NASA Technical Memorandum 4025

NASA Oceanic Processes Program

Biennial Report—Fiscal Years 1986 and 1987

FEBRUARY 1988

NASA

NASA Technical Memorandum 4025

NASA Oceanic Processes Program

Biennial Report—Fiscal Years 1986 and 1987

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

NASA

National Aeronautics
and Space Administration

Scientific and Technical Information Division

1988

PREFACE

The present time is especially active regarding planning and implementation of capabilities for observing the oceans from space. The Navy's Geosat Exact Repeat Mission has been in operation for almost a year and the data look good. The first SSM/I-equipped Air Force DMSP satellite was launched this past June and appears to be operating satisfactorily. The Navy's N-ROSS, initially cancelled last November, is now in the process of reinstatement. This is particularly critical for NASA as N-ROSS is the platform upon which we are to fly our NSCAT; the set of six NSCAT flight antennae have been delivered to JPL. Implementation of ESA's ERS-1 mission is proceeding well, and ESA has just selected the team of investigators in response to their AO. The Japanese are progressing with development of their ERS-1 mission. Implementation for our Alaska SAR Facility (ASF) is proceeding well, and we have reached agreement, in principle, with NASDA in Japan regarding reception of their ERS-1 SAR and optical data at the ASF. TOPEX, a joint mission (TOPEX/POSEIDON) with the French Space Agency (CNES), was approved by Congress in the FY 87 budget; we have selected a science team in response to a joint NASA/CNES AO; and Fairchild has been selected as the satellite contractor. Especially considering the demise of the Nimbus-7 CZCS this past winter, we are actively supporting EOSAT to include a color scanner (Sea-WiFS) in the sensor complement of Landsat-6; funding for implementation of Landsat-6 has just been appropriated by Congress. The Canadian Government has approved their Radarsat mission, contingent on working out agreements with their U.S. (NASA, and possibly NOAA) and British partners.

This biennial report for NASA's Oceanic Processes Program, covering fiscal years 1986 and 1987, provides an outline of our recent accomplishments, present activities, and future plans. We hope you find the report useful, and we would appreciate hearing from you in the event you have any questions or comments. We would like to express our appreciation to all those individuals who have contributed material to our report. We are particularly grateful to Penny L. Peters, Joint Oceanographic Institutions Inc., for editing this document.

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

James R. Greaves
Eni G. Njoku
James G. Richman
Robert H. Thomas
William F. Townsend
W. Stanley Wilson
James A. Yoder
Ernest T. Young

November 1987

TABLE OF CONTENTS

SECTION I - INTRODUCTION

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

The program is organized into five components; they and their respective program managers are: (1) Physical Oceanography -- Dr. James G. Richman and Mr. Ernest T. Young; (2) Ocean Productivity -- Dr. James A. Yoder; (3) Polar Oceans -- Dr. Robert H. Thomas; (4) Oceanic Flight Projects -- Mr. William F. Townsend and Mr. James R. Greaves; and, (5) Ocean Data Systems -- Dr. Eni G. Njoku. Dr. Thomas replaced Dr. Kenneth C. Jezek on October 15, 1987, at which time Dr. Jezek returned to the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), and the Thayer School of Engineering, Dartmouth College.

The distribution of NASA's FY 86 and 87 ocean-related funding is approximately as follows:

	FY 86	FY 87
Jet Propulsion Laboratory*	$ 8,250 K	$ 6,180 K
Goddard Space Flight Center	2,250	3,500
Academic Institutions	3,150	5,050
Industry	550	220
Other Government Agencies	60	220
Miscellaneous**	1,920	1,860
Total	$ 16,180 K	$ 17,030 K

*$4.2M for TOPEX study activities included in FY-86; TOPEX covered by separate line item in FY-87.

**Includes program manager salaries, support contract services, Resident Research Associate program, and WOCE/TOGA/GOFS planning activities.

Additional funding that benefited the Oceanic Processes Program in FY 86 included : $13.1M to initiate development of the NSCAT sensor and its associated data system, $1.1M for operational processing of NIMBUS-7 CZCS and SMMR data at Goddard Space Flight Center, $0.56M for developmental activities related to the NASA Ocean Data System (NODS) at Jet Propulsion Laboratory, and $0.70M for developmental activities related to the Alaska SAR Facility (ASF); this brings the total FY 86 budget of NASA ocean-related funding up to $31.64M.

Additional funding that benefits the Oceanic Processes Program in FY 87 includes: $26.5M to continue development of the NSCAT sensor and its associated data system, $18.2M for TOPEX, $0.75M for operational processing of NIMBUS-7 CZCS and SMMR data at Goddard Space Flight Center, $0.49M for developmental activities related to the NASA Ocean Data System (NODS) at Jet Propulsion Laboratory, and $5.47M for develomental activities related to the Alaska SAR Facility (ASF); this brings the total FY 87 budget of NASA ocean-related funding up to $68.44M.

Various Science Working Group (SWG) activities have been underway during the past few years and are outlined in Table 1, page I-15. National and international ocean-related spacecraft activities for the next decade, which are at various levels of planning and development, are outlined in Table 2, page I-16. (In addition to the acronyms and definitions accompanying Table 2, we have included a brief paragraph describing each of the spacecraft listed and commenting on their present status.)

A summary of the more recent SWG activities is given in Section 2; written reports for each are available from NASA Headquarters.

Notable publications which have recently appeared include:

Beal, R. C., ed., 1987: Proceedings of the Symposium Measuring Ocean Waves from Space. *Johns Hopkins APL Tech. Digest*, **8**(1), 147 pp.

Carsey, F. D., K. C. Jezek, J. Miller, W. Weeks and G. Weller, 1987: The Alaska Synthetic Aperture Radar (SAR) Facility Project. *EOS*, **68**(25), 593-596.

Esaias, W. E., G. C. Feldman, C. R. McClain and J. A. Elrod, 1986: Monthly satellite-derived phytoplankton pigment distribution for the North Atlantic ocean basin, *EOS*, **67**(44), 835-837.

Liu, W. T., 1987: 1982-83 El Niño Atlas Nimbus-7 Microwave Radiometer Data. JPL Pub. 87-5, National Aeronautics and Space Administration, 68 pp.

Muench, R. D., S. Martin, J. E. Overland, 1987: MIZEX Special Issue. *J. Geophys. Res.*, **92**(C7), 6715-7225.

Parkinson, C. L., J. C. Comiso, H. J. Zwally, D. Cavalieri, P. Gloersen and W. J. Campbell, 1987: Arctic Sea Ice, 1973-1976: Satellite Passive-Microwave Observations. NASA SP-489, National Aeronautics and Space Administration, 296 pp.

