driving mechanisms of the seasonal circulation in the Northern Adriatic during different seasons; ii) to improve model performances and realism through assimilation of satellite derived data.

Approach. i) Traditional analysis of CZCS imagery. ii) Evaluation of the statistical properties of the satellite images. iii) Use of a multi-level numerical model for the Northern Adriatic Sea which has active thermodynamics and includes an advection-diffusion equation for a passive tracer (Malanotte-Rizzoli and Bergamasco, 1983).

Current Status. 27 CZCS images of the Northern Adriatic for the years 1978-79-80 have been thoroughly analyzed. For 11 of them simultaneous sea truth data were collected by Italian institutions and made available to the project. A quantification has been carried out of the statistical properties of the surface fields evaluating from the satellite data: i) basic moments: seasonal mean and variance maps for the available years; ii) a classification of the different water masses and their areal extension (histogram algorithms). The evaluation of the Empirical Orthogonal Functions of the surface seasonal fields has begun and is now in progress. A first qualitative study has been made of the analyzed imagery correlating the results with the known phenomenological properties of the Northern Adriatic. The known difference between the winter and summer patterns emerged clearly from the imagery. The winter average situation is dominated by warmer open sea waters spreading from the south along the Yugoslavian (eastern) coast. A much colder water mass is seen to protrude from the northernmost end of the basin into the interior. This feature is probably associated with the deep water formation events occurring in winter in the Northern Adriatic (Hendershott and Malanotte-Rizzoli, 1976). The summer average situation is on the other side dominated by the Po River plume which spreads in cross-basin direction occupying most of the northern part of the basin. Interannual variability of the plume spreading is also important and the (speculated) existence of a local sub-gyre produced by the plume seems to be confirmed by the analyzed imagery. Advection-diffusion experiments with the numerical circulation model have already started in the two-level version corresponding to the summer circulation.

TOPEX RADAR ALTIMETER

ADVANCED TECHNOLOGY MODEL

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Long Term Interests: To participate with the Jet Propulsion Laboratory (JPL) in the Ocean Topography Experiment (TOPEX) Mission, through initial project planning, development of the necessary spaceflight qualified Radar Altimeter hardware, establishment of the related sensor and geophysical data reduction algorithms, operations of the Radar Altimeter on-orbit, and the distribution of validated geophysical data to the oceanographic science community.

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

Approach: The TOPEX 2-centimeter precision requirement necessitated the examination of the applicabilty of existing Radar Altimeter design. This defined a system configuration whereby some existing designs could be used, but also established the need for other refinements, i.e., a second frequency or channel to remove the range delay or apparent height bias caused by the electron content of the ionosphere, higher transmit pulse repetition frequencies for correlation benefits at higher sea states to maintain precision, and a faster microprocessor to accommodate two channels of altimetry data. Additionally, an examination of the associated data processing algorithms required to support a TOPEX-class Radar Altimeter was undertaken to establish the utility of the then current Radar Altimeter data processing algorithms.

Current Status: In FY 1983, a conceptual design of the TOPEX Flight Project Radar Altimeter was established, followed by a detailed design of an Advanced Technology Model or TOPEX breadboard unit. During FY 1984, a dual-channel Signal Processor was developed and recent test results indicate the TOPEX precision requirement can be achieved. Also in FY 1984, a high-power solid state C-band transmitter for the ionospheric correction channel was developed and satisfactorily tested. For FY 1985, the plan is to complete the development of the outstanding elements comprising both the C-band and the Ku-band RF subsystems, and integrate and test them as a unit with the existing dualchannel Signal Processor. Additionally, preliminary interface definitions for the Radar Altimeter hardware have been generated. In parallel with this hardware development activity has been the establishment of a preliminary set of functional specifications for the necessary Flight Project Radar Altimeter data reduction algorithms. Also a number of detailed resource estimates considering a variety of Project schedules and implementation strategies have been generated.

SAR AND MICROWAVE REMOTE SENSING OF SEA ICE

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Our work is directed towards the interpretation of remotely sensed data for information on sea ice, including the concentration of ice of various thicknesses, ice motion and deformation. These data serve the enhancement of our ice forecasting capability, and studies of ice climatology and air-sea-ice interaction.