PHYSICAL OCEANOGRAPHY PROGRAM

The goal of the Physical Oceanography Program is to develop and apply spaceborne remote sensing techniques to determine the general circulation of the ocean and its variability and response to forcing by wind stress and air-sea heat fluxes, with the aim of developing an improved understanding of the ocean's role in the climate of the earth. To provide a sound scientific framework for the interpretation of satellite data, emphasis is placed on theoretical analyses, field experiments, modeling based studies aimed at the assimilation of satellite and in situ data, and the analysis of historical data collected from space. The Program has two areas of focus, Ocean Circulation and Air-Sea Interactions, based upon the utilization of the data to be obtained from two ocean-related space flight opportunities, the Ocean Topography Experiment (TOPEX) using a satellite altimeter and the NASA Scatterometer (NSCAT), planned for the early 1990's. The Program acitivites are being coordinated with the planning efforts for the two large, international field experiments to take place in the early 1990's, the World Ocean Circulation Experiment (WOCE) and the Tropical Oceans-Global Atmosphere Program (TOGA)

The significant accomplishments in Ocean Circulation studies during the past two years include analysis of historical data from the GEOS-3 altimeter to describe the seasonal variability of the transport of the Gulf Stream, development of new techniques to reduce orbit errors, and the development of techniques to assimilate satellite data into numerical ocean circulation models. Despite the large instrument and orbit errors in the GEOS-3 altimeter data, a strong seasonal cycle in the Gulf Stream transport can be observed, using a crossover analysis technique. The observed seasonal cycle in the altimeter data is consistent with historical hydrographic data. The power of the crossover analysis technique to reduce orbital errors in the altimeter data has led to further efforts to improve this technique and reduce the number of constraints necessary for its application. The present generation of numerical ocean circulation models can not readily accommodate sea level data. Investigations are underway to develop new techniques to assimilate altimeter data into the models and understand how errors in the altimeter data are propagated through the model solution.

In mid-1986, NASA released an Announcement of Opportunity (AO) soliciting scientific investigations that will ultiize data from the joint U.S. and French TOPEX/POSEIDON mission. These investigations will be coordinated with the World Ocean Circulation Experiment and the Tropical Oceans-Global Atmosphere Program. In September 1987, the selections for the TOPEX Science Definition Team were announced. During the pre-launch phase of the TOPEX Program, the Science Definition Team will make recommendations to the project engineers and manangement to optimize the mission design to best meet the experiment objectives. The Science Definition Team is also charged with developing a Science Plan for the Mission.

As part of the activities preparing for TOPEX, NASA sponsored an international workshop to evaluate the geophysical algorithms used to process raw altimeter sensor data to obtain sea level. This workshop considered the historical algorithms used for SEASAT as well as the algorithms being used presently for the Navy's Geodetic Satellite (GEOSAT) and the algorithms contemplated for the European Space Agency's altimeter on ERS-1, NASA's altimeter on TOPEX/POSEIDON and the French Space Agency's altimeter also on TOPEX/POSEIDON. The discussion and recommendations from this workshop should be published in late 1987.

Several investigations have commenced using GEOSAT altimeter data to study the circulation in the Southern Ocean and the North Pacific as well as careful assessment of the performance of the altimeter and its precision orbit determination. GEOSAT was launched by the Navy in March 1985. For the first eighteen months, the primary mission of the satellite was geodetic mapping and the data was classified. In November 1986, the satellite was maneuvered into an exactly repeating orbit. The data from this Exact Repeat Mission (ERM) is unclassified. The geophysical data records are being produced the National Geodetic Survey and distributed by National Ocean Data Center (NODC). Our use of GEOSAT data to address ocean variability will provide assistance in preparing for TOPEX as well as increasing our understanding of the circulation of the ocean.

The goal of the Air-Sea Interaction studies is to determine the winds and exchange fluxes over the world's oceans with sufficient accuracy to advance our understanding of the physical processes occurring in the layers of the ocean and atmosphere close to the sea surface. The specific objectives are to assess our ability to determine surface wind stress, ocean surface waves, air-sea fluxes of momentum and heat, and wind-driven ocean currents using spaceborne remote sensing techniques.

The effective use of radar backscatter data to be obtained from the NASA Scatterometer (NSCAT), planned for flight on board the Navy's Remote Ocean Sensing System (N-ROSS), forms the basis for the Air-Sea Interaction Program. In February 1986, the Science Definition Team for the NSCAT Program was selected. This team has been working with the NSCAT Project to refine the geophysical processing algorithms for scatterometry and to develop a data system for the Project. In addition, the team members have been pursuing their scientific investigations and developing the Science Plan for the Mission. Confirmation of the Science Working Team has been delayed due to the uncertain status of N-ROSS.

Several NASA investigators participated in the Frontal Air-Sea Interaction Experiment (FASINEX), with two aircraft flying to measure directional wave spectra and radar backscatter from Bragg scatterers. On one particular day, an abrupt change in the radar backscatter was observed when crossing the surface temperature front in the ocean. While the wind blowing over the ocean was near constant across the front, the measured wind stress, atmospheric stabilty and surface gravity wave spectra did change markedly across the front. The data from this flight should provide an excellent case study for the role of surface gravity waves, wind stress and atmospheric stabilty in modulating the capillary waves responsible for Bragg scattering the electromagnetic radiation.

In April 1986, a symposium was sponsored by NASA to discuss the utility and capability to measure the properties of surface gravity waves from space. The papers presented in this symposium were published in a special edition of the Johns Hopkins Applied Physics Laboratory Technical Digest, Volume 8, No. 1, 1987.

The SEASAT scatterometer (SASS) data over the Southern Ocean has been reanalyzed to investigate the spatial structure of the winds over this ocean. The eastward propagation of weather systems around the South Pole can be observed with a dominant zonal wavenumber 3 structure. The large scale structure in the SASS winds is similar to the geostrophic wind analyses produced by the Australian Bureau of Meteorology, but the SASS winds exhibit considerable small scale structure not seen in the geostrophic winds.

Efforts are continuing to study the potential impact of scatterometer winds on numerical weather forecasting and to develop numerical atmospheric circulation models that can assimilate scatterometer winds. Using improved planetary boundary layer models, it has been shown that scatterometer winds can predict the geostrophic flow above the boundary layer. This result implies that improved boundary layer formulations in numerical weather forecasting models would improve the impact on scatterometer winds on the forecasts.

In support of TOGA, we are studying the circulation of the tropical oceans with the broad goal of understanding and learning how to model the sea surface temperature and sea level elevation with a focus on simulating the coupled ocean-atmosphere interaction. Two new models have been developed to study and attempt to forecast El Nino, a major perturbation in the atmospheric and ocean circulation in the tropics and mid-latitudes.