This work has two immediate objectives. The first is the study of the field of deformation and its relation to the formation of new leads (where ice growth is rapid). We have measured on a 4 km grid the ice deformation occurring between a sequential pair of 100 x 100 km SEASAT synthetic aperture radar (SAR) images. These kinematic data reveal rigid pieces tens of kilometers across, with regions of intense deformation in between. The pieces are several times larger than observed summertime floes. The motion and rotation of these pieces are similar to the average motion and vorticity of the whole scene and are, to a good approximation, in response to the wind stress and its curl. The deformation measurements have been extended to a region 100 x 300 km.

We have developed an algorithm for making these deformation measurements automatically. This technique will be applied to several more images to test its robustness.

The second objective is the study of SMMR data with eigenvalue techniques. Ten channel SMMR data from six days in April 1978 have been analyzed. All ten channels are positively correlated. Correlation coefficients between pairs of channels are as high as 0.98. Four channels contain 97% of the variance. Scatter plots between two channels support the idea that the ice surface is a mixture of three pure surface types, which we can interpret as open water (OW), first-year (FY) ice and multiyear (MY) ice. Only mixtures of OW/FY and FY/MY occur. Mixtures of OW/MY and OW/FY/MY were not seen. Within each mixture was a dominant eigenvector corresponding to the mixture ratio. A smaller but resolvable eigenvector was attributed to the physical temperature of the surface. A third eigenvector of yet unknown cause is barely resolvable, but may contain geophysically relevant information.

Considerable effort has gone into surveying the market and selecting an image processing system funded by a Department of Defense grant. A system has been selected and should be operational by early summer 1985. It will greatly enhance all the research discussed here.

This work is jointly funded by NASA and the Office of Naval Research, and also enjoys the collaboration of Dr. Michel Fily who is funded by the European Space Agency.

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 gauge measurements.

Specific Objectives: To test the technique initially on a small water body such as Lake Superior in order to evaluate its 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 normal 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 method has been applied in the Atlantic-Indian and Pacific Ocean basins using a 6° x 6° grid. The results are presented in the Geodynamics Branch Research Reports for 1983 and 1984. The computations are now being performed using a 3° x 3° grid.

COUPLED OCEAN-ATMOSPHERE VACILLATIONS
IN THE TROPICS

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Long-Term Interests: Our goals are to understand the important interactions between the tropical upper ocean and the atmosphere.

Objectves: The objective of the present investigation is to identify the energetics and physics of the tropical ocean/atmosphere vacillation known as the El Nino/Southern Oscillation (ENSO). We wish to know whether the vacillation is a random event or more oscillatory, where the energy for the transients comes from, and (if oscillatory) what sets the period of the oscillation.

Approach: We are undertaking a series of numerical experiments with a coupled model of the upper tropical Pacific and global atmosphere. The models interact through heat and momentum fluxes which are parameterized as linear functions of the air-sea temperature difference and the surface wind.

Current Status: The coupled models have produced vacilations which are characterized by SST anomalies in the eastern equatorial ocean basin which vary in strength from ~1C to ~5C. They are quasi-periodic, with a period of ~42 months. The energy source for the vacillations is similar to that in coupled linear models.

A non-linear oscillator has been put forth as a paradigm of the system, and we are investigating the character of the system as a function of the coupling strength. It appears that the vacillation is the manifestation of the non-linear response in a bounded ocean basin to the linear coupled instability (the system bifurcates directly into the oscillatory solution).

The character of the ENSO phenomenon as a non-linear oscillator implies that there is "memory" in the system that may be exploited in a prediction scheme. However, the basic character of the growth as an instability means that small perturbations to the system may grow and thereby degrade predictability. In the basic experiment, the atmosphere is non-linear and has no annual cycle. The natural variability of the atmospheric non-linearity is sufficient to produce the inter-event variability in the coupled system. Small changes in the conditions in which an event grows produce large changes in the eventual strength. When a linear version of the atmospheric model is substituted, the vacillations become almost completely regular.

We are exploring ways in which scatterometer winds and surface height observations may be used to recover the memory of the system, and how the instability affects the application of scatterometry in initialization and prediction.

ADVANCED SAR TECHNIQUES FOR OCEANOGRAPHY

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Objective: The objective of this task is to investigate various modifications to the conventional SAR system design and configuration, in order to determine their utility for oceanographic remote sensing.

Approach: Present investigations are centered on the SIR-B data sets collected during the Agulhas Current experiment. One of these data sets was collected with a variable squint, or azimuthal look direction. The purpose of this data collection and analysis is to determine whether additional information on wind speed and direction, as well as wave conditions, can be obtained by operating in this mode. Another data set collected over the Agulhas Current will be used to determine whether current speeds can be obtained from the complex SAR data by special reprocessing.

Status: Signal data has been obtained for part of the SIR-B variable squint pass, and is undergoing initial examination and analysis. The Agulhas Current data set has not yet been processed.

Long-Term Interest: The long-term interest of the investigators in this area is to assist in the evolution of a set of specialized SAR systems and techniques for use in oceanographic remote sensing.

SAR OCEAN WAVE IMAGING STUDIES

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Objective: The objective of this task is to determine the quantitative relationship between the ocean surface, as specified by the wave height spectrum, and the SAR image spectrum under various conditions.

Approach: A SAR image simulation program has been developed which incorporates the effects of surface motions as well as radar cross section variations. *In situ* measurements of the wave height spectrum are used as inputs, and the predicted SAR images and spectra are compared with actual images and spectra.

Status: The primary data set currently under investigation is the SIR-B data and the surface measurements made concurrently near the coast of Chile during the SIR-B experiment coordinated by Robert Beal of the Applied Physics Laboratory. These data sets have been received and are currently being analyzed and prepared for use as inputs to the simulation model. Additional data sets including aircraft and Seasat SAR data will also be included in this study.

Long-term Interests: The long-term interests of the investigators are the development and utilization of SAR as an oceanographic tool. This investigation is expected to increase the utility of SAR for ocean wave measurements by enabling more accurate spectral estimations to be made from SAR imagery.

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 (Joyce et.al.,1984; Evans et.al., 1985; Smith and Baker, 1985) and primary productivity (Brown et.al., 1985); and the relationship of this variability to the distributions of organisms at higher trophic levels.

Approach

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

Status

For the SCB we are working to improve techniques for assessing regional phytoplankton biomass and primary productivity (Smith, 1984) and are in the process of analyzing several years of CZCS and ship data in order to provide a pigment time series for this region. Several articles describing a parallel effort for the Gulf Stream WCR area have been accepted for publication (Joyce et.al., 1984; Evans et.al., 1985; Brown et.al., 1985; Smith and Baker, 1985) and others are in progress.

RADAR STUDIES OF THE SEA SURFACE

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

Specific Objectives (Satellite Oceanography): The usefulness of satellite data depends to a great extent on the degree with which the user community understands satellite measuring techniques, their accuracies, and their applicability. To contribute to this understanding, I have worked with the University of California Press to complete publication of a book on the Methods of Satellite Oceanography. I am also reviewing the results of the Seasat mission and will be summarizing the results for a NASA report and for a review paper. The satellite has revolutionized our ability to observe the sea from space, and has contributed to our understanding of the ocean, especially marine geophysics.

(Oceanic Rainfall): The development of techniques for remotely measuring oceanic rainfall is hampered by a lack of accurate means for calibration. Rain gauges on ships are notoriously inaccurate, and shipborne radars are expensive and not sufficiently developed to yield accurate measurements. Noise produced by rain falling on the sea offers a new method for calibrating rain rate. A graduate student working with me at the Scripps Institution of Oceanography, J. Nystuen, has measured rain noise in a laboratory tank, in a lake, and in the ocean. He finds a useful correlation between noise and rain rate, has developed a theory for rain noise, and is now writing a thesis on his results. I have also begun investigating the accuracy of SHF radiometer observations of rain.