In addition, a pilot study, the TOGA Heat Exchange Program (THEP), is underway to evaluate the potential for determining air-sea heat fluxes from remotely sensed data. Due to problems of data availability, the pilot study is focusing on the eastern tropical Pacific. The monthly mean fluxes for the 1982-83 El Nino have been computed and work has started on the non-El Nino period of 1979-81. The data set from this pilot study will be made available through the NASA Ocean Data System (NODS).

OCEAN PRODUCTIVITY PROGRAM

The goal of the Ocean Productivity Program is to develop and apply remote sensing techniques to measure the primary productivity of the oceans, its variability, and how it in turn influences the marine food chain, and global biogeochemical cycles of carbon and other elements. The primary spaceborne measurements are ocean color from the present NIMBUS-7 Coastal Zone Color Scanner (CZCS) and the proposed Sea-WiFS and sea surface temperature from the NOAA Advanced Very High Resolution Radiometer (AVHRR). Field studies are closely coordinated with Navy, National Science Foundation, and Department of Energy supported shipboard and in situ measurement programs to provide maximum scientific benefit.

In the last three years, major advances have been made in techniques used to determine chlorophyll pigment concentrations from the CZCS ocean color measurements. Among these improvements are the refinement of sensor degradation 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. The capability to analyze CZCS data has increased substantially with improved image processing techniques, software, and additional processing facilities. Procedures are being developed for compositing data from numerous satellite passes to produce ocean basin and global images, and the first basin and global prototype images were widely distributed in the oceanographic community. The availability of data is also rapidly improving with the establishment of a dial-up catalog and microfilm browse file search capability. Laser disk browse files are being developed which will greatly improve this process.

Estimating primary productivity from ocean color and other remotely sensed parameters with a minimum of in situ measurements is a new emphasis of the program. Numerical models which use satellite imagery as input and for verification are the main tools used to address hypotheses in this area. An empirical model for estimating the vertical profile of ocean productivity from CZCS data has been developed using large in situ data sets. Several existing analytic productivity models are being investigated to see if they will work with only satellite data as the input. Regional-scale models have been developed to simulate intermittent time series of CZCS data in areas such as New York Bight, Gulf of Mexico, and coastal waters off the northwest and southeast U.S. These models use in situ data collected from ships and moorings to supplement satellite ocean temperature and color data. The models simulate water circulation and plankton dynamics to fill temporal gaps between cloud-free CZCS images. Finally, we have initiated the development of basin scale models to assess the role of ocean primary production in the global CO_2 budget.

Processing and analysis of time series of temperature and pigment concentrations on a regional basis has been initiated. A five-year color and temperature time series for the West Coast of the U.S., and a similar time series for the entire North Atlantic are underway. The eventual plan is to process all available CZCS data to maps of chlorophyll distribution and to put these products into a new archive.

Development of airborne techniques to aid in oceanographic process studies, satellite ocean color algorithm development, and satellite data validation continues at the Wallops Flight Facility. The Wallops P-3 is equipped with an Airborne Oceanographic Lidar (AOL) which measures passive spectral radiance and laser-stimulated fluorescence emission spectra. This unique instrument is supported by a PRT-5 for surface temperature measurements, AXBT for temperature profiles, and ship to aircraft communication and data telemetry. We have refurbished the Multichannel Ocean Color Scanner (MOCS) with a new state-of-the-art data system and it is available to fly on a variety of aircraft in support of oceanographic studies. Also, in a joint effort with NOAA, we are developing an inexpensive, reliable Oceanographic Data Acquisition System (ODAS) to make aircraft color and temperature data widely available to the oceanographic community. Wallops and Goddard personnel are meeting regularly with the planning committees of the NSF/NASA-sponsored Global Ocean Flux Study to discuss the role of aircraft-borne sensors in large field programs planned for the early 1990s.

In May 1986, we sponsored an Ocean Color Program retreat that was attended by 35 scientists and federal agency representatives. During the 3-day retreat, investigators funded by Oceans Branch presented recent results and discussed future plans. A second retreat is planned for October 1987. In February 1987, Oceans Branch helped EOSAT organize the Sea-WiFS Working Group to discuss and document commercial, operational, and research applications for ocean color imagery; define user's requirements for sensor performance and for data products; and, determine the feasibility of meeting the users' requirements on Landsat-6. The working group report was released in August 1987.

POLAR OCEANS PROGRAM

The objectives of this program are to use spaceborne sensors to determine the characteristics of the polar ice cover and to understand how polar ice is influenced by and in turn influences the atmosphere and ocean. Specific, long range scientific goals include determining the energy flux between the ocean and atmosphere at high latitudes, identifying the processes that control the formation of intermediate and deep ocean water, measuring the mass balance of the great ice sheets, and understanding the processes which control the growth motion and decay of sea ice.

Our immediate goal is to improve our capability to measure from space the extent, type, movement, and surface characteristics of ice cover. This involves research to understand the relationships between ice morphology and electromagnetic wave propagation and the development of algorithms developed on that basis to extract geophysical parameters from the satellite data. In each case, NASA has been working closely with ONR to collect and analyse data collected from surface ships and aircraft on the scattering and emmision properties of sea ice. Significant progress in this area has occurred this year including developing a better understanding of the role of snow cover and wetness on the microwave signature of sea ice. In turn, this activity will likely impact on work intiated this past year to characterize the spring melt of the Arctic ice pack from SMMR observations. Algorithms to exploit detailed knowledge of microwave signatures continue to mature with the successful tests and comparisons of ice concentration algorithms for both active and passive microwave data. This work is leading to a better understanding of where the two techniques can be used to produce complementary ice concentration estimates. For example, SAR may provide better estimates in areas of low ice concentration but issues remain involving the separation of ice, smooth water and wind roughened water microwave signatures.

NASA investigators participated in several productive field programs to collect information on the emissivity of sea ice. Two cruises of the German research vessel Polarstern took place in the Weddell Sea, one in the austral spring/summer and one in the austral fall/winter. The goal of the work was to characterize the emissivity spectrum of the Antarctic Sea (unique because it is almost entirely first year ice and is predominantly formed from frazil ice production) in a region where large and important polynyas are known to occur. During this past May, the NASA P-3 was flown over the Arctic Ocean and the Greenland Sea as one component of a multi-sensor program (including X-band SAR and under-ice acoustic profiles collected by a British submarine) to study the characteristics of Arctic multi-year sea ice.

Onboard the NASA aircraft were passive microwave radiometers and photographic equipment; most exciting was the operation of an airborne optical lidar integrated with a global positioning system for measuring surface elevation, potentially a key indicator of ice type and thickness. Preliminary results suggest that elevation of the sea ice can be measured accurately to a few centimeters.