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

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

Approach: SeaSat and NIMBUS-7 SMMR data are presently being examined to assess the advantages and limitations of recently developed algorithms to quantify sea ice. With the limitations identified, the algorithms can be upgraded to improve data interpretation of the SSM/I, which is the next generation space-borne radiometer system. Weather correction is one example of an algorithm improvement. Similarly, SeaSat scatterometer data collected over the polar regions are being examined with the future interpretation of SIR-B prime and SIR-C in mind.

During 1984, our C-Band Stepped Frequency Microwave Radiometer (SFMR) was installed in the NASA P-3 to collect sea ice data over the Denmark straight and to observe emission from the Greenland ice sheet. Later, the SFMR was reconfigured for installation on the NOAA P-3 to participate in MIZEX, and later in hurricane experiments. During the latter experiment, flights were conducted over Pacific Hurricane Norbert and Atlantic Hurricanes Isadore and Jenifer.

Status: We are routinely processing the entire SeaSat SMMR data set to better define the emissivities of first-year and multi-year sea ice. Cross-plots of various combinations of SMMR brightness temperatures are being clustered to identify and isolate weather effects. The weather corrected algorithm has been cast into several forms, and the SeaSat data base is being used to identify the optimuum approach.

Calibration coefficients for the SFMR are being established to reduce the data collected on a priority basis.

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 interests 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 non-horizontal air/water interfaces. In addition, the model was to be expanded to investigate range and depth gating.

Approach: The SALMON code was implemented on the Hampton University VAX 11/780 computer. The code was modified to allow for ocean waves. Simulation results were obtained for both horizontal and non-horizontal air/water interfaces. 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. The model was expanded to accumulate signals as a function of depth and as a function of time.

Current Status: The results of this year's efforts indicate that statistically significant differences can be seen, under certain conditions, between horizontal and non-horizontal air/water interfaces. A paper has been submitted for publication on range gating and depth gating results. One report was presented at a professional meeting and one paper appeared in print.

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, ships and wakes.

Research Task Objective: 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 manifest themselves in SAR images. In particular we want to put SAR measurement of the directional waveheight spectrum on a quantitative footing.

Research Approach: Our approach is 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 theoretical predictions. This research is done in collaboration with Dr. Werner Alpers and Mr. Brian Barber.

Current Status: Software to read the digital image tapes, compute spectra, correct for instrument reponse and display spectra in both x,y and contour plot form is complete. Analysis of the JASIN experiment images delivered from Europe has been completed. The digital images produce a much larger portion of the spectrum (in terms of wavenumber). Results show better agreement between SAR and surface wave measurements than do the same comparisons using optically imaged data. Work on GOASEX and hurricane IVA data sets has been delayed because SIR-B SAR data processing took higher priority at JPL. We anticipate receiving the required GOASEX SAR data by April of 1985.

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

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

Research Task Objectives: Synthetic aperture radar (SAR) images provide an excellent (all weather and day-night) technique for both observation and prediction of sea ice motion and deformation. However, identifying unique features over a series of images is a tedious and lengthy process to do manually even when computer assisted. Our research objectives are to develop automatic SAR image processing algorithms for the following tasks: (1) automatically identify and track unique features in sea ice images, (2) mathematically model the vector field of sea ice movement and deformation, (3) display results in truly useful and undistorted formats, and (4) predict future sea ice motion and deformation.

Research Approach: Four major items have been pursued thus far: (1) development of a straightforward sea ice tracking algorithm, (2) application of this algorithm to a simple sea ice model, (3) mathematical modeling and display of sea ice movement and distortion, and (4) acquisition of a major new Data General computer system for remote sensing. These very specific items are currently underway. The following items concern the next steps: (5) apply straightforward tracking algorithm to SEASAT SAR images of sea ice in the Beaufort Sea, (6) develop advanced sea ice tracking, display and prediction concepts to improve the straightforward approach and possible yield a new tracking algorithm altogether, and (7) investigate methods for remote sensing of ice thickness.

Current Status: A straightforward sea ice tracking algorithm based on correlation has been developed and applied to a simple sea ice model. This algorithm successfully tracked model ice floes in uniform motion. A real sea ice displacement field was examined. This displacement field was well modeled by five rigidly rotating and translating plates. Data General Corp. has donated an MV10000 computer system to Stanford specifically for use on this (and other related) projects. The high resolution, large format display terminals and array processor are particularly well suited to this research.

This research is also supported by Office of Naval Research.

APPLICATION OF SURFACE CONTOUR RADAR TO OCEANOGRAPHIC STUDIES

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

Specific Objectives: (1) To acquire data on the scattering characteristics on the ocean fronts and sea ice in the vicinity of Iceland and the ice sheet on top of Greenland, (2) to acquire comparative data sets with the Radar Ocean Wave Directional Spectrometer (ROWDS) and the SIR-B imaging radar, (3) to expand the data base of observations of EM bias in support of the TOPEX altimeter.

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

Current Status: NOAA sponsored the NASA/GSFC P-3 aircraft to participate in their Arctic Cyclone Experiment in January 1984 and good quality scattering data using the SCR, the AAFE Altimeter, and the Airborne Oceanographic Lidar (AOL), and radiometric data from the UMASS C-band radiometer was obtained on the top of Greenland and the sea ice and ocean fronts north of Iceland. Analysis of the data is in process and a preliminary intercomparison of SCR and AAFE Altimeter data was published in "The evolutionary trend in airborne and satellite radar altimeters" by L. S. Fedor and E. J. Walsh in the Proceedings of the URSI Commision F Symposium and Workshop, Shoresh, Israel, May 14-23, 1984, NASA Conference Publication 2303. The Navy funded the P-3 to participate in the SIR-B experiment in the high wave conditions off the tip of South America in October 1984. SCR data was acquired on a number of flights underflying the SIR-B imaging radar on Challenger. Initial intercomparisons of SCR spectra with those of SIR-B and the ROWDS and data from the AOL showed good agreement. A paper "Directional wave spectra measured with the Surface Contour Radar" by Walsh et al. documenting analysis techniques and intercomparisons of the SCR with wave riders and the XERB and ENDECO pitch-and-roll buoys will appear in the Journal of Physical Oceanography in May '85. A paper "Elimination of directional wave spectrum contamination from noise in elevation measurements" by Walsh et al. detailing data processing techniques for the SCR has been submitted for publication in the IEEE Journal of Oceanic Engineering. Modifications to the antenna system of the ROWDS are being investigated to allow it to acquire backscatter data with a 0.9° two-way beam at nadir colocated with the SCR antenna. Operating at 150 m altitude the SCR topography and the ROWDS backscatter could combine to determine the EM bias at the 13 GHz TOPEX operating frequency. Plans are being formulated for a joint hurricane flight with the NOAA P-3 during the '85 season.

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

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

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

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

Status: A 1979 time series of CZCS images during northwest wind events in March, April, May, and June has been compared to shipboard under-way chlorophyll maps and fluorescence/temperature/depth profiles taken during cruises in the same time period. A manuscript, "Satellite detection of shelf export during the 1979 spring bloom," has been submitted to Deep-Sea Research. A barotropic circulation sub-model has been developed at USF to simulate the flow response to winter-spring wind events. Using this sub-model, the simulated algal populations within the mid-Atlantic Bight are now being compared to the 1979 CZCS data set. Compilation of the 1979-84 CZCS time series is now also underway at RSMAS.

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

INVESTIGATION: STUDIES RELATED TO THE REMOTE SENSING OF SEA ICE

PRINCIPAL INVESTIGATOR: W. F. Weeks
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Long-Term Interest: I am interested in developing and implementing effective satellite-borne remote sensing methods for observing the polar regions in that I believe that the only hope of resolving many sea ice and ice sheet problems is through such an approach. I am particularly interested in the analysis of SAR imagery in that it gives a detailed view of sea ice that can be useful in many application areas.