Important work was completed this year on analysing the contribution of polynyas in the Sea of Okhotsk to the flow of intermediate depth ocean water into the North Pacific. Based on ice concentration estimates derived from SMMR data and on heat flux estimated from WMO weather stations, investigators have estimated the flux of cold, dense water shelf produced in the polynyas and along the coast to be on the order of 0.5 Sverdrups. Other research also focusing on the Sea of Okhotsk and the Bering Sea shows that fluctuations in the extent of sea ice in these areas is strongly coupled to the position of high and low pressure systems over the Aleutian Islands and Siberian Coast. We hope that more work that utilizes satellite data to study large scale geophysical processes will be stimulated by the publication this year of the Arctic Sea ice atlas compiled from ESMR data collected between 1973-1976.

The Special Sensor Microwave Imager (SSM/I) was successfully launched this summer as part of the Defense Meteorological Satellite Program. In an effort to make available to the polar community gridded brightness temperature data and derived products from SSM/I, NASA's Jet Propulsion Laboratory and the National Snow and Ice Data Center (NSIDC) in Boulder, Colorado, are implementing at NSIDC a node of the NASA Ocean Data System dedicated to SSM/I data. Over the past year, software for loading SSM/I data and producing maps of sea ice concentration and extent have been put in place at NSIDC as part of the plan for establishing the NSIDC as the operational node for SSM/I retrospective data. In addition, a calibration and validation team was established and tasked with determining the degree to which the sea ice and snow parameters derived from SSM/I data meet the observational requirements of the science community; this group also will provide the NASA's Sea Ice Algorithm Working Group with necessary and sufficient information in order for that group to make recommendations for possible algorithm changes, monitor the performance of the sensor, and provide for routine checks of product quality. To facilitate the comparison of data collected by passive microwave imaging instruments, both ESMR and SMMR data are being integrated into the node and will be provided to investigators on the SSM/I grid.

Research into the utilization of radar altimeters to measure the surface topography of ice sheets is continuing and much progress has been made in compiling elevation maps of the Greenland Ice Sheet using GEOSAT data. Comparison with similar maps prepared from Seasat altimeter data have been complicated by unanticipated orbit uncertainties. Resolution of this issue, as well as a critical evaluation of the capabilities of altimeters to ice sheet glaciology, will be a focus of a NASA Science Working Group planned to convene this Fall.

Much progress has been made on the Alaska SAR Facility Project this past year. Preliminary designs for the receiving ground system and the SAR processor system were approved. A functional design of the archive and operations system has also been proposed and the details of the design will be the objective of a review this Fall. The University of Alaska is becoming more active as the program matures. Bids have been let by the UAF for modifications to the Elvey Building where the ASF will be installed and current plans call for installation of the antenna system next summer. The UAF convened the first meeting of the Prelaunch Science Working Team in July. The group is tasked with providing and updating science requirements for the facility, developing a prelaunch science plan, and making recommendations for a geophysical processing capability to be ready at the time of J-ERS-1 launch. With regard to the last point, a subpanel of the PSWT has been formed to look at extracting ice motion from SAR data. Several promising approaches have been proposed including methods that rely on initialization by an operator or are fully automated. Potential algorithm schemes include hierarchical correlation, feature tracking, or hybrid methods relying on aspects of both of the other techniques. Work on these algorithms is expected to continue through this winter in an effort to refine their accuracies in regions of strong shear or rotation. By late next spring, the subpanel is tasked with recommending an algorithm for implementation at ASF.

Progess in concluding an agreement between the Japanese National Space Development Agency (NASDA) and NASA is proceeding for the acquisition of real time SAR and optical data at the ASF as well as access to the J-ERS-1 global data set. Pending the outcome of these negotiations, NASA plans to expand the processing capability of the ASF to include optical data and to that end, the Goddard Space Flight Center is conducting Phase A studies of what that processor might consist.

The Polar Communications Science Working Group has nearly completed its work and plans to issue its report sometime in the Fall of 1987. The report is slanted more towards Antarctic communications issues and provides an overview of communications technology available to field investigators. The report also includes specific recommendations to be considered in specifying the functional requirements of future systems. These include an assessment of future data volumes from the polar regions, the need for both voice and data transmission capabilities and provision for communication links to remote field parties.

In the coming year, we look to several developments facilitating the continued acquisition and distribution of satellite data over the polar regions, the analysis of those data in terms of geophysical parameters, and the application of that analysis to ocean and ice problems. Early next year, NASA's new DC-8 aircraft should be ready for missions that have on board the JPL multifrequency, quad-polarization SAR and a suite of passive microwave instruments including a new 92 Ghz radiometer. A planned flight over the Chukchi and Beaufort seas next March will be an integral part of the SSM/I validation activity and provide critically needed C-band SAR data over sea ice to the ASF science team .

OCEANIC FLIGHT PROJECTS

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

DATA SYSTEMS PROGRAM

The necessity of an adequate and appropriate data archival and management system to assimilate data from past, present, and proposed satellite sensors continues to provide the focus for this program. The goal is to develop a distributed NASA Ocean Data System (NODS), which will provide the ocean research community with easy access to oceanographic spacecraft data and other ancillary data sets. The Pilot Ocean Data System (PODS), developed at JPL under Code EI funding, has now transitioned to become the first operational node of the NODS distributed system, funded primarily by Code EEC. Each node of NODS will be designed to conform to an evolving set of standards governing the archiving, cataloging, and distribution of satellite and allied in situ oceanographic data. These nodes, and research users at oceanographic institutions, will be connected by an electronic network to provide transparent access to the data sets.

Data currently supported at NODS/JPL include Seasat (SCAT, ALT, SMMR, VIRR), Geos-3 ALT, and the CZCS/AVHRR West Coast Time Series. Other NODS nodes currently under development include those at the NOAA/National Snow and Ice Data Center (NSIDC)--for DMSP SSM/I polar data, Nimbus-7 SMMR polar data, and Seasat and Geosat ALT ice-sheet data; the GSFC/National Space Science Data Center (NSSDC)--for global Nimbus-7 CZCS data products; and the Alaska SAR Facility (ASF)--for SAR data from E-ERS-1, J-ERS-1, and possibly Radarsat, and Optical Sensor data from J-ERS-1. Potential future nodes include the Universities of Rhode Island, Miami, and the Scripps Institution of Oceanography--for AVHRR and CZCS data, and the NOAA/National Oceanographic Data Center (NODC)--for sea surface temperature products. Data from TOPEX and NSCAT will be archived at NODS/JPL, while data from the proposed Sea-WiFS sensor will be archived at NODS/NSSDC. Details of the SSM/I, TOPEX, NSCAT, ASF, and Sea-WiFS projects are provided in Section II.