Objectives: At present I am trying to develop a programmatic basis leading to the implementation of various programs that will result in the collection and analysis of SAR data from sea ice terrains. I am also interested in the ice ridging phenomenon, in variations in the roughness of the ice pack, and in the application of probabilistic approaches to ice problems.

Approach: I am currently completing several papers on ice surface roughness as determined by laser profilometry both in the Arctic and the Antarctic, on combined stochastic - deterministic models of ice induced gouging, on ice structure as it affects remote sensing, and on future remote sensing programs for the polar oceans. I have also served on a wide variety of NASA committees: the Space Applications Advisory Committee, the Earth System Sciences Committee, the PIPOR (Programme for International Polar Ocean Research) Committee (joint ESA/CCRS/NASA). I am also a member of the NAS group preparing to brief the President's Science Advisor (Dr. Keyworth) on Earth Viewing Remote Sensing.

ADVANCES IN THE ESTIMATION OF OCEAN SURFACE WINDS AND WAVES WITH MICROWAVE RADAR MEASUREMENTS

Principal Investigator: Dr. David E. Weissman
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Long Term Interests: To gain a more complete understanding of the effect of ocean surface winds and waves on the reflected and backscattered microwave signal amplitude so that new algorithms can be developed to improve the accuracy of remote radar measurements. These studies will combine knowledge of atmospheric fluctuations and turbulence that interacts with the surface waves to create a reflectivity distribution that must be modeled with functions of several variables.

Specific Objectives: The goal is to provide improved algorithms for estimating ocean surface winds and waves from airborne and space (NSCAT Scatterometer) radar observations. These algorithms will be developed from radar experiments that combine the observations of environmental physical variables and the wave spectrum with the backscatter data.

Approach: Measurements obtained in the Gulf of Mexico by the Naval Research Laboratory and aircraft data expected from the FASINEX Experiment will serve as the focus of the empirical part of this study. The development of functional models that relate the backscattered radar cross section to the mean wind speed, the fluctuating wind component, the modulation transfer function of the surface waves and their interaction, has begun. Preliminary studies demonstrate that an algorithm which combines RMS wave slope with the radar cross section data yields estimates of the surface wind that have significantly smaller mean square error than an algorithm that only relates radar cross section and wind speed. This type of evaluation is continuing.

Current Status: The realization that wave induced airflow and wind fluctuations affect the radar cross section, in addition to the mean wind, is a recent addition to the knowledge that influences algorithm development. Previous studies in the literature that focus on the correlations between the wave spectral components and the wind spectrum are being studied in conjunction with the Gulf of Mexico data analysis to create new functions that not only have good statistical properties but also have a physical justification. Statistical models have been developed for stable and unstable environmental conditions using regression analysis and they are being evaluated for the improved accuracy they may provide for remote sensing measurements.

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, II and III have been completed. The new SEASAT SMMR and SASS geophysical data sets are now available.

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

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-wave length 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 (ending with the expected TOPEX AO this summer), and as US Co-chairman of the Science Steering Group for the World Ocean Circulation Experiment (WOCE). (2) Work continues, using several different forms of inverse theory, (linear and non-linear programming, objective mapping, etc.) toward combining altimetry, gravity, wind stress topography, and the ocean circulation into internally consistent pictures of the sea surface, the geoid and the ocean circulation. H. Mercier, J. Schröter, and others are collaborating with the PI.

* 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: To understand how physical and biochemical systems affect the distribution of light-absorbing and light-emitting microorganisms in oceanic waters, and to identify the physical oceanographic mechanisms which alter the biooptical characteristics of water masses.

Objectives of this Research Task: To identify the oceanographic mechanisms responsible for the changes in light absorption and emission by planktonic organisms. We attempt to establish an ataxonomic method for rapid characterization of populations, and believe that the causes of these distributions will lead to an understanding of the oceanic distributions in time and space.

Approach: The excitation, emission and attenuation spectra of organisms are measured utilizing spectrophotometry and spectral fluorometry, in conjunction with measurement of other parameters in the water column, i.e. nutrients, and temperature and density. Most observations have been taken in regions where warm core eddies are spawned from the Gulf Stream. These regions provide physical diversity in water mass characteristics and hence, are an ideal site to test above hypotheses.