To provide guidance, oversight, and scientific involvement in the development of NODS, NASA--in concert with NSF, NOAA, and the Navy--established the Satellite Ocean Data Systems Science Working Group (SODSSWG) in 1985. Under the chairmanship of D. J. Baker of the Joint Oceanographic Institutions Inc. (JOI), SODSSWG has formed five panels to carry out its charter: a NODS Advisory Panel (O. Brown, chairman), an Archive Panel (M. Abbott, chairman), a Networks Panel (C. Koblinsky, chairman), a Catalog Panel (P. Cornillon, chairman), and a Non-NASA Missions Panel (F. Eden, chairman). During FY 86 and 87 these panels have completed and submitted reports on the status of oceanographic satellite data and information management in their respective domains, and provided recommendations to NASA for its future development of NODS. During the coming year, NASA will be working with SODSSWG and its panels to implement these recommendations. SODSSWG has also worked closely with the WOCE/TOGA Data Management Working Group (WTDMWG), chaired by F. Webster, to coordinate the satellite and in situ data management components for these programs. In future, SODSSWG will work equally closely with the data management groups of GOFS and other large-scale oceanographic research programs.

Within NASA's Earth Science and Applications Division (Code EE), a new initiative on Earth Science and Applications Data Systems (ESADS) was begun in FY 87. The Ocean Data Systems Program, along with the other Earth Science discipline programs in Code EE, is working under the ESADS framework to encourage resource sharing and interoperability among the discipline data systems (NODS, Pilot Climate Data System, Pilot Land Data System). This will facilitate access to data of interest to more than one discipline or user community, and is a necessary step in preparation for the increasingly interdisciplinary nature of Earth Science research. As the first operational data system of the NASA Pilots, NODS can provide useful leadership to NASA and the research community in this area.

In addition to general progress in the areas described above, specific accomplishments in the five panel areas follow.

1. NODS Advisory:

Following recommendations of the NODS Advisory Panel, NODS is actively pursuing a distributed architecture for its development with the requisite telecommunications network capability. Science requirements for the new Version 1 of the GOLD catalog, now under development, were derived from a Catalog Workshop held in October 1986, and further refined by NODS and the SODSSWG community. This catalog will support both satellite and in situ data, and will have standard interfaces between its directory, catalog, and inventory levels. The catalog will be made available to all NODS nodes, and other research institutions who desire to catalog their data in a compatible manner. It is also being designed in conjunction with the NASA Catalog Interoperability project, in which other NASA Earth Science data systems and NOAA/NESDIS are participants. NASA actively desires and solicits the participation of the user community in testing the current version of GOLD (and Version 1 when it becomes available), developing future versions of the catalog, and populating the catalogs with their local holdings of data, so that eventually a community-wide catalog system can evolve. Efforts to collaborate with NOAA and NSF-funded institutions in this arena have made good progress during the past year. NOAA is actively participating with NASA in catalog development and testing, and network links between the NASA and NOAA catalog sites are being implemented. The SODSSWG Catalog Panel was formed during FY 87 in response to the need for continuing science guidance to the cataloging activity, and to consider approaches for a future version (Version 2) of the evolving catalog system.

To enable full use of NODS/JPL computers for data management activities, Code EEC has provided separate computing facilities for the JPL oceanography group. JPL oceanographers will, however, remain closely involved with the quality assurance and data handling of data sets archived at their local NODS node. This close coupling of scientists to the archived data will be encouraged and maintained at all NODS nodes.

A special Ad-Hoc Working Group on Optical Storage Media for Satellite Oceanography was formed and provided a report in FY 87. The report (prepared by P. Zion) reviewed the status of optical disk storage media and the availability of industry standards. Currently, a variety of optical disk media are in use by the oceanography community, tailored to specific (and different) performance needs. The market was considered to be too much in flux at the present time for Code EEC to propose discipline-wide standards for optical disk hardware procurements.

Preparation at NODS for the processing, archiving, and distribution of SSM/I data has proceeded well in conjunction with NSIDC. A revised implementation plan is in place to govern the transfer of responsibility for SSM/I data from JPL to NSIDC during a 15-month period after initial receipt of the data.

An archive for Nimbus-7 CZCS global data products is being developed at NSSDC as a node of NODS. Initial products from this archive should become available during FY 88. An archive for derived SST products from AVHRR and other sensors is in the joint planning stage between NASA (Code EEC) and NOAA (NODC). A Science Working Group under the chairmanship of P. Cornillon has been formed to identify useful SST products and archive requirements in order that a NODS-compatible node can be established at NODC.

Significant progress has been made in improving the interfaces between NODS and the JPL flight projects. JPL has agreed in principle to the "one-stop shopping" concept, and a team comprising NODS and flight project personnel (TOPEX, NSCAT, ASF) is now actively working to produce an implementation plan. This will be assisted by the preparation of Project Data Management Plans (PDMPs) by each flight project, according to guidelines produced by NSSDC and as required by NASA Headquarters management.

2. Archive:

The general recommendations of the SODSSWG Archive Panel will be adopted during the coming years, specifically with regard to strengthening the links between the three "tiers" of data producers, small-scale data centers, and large-scale data centers.

NASA has participated in the preparation of a multi-agency Data Submission Policy for oceanographic in situ data. This provides encouragement and incentives for federally funded investigators to submit their quality-controlled and documented data sets to designated archives in a timely manner. Future versions of the policy will be extended where feasible to include satellite data sets.

Under the framework of the NOAA/NASA Data Management Working Group, links are being strengthened between NOAA/NESDIS and NSSDC. These include: network links between NOAA/SDSD and NSSDC; participation by NOAA on NASA data working groups and adoption of common terminology, catalog standards, and contents; and, formulation of agreements on archiving and charging policies for data sets of common interest. Under the framework of the Committee on Earth Observing Satellites (CEOS) Working Group on Data (WGD), discussions are underway with CNES and ESA (Earthnet Program Office) to encourage adoption of common data format and catalog standards for oceanographic satellite data. These efforts will be intensified in the coming year. Links between NODS and NSSDC will be improved with the imminent implementation of a NODS/NSSDC MOU to define the shared responsibility of these two archives for the long-term preservation and dissemination of oceanographic data.

With the development of NODS as a distributed system, NASA Headquarters, through its Ocean Data Systems Program, has an increased role in coordination and overall management of the system. This includes providing encouragement and incentives for university-based data archives to participate in the development of NODS. This will be a major thrust during the coming year. NODS/JPL will retain its role as the project management and coordination node of NODS with responsibility for system-wide standards and technical implementations.