Current Status: We have demonstrated that the major changes in optical characteristics occur across frontal regions; the fronts are primarily defined by differences in the degree of stratification between two water masses. The optical changes appear to be due to changes in growth, presumably as regulated by nutrient enrichment or impoverishment. This supports the hypothesis that the changes in ocean color as seen from the Coastal Zone Color Scanner are largely due to differences in vertical motion associated with meso- and macroscales of ocean circulation. We have conceptually modeled changes in optical properties due to physical/chemical mechanisms as associated with frontogenesis in warm core rings and are working on the variability and fluorescence emission in different populations. We are attempting to relate these to the chromaticity of the natural light fields, and also are attempting to factor in the amounts of fluorescence from algae in terms of affecting the upwelled light characteristics.

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

Determination of the General Circulation of the Oceans from Satellite Altimetry.

Victor Zlotnicki

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GOAL: to measure the surface expression of the general circulation of the oceans using satellite altimetry.

SPECIFIC OBJECTIVE: the recovery from mean sea surfaces constructed from Seasat and GEOS-3 data of the small, steady state signal associated with the general circulation, a signal that cannot be distringuished from the geoid on the basis of its time variations.

APPROACH: we avoid any geoid computation, the weak link in previous efforts. The altimetric data are transformed to gravity accelerations, these are compared with ship gravity measurements, and the residuals are converted to water velocities.

STATUS: the application to the North Atlantic circulation defines well the North wall of the Gulf Stream using 7 gravity cruises, a number totally insufficient for a geoid computation (these results are presented at the 1985 Spring meeting of the AGU). We are currently extending the calculation to the other ocean basins, and adding finer detail to the North Atlantic estimate.

ICE MARGIN MAPPING BY SATELLITE ALTIMETRY

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

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

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

Status: The Seasat radar altimeter data set, which was previously computer retracked to correct range errors, was sorted and placed on an HP9845C disc in a format suitable for coastline mapping. Software was developed for interactive data analysis including presentation of waveforms in the vicinity of an ice margin crossing, examination and correction of the track points, display of apparent elevations, and calculation and mapping of the ice margin position.

MESOSCALE ICE DYNAMICS AND PROCESSES

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Long Term Interests: (1) To investigate the general characteristics of the sea ice cover and how they relate to oceanic and atmospheric processes, (2) To investigate the dynamics of the multiyear ice cover in the Arctic Region.

Specific Objectives: (1) To quantify the variability the open water area inside the ice pack due to the opening and closing of offshore polynyas and estimate the ice production and salinity enhancement, and (2) To quantify the areal extent and concentration of multiyear ice cover and the large-scale drift of the Arctic ice pack.

Approach: Daily and 3-daily averages of Nimbus-5 ESMR brightness temperature data are used to investigate openings and closings of leads and polynyas in the Antarctic region. The amount of salt production from the freezing of leads and polynyas is estimated and compared with measured salinities around the Antarctic coast. Using a current algorithm for classifying first year and multiyear ice, polar maps of multiyear ice cover are generated from Nimbus-7 SMMR passive microwave data. The extent of the multiyear ice pack is defined by the multiyear concentration line of $\geq$20 percent. Variations in the multiyear extent in sequences of maps are used to estimate the ice drift on time scales from daily to seasonal.

Status: The results of the Antarctic near-shore leads and polynyas studies are being published in "Antarctic Offshore Leads and Polynyas and Oceanographic Effects " and other results are included in two papers, "Satellite Observations of Sea Ice" and "Observing Polar Ice Variability." Preliminary results on the drift of the multiyear ice pack show that drift velocities can be derived from the passive microwave data and that the obtained values of several km/day are consistent with the velocities obtained by drifting data bouys.

SECTION IV - BIBLIOGRAPHY

This section contains a list of scientific research papers supported wholly or in part by NASA which were published or accepted for publication in refereed journals.

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16. Abstract

This, the Fifth 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 1984 (October 1, 1983 to September 30, 1984), the period covered by the Introduction includes April 1985. 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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