3. Networks:

During FY 87 the initial implementation of the SPAN/Ocean network was completed. This included 9.6 kbps tail circuits to most of the major oceanographic institutions, and a 56 kbps backbone linking NASA centers. Some particularly high-rate routes were also provided 56 kbps lines. The SPAN/Ocean network is managed through NSSDC and provides electronic mail, file transfer, and data center access to the NASA oceanographic community.
Links to additional oceanographic centers are in the process of implementation. SPAN/Ocean will be of major use in the planning and implementation of the WOCE/TOGA data management program. The WTDMWG (F. Webster) has implemented a SPAN/Ocean Network Information Center (SONIC) to assist in the utilization of SPAN by ocean researchers.

New efforts are being made to provide connectivity to TCP/IP-networked oceanographic institutions, since SPAN is based on the DECNET communications protocol and a growing fraction of the user community are acquiring non-DEC (Digital Equipment Corporation) computer equipment. Proteon gateways have been installed at some sites to provide access by either protocol, and installation of Janus hosts (for protocol translation) are being implemented as part of the overall NASA Science Internet (NSI) project. The NSI will provide gateways to non-NASA networks such as NSFnet, BITnet, ARPAnet, etc.

The development of real-time ship support communications as part of NASA's networking activities is in the planning stage. A pilot demonstration is planned for FY 88 which, if successful, could lay the basis for continued integration of real-time satellite links into the ocean data network.

4. Catalog:

Present cataloging activities have been discussed in section 2 above. The SODSSWG Catalog Panel was formed subsequent to the other panels in recognition of the particular and important role catalogs play in unifying access to oceanographic data, both satellite and in situ. NASA is committed to making new technologies available to the community for locating, browsing, and ordering data in distributed archives. The Catalog Panel will provide a mechanism for science input to the design of future versions of the NODS catalog, and science involvement in its development and implementation.

5. Non-NASA Missions:

NODS (including nodes at the NSIDC, ASF, and NSSDC) will be the designated NASA archive for data from the DMSP SSM/I (derived products from polar regions only), Geosat ALT, E-ERS-1 SAR, J-ERS-1 SAR and OPS, Landsat-6 Sea-WiFS, and possibly RADARSAT and E-ERS-1 low bit rate radar data. If a node is established with NODC, NODS may also participate in the archiving of NOAA and E-ERS-1 ATSR SST products. Efforts are continuing at the interagency level to make arrangements for the reception and archiving of these data. Justification for NASA's initiatives in archiving these and future non-NASA data sets comes from SODSSWG Panels or special Science Working Groups convened by NASA for this purpose.

OCEAN TOPOGRAPHY EXPERIMENT (TOPEX/POSEIDON)

This international effort merges NASA's TOPEX with the POSEIDON oceanographic mission of France's National Center for Space Studies (CNES). The U.S. satellite will be launched by the French-provided ARIANE launch vehicle, carrying two French instruments in addition to five instruments provided by NASA, and NASA and CNES will collaborate on the TOPEX/POSEIDON Science investigations.

TOPEX was approved as an FY 87 new start. With this approval to initiate full-scale development of TOPEX/POSEIDON, launch is currently planned for December 1991. This date coincides with two major international field programs--the World Ocean Circulation Experiment (WOCE) and the Tropical Ocean Global Atmoshpere (TOGA) program.

Similarly, the French have recently received their budget approval, and the Memorandum of Understanding between NASA and CNES for the conduct of the joint mission was signed in March 1987. Also, NASA recently awarded the contract for the satellite development to the Fairchild Space Company. Approximately 60 proposals were received by NASA, and 25 by CNES, in response to the July 1986 NASA and CNES Announcements of Opportunity (AO). The selection of a Science Definition Team was completed on September 2, 1987. In addition to refining their own plans for specific research investigations with the data, this Team will advise the project on implementation matters crucial to the scientific success of TOPEX/POSEIDON. All other areas of the project are moving ahead similarly.

If NASA's FY 88 funding request for TOPEX/POSEIDON is approved at the level requested, work will continue as planned towards a December 1991 launch date. More specifically, preliminary design reviews are planned for all major elements of the project, including the satellite, sensors, and ground data system. In addition, final confirmation of the Science Team is planned.

NASA SCATTEROMETER (NSCAT)

The NASA Scatterometer (NSCAT) is an active microwave radar that will collect detailed global data on near-surface ocean winds. Although similar in design, NSCAT represents significant improvements over the prototype instrument flown on Seasat in 1978.

NSCAT had been planned for flight on the Navy's Remote Ocean Sensing System (N-ROSS) in September 1990. With the Navy's cancellation of N-ROSS in December 1986, our efforts shifted to identifying a suitable alternative platform for the flight of NSCAT in the TOPEX/POSEIDON timeframe. Six alternative platforms for NSCAT were examined with three currently viewed as viable. These are the Air Force's Defense Meteorological Satellite Program (DMSP), their Space Test Program (STP), and TOPEX/POSEIDON itself. At about the time these feasibility assessments were being completed, the Navy decided to reinstate the N-ROSS program with launch now planned for late 1991 (essentially the same as planned for TOPEX/POSEIDON). While the reinstatement process will not be complete until this Fall, we have tentatively shifted back to assuming that NSCAT will be flown on N-ROSS. To the extent feasible and practical, we are keeping the other fight options open should an unexpected problem develop with the N-ROSS reinstatement process.

If NASA's FY 88 funding request for NSCAT is approved at the requested level, work will continue toward an instrument delivery date of no earlier than February 1990 (as required by the N-ROSS schedule). In addition, development of the ground data system is being continued, as is the refinement of postlaunch research and verification plans, and final confirmation of the Science Team is planned.

OCEAN COLOR IMAGER (OCI)

An Ocean Color Imager (OCI) is one of the three instruments identified by the Joint Oceanographic Institutions Inc. as essential for the major oceanographic studies planned for the 1990s. In particular, satellite ocean color measurements are a key to the success of the Global Ocean Flux Study (GOFS), a major component of NSF's Geosciences Initiative. The scientific use of ocean color measurements will be greatly enhanced if the mission is concurrent with NASA and ESA altimeter and scatterometer missions scheduled for the early 1990s.

To meet the scientific, commercial, and operational requirements for global satellite ocean color measurements, the Earth Observation Satellite Company (EOSAT) is planning for an OCI (Sea Wide Field Scanner or Sea-WiFS) to fly on Landsat-6, scheduled for launch in late 1990. Under the EOSAT plan, NASA would share the cost of the sensor and develop a global data processing system and archive in support of GOFS and other science programs. Assuming that EOSAT remains viable, NASA's opportunity to support research use of

Sea-WiFS data will require budget augmentations beginning in FY 89 and the necessary funding is presently under review.

ALASKA SAR FACILITY (ASF)

Three SAR-equipped satellites are planned for launch in the early 1990's. These are the European Space Agency's First Remote Sensing Satellite (E-ERS-1), Japan's Earth Resources Satellite (J-ERS-1), and Canada's Radarsat. There is no provision for recording SAR data aboard E-ERS-1. Thus, as data are received by that satellite, they must be transmitted in real-time to ground receiving stations within view of the satellite. The J-ERS-1 spacecraft does have onboard recording capability and offers the prospect of a global data set.

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

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

Funds to begin design and implementation of the facility were authorized in the FY 86 budget and continue through FY 89. The highlight of the facility will be a new SAR processor currently under development at NASA's Jet Propulsion Laboratory. The processor will be capable of handling data from all three satellites, processing the raw data into images in about 1/10th real time (presently agreements are in place between NASA and ESA for acquisition of E-ERS-1 data at the ASF; acquisition of J-ERS-1 and Radarsat data at ASF are pending international agreements). An advanced data archive system is also under development and is being designed to facilitate access to the ASF by users from around the country. In anticipation of successfully concluding an agreement with the Japanese government, NASA's Goddard Space Flight Center is engaged in Phase A studies of an optical processor system that will make use of the optical sensor onboard J-ERS-1. The SAR related components of the ASF are planned to be functional in time for the launch of E-ERS-1 in April 1990.

TABLE 1

RECENT NASA SCIENCE WORKING GROUPS

SCIENCE WORKING GROUP	CHAIRMAN	ESTABLISHED	REPORT
Alaska SAR Facility Pre-Launch Science Working Team	Frank Carsey, JPL Willy Weeks, UAF	Jun. 1987	--------
Sea Surface Temperature Archiving Science Working Group	Peter Cornillon, URI	Mar. 1987	--------
Sea-WiFS Working Group	D. James Baker, JOI	Feb. 1987	Aug. 1987
Polar Communications Working Group	Ted Rosenberg, U. of Md.	Aug. 1986	Oct. 1987
Satellite Ocean Data System Science Working Group:	D. James Baker, JOI	Nov. 1985	see below
NODS Advisory Panel	Otis Brown, U. of Miami		Mar. 1987
Networking Panel	Chet Koblinsky, GSFC		May 1987
Archiving Panel	Mark Abbott, SIO/JPL		Sept. 1987
Non-NASA Missions Panel	Frank Eden, JOI		Jun. 1987
Cataloging Panel	Peter Cornillon, URI		--------
Ice Sheet Science Working Group	Robert Thomas, JOI	Apr. 1984	Nov. 1985
Ocean Surface Energy Fluxes Science Working Group	Peter Niiler, SIO	Mar. 1984	Aug. 1985
West Coast Chlorophyll Temperature Time Series Science Working Group	Mark Abbott, SIO/JPL	Jun. 1984	Jun. 1985
SSM/I Sea Ice Research Science Working Group	Norbert Untersteiner, U. of Wash.	Dec. 1982	Jun. 1984
In-Situ Science Working Group	Russ Davis, SIO	Sept. 1981	Mar. 1984
ERS-1/SAR Sea Ice Study Team	Gunter Weller, U. of Alaska	Apr. 1982	Dec. 1983
Satellite Ocean Color Science Working Group	John Walsh, BNL/Stonybrook	Oct. 1981	Dec. 1982
Satellite Surface Stress Team (S-Cubed)	James F. O'Brien, FSU	July 1981	July 1982
Topex Science Working Group	Carl Wunsch, MIT	Feb. 1980	Mar. 1981

TABLE 2

OCEAN-RELATED SPACECRAFT: NEXT DECADE

SATELLITE	SPONSOR	OCEAN-RELATED SENSORS/COMMENTS	LAUNCH	STATUS
NOAA Series	NOAA	IR (AVHRR)	On-going	Operational
GEOSAT	USN	ALT	Mar. 1985	Operational
MOS-1	JAPAN	CS, IR, MR	Feb. 1987	Operational
DMSP Series	USAF	MR (SSM/I)	Jun. 1987	Operational
	NASA	Data Facility with NSIDC		Approved
SPOT-2	CNES	Tracking System	1988	Approved
MOS-1B	JAPAN	CS, IR, MR	1990	Proposed
E-ERS-1	ESA	ALT, SAR, SCAT, IR	Mar. 1990	Approved
	NASA	Alaska SAR Facility		Approved
LANDSAT-6	EOSAT	CS (Sea-WiFS)	1991	Proposed
	NASA	Data Purchase & Data Facility		Proposed
TOPEX	NASA	ALT, Tracking	Late 1991	Approved
POSEIDON	CNES	ALT, Tracking		Approved
N-ROSS	USN	ALT, MR	Early 1992	Reinstated?
	NASA	Contribute SCAT		Approved
J-ERS-1	JAPAN	SAR, VR	1992	Approved
	NASA	Alaska SAR Facility		Proposed
E-ERS-2	ESA	ALT, SAR, SCAT, IR	1993	Proposed
GRM	NASA	Two low satellites	1993	Proposed
SOLID EARTH	ESA	GRADIO	1993	Proposed
ADEOS	JAPAN	VS, CS (OCTS),.....	1993	Proposed
RADARSAT	CANADA	SAR	1994	Contingently Approved
	NASA	Contribute Launch		Proposed
	NOAA	Distribute Data		Proposed
	UK	Contribute BUS & Sensor		Proposed

GEOSAT — This is a U.S. Navy sponsored mission to provide the Defense Mapping Agency with a larger quantity of altimeter data of Seasat quality. The primary, eighteen month mission to map the marine geoid should be completed in late summer or early fall 1986. Following this is an eighteen month oceanographic mission (known as the Exact Repeat Mission) having a 17 day repeat cycle and a 150 km equatorial track spacing. In general, the mean sea surface data from the initial eighteen-month geodetic mission will be classified, with the residuals from this surface being unclassified. Although not yet formally promulgated, data from the second eighteen-month mission are planned to be unclassified.

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.

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

SPOT-2 — This French satellite will carry the prototype of the DORIS tracking system, which will be subsequently flown as a French contribution on the TOPEX/POSEIDON mission.

MOS-1B — This is a duplicate of MOS-1.

ESA's ERS-1 — The European Space Agency's First Remote Sensing Satellite is a marine science and applications mission whose purpose is to establish, develop and exploit ocean and ice applications of remote sensing data. On board the spacecraft, planned for sun-synchronous orbit, will be a C-band SAR (for obtaining high resolution maps and, in a low power mode, for use as a wave scatterometer), a radar altimeter and an along-track scanning radiometer. The satellite is planned for launch in April 1990. Acquisition and exchange of E-ERS-1 data between ESA and NASA is the subject of a Memorandum of Understanding (MOU) signed in January 1986.

Sea-WiFS — Sea-WiFS is an improved version of the Coastal Zone Color Scanner which operated on Nimbus-7 from 1978-1986. EOSAT is planning to put Sea-WiFS on Landsat-6. NASA's role would be to share the cost of the sensor and develop a global data processing and archive system to support research users of Sea-WiFS data.

TOPEX/POSEIDON This is a dedicated altimeter mission whose data--when combined with data from NASA's Scatterometer on N-ROSS--will be utilized to advance our understanding of the general circulation of the oceans. TOPEX/POSEIDON is a joint mission between NASA and CNES. Agreement has been reached whereby NASA will provide the satellite and TOPEX sensors and CNES will provide an Ariane launch and the POSEIDON sensors. The orbital characteristics are: inclination of 63 degrees, altitude of 1300 km, equatorial track spacing of 300 km, and track repeat of 10 days. Primary tracking will be provided by DMA's Tranet system. Satellite design studies have been completed, and according to present schedules, TOPEX/POSEIDON will be launched in December 1991, thus providing a significant overlap with the N-ROSS/NSCAT mission.

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

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

E-ERS-2 This is a duplicate of ESA's E-ERS-1.

GRM This is a proposed NASA 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.

SOLID EARTH This is a proposed ESA mission to fly the GRADIO system for the purpose of improving our understanding of the Earth's gravity field.

ADEOS — This is the proposed Japanese Advanced Earth Observation Satellite. It is viewed as an intermediate step between the J-ERS-1 and the technically more sophisticated Japanese Polar Platform.

RADARSAT — This is a mission employing a C-Band SAR to monitor sea ice characteristics in the Arctic Ocean and marginal seas. Measurements would be used to support shipping and petroleum exploration operations principally in the Beaufort and Labrador Seas by providing forecasts of sea ice conditions. The Canadian government has recently approved Radarsat contingent upon working out acceptable arrangements with NASA, NOAA, and the UK.

ACRONYMS

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

SPACEBORNE OCEAN-SENSING TECHNIQUES

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

SECTION II - PROJECT AND STUDY SUMMARIES

NIMBUS-7 OBSERVATORY

Dr. Edward J. Hurley, Nimbus Manager, GSFC
Code 636, Greenbelt, MD 20771, 301-286-9414

The Nimbus-7 Satellite, in operation since 1978, continues to be the most significant source of experimental data from Earth orbit relating to atmospheric and oceanic processes. Two of its eight experiments have been primarily involved in observations of the oceans. The Coastal Zone Color Scanner (CZCS) instrument, which has collected observations of ocean color parameters for over eight years, was turned off in the summer of 1986 due to insufficient spacecraft power. Attempts to restart the instrument in December 1986 failed, and the instrument will remain off permanently. The Scanning Multichannel Microwave Radiometer (SMMR), operating without the 21 GHz channel which was turned off permanently in March 1985 due to spacecraft power limitations, is still returning data on sea surface temperature, sea surface wind, total column water vapor, and sea ice. The development of data sets from these experiments is discussed below.

COASTAL ZONE COLOR SCANNER (CZCS)

Gene Carl Feldman, GSFC, Code 636, 301-286-9428

The Coastal Zone Color Scanner (CZCS) was operated through June 24, 1986 at which time it was turned off. Repeated attempts to restart the instrument were carried out during December 1986 with no success. Based upon these tests, the sensor's operating characteristics for the past few years and on the recommendation of the engineers responsible for the spacecraft's operation, it was decided to declare the CZCS non-operational.

The major problem with the CZCS during the last two years of its operation was the failure of the system's scan motor and momentum compensation motor to achieve proper synchronization which resulted in an automatic shutdown of the sensor. This "sync failure" has been traced to the scan motor encoder and, in particular, to the light emitting diode (LED) that is used to determine the motor's rotation speed. The performance of the LED is correlated with temperature and for a period it was possible to obtain sync by heating the sensor. However, as the LED degraded over time, it was no longer possible to heat the sensor enough to obtain synchronism.

During its lifetime, the CZCS acquired approximately 66,000 individual scenes which are currently archived on 23,000 1600 bpi magnetic tapes. The Nimbus Project in collaboration with the GSFC Laboratory for Oceans and the University of Miami has begun production of a Global Ocean Color Data Set. The production, status and proposed archival of this data set are described in a separate article in this annual report.

SCANNING MULTICHANNEL MICROWAVE RADIOMETER (SMMR)

Dr. Daesoo Han, GSFC, Code 636, 301-286-2560

The objective of the Scanning Multichannel Microwave Radiometer (SMMR) is to obtain sea surface parameters required by oceanographers for developing and testing global ocean circulation models and other aspects of ocean dynamics. These parameters include sea surface temperatures, near surface wind speed, sea ice parameters and total atmospheric water vapor. All parameters are derived from open ocean observations.

Seven years of data have been processed, validated, and archived at the NSSDC. The archived data are: (a) TCT: calibrated brightness temperature for each channel in its original pixel resolution, (b) TCT $1/2^{o}$ map: TCT data mapped into a $1/2^{o} \times 1/2^{o}$ (55 km resolution) grid system, (c) TCT $1/4^{o}$ map: 37 GHz data from TCT, mapped into a $1/4^{o} \times 1/4^{o}$ grid system, (d) CELL data tape: calibrated brightness temperature data arranged by orbit and binned into cells ranging in size from 30 km x 30 km to 150 km x 150 km, (e) PARM tape: extracted geophysical parameters, i.e., sea surface temperature, sea ice concentration, multi-year ice fraction, total atmospheric water vapor and near surface wind speed in the same format as the corresponding level 1 CELL data and (f) MAP tape: PARM tape data mapped into mercator and polar stereo projections. Beginning with the sixth year of data, MAP products are being replaced by a new product called PARMAP. Each PARMAP tape contains individual geophysical parameters mapped with a $1/2^{o} \times 1/2^{o}$ spatial resolution Earth grid. This change in format was adopted to facilitate scientific uses of the data that involve combining and/or comparing SMMR data with weather satellite and surface observations. PARMAP will also be produced for data years 1 through 5 and beyond. All data are in the form of computer compatible tapes. In addition to the tape specification for each of the aforementioned data tapes, three user's guides are available: (a) CELL Data User's Guide, (b) PARM Tape User's Guide and (c) MAP Tape User's Guide. All documentation may be obtained from the NSSDC or from the Nimbus-7 Project at the GSFC.

The SMMR Calibration Assessment Team (SCAT) was formed in August of 1986 to assess the SMMR instrument response characterization and to recommend methods of improving the brightness temperature data set. The SCAT has identified three basic problem areas: long-term drift, warm-up transients, and other systematic errors. Based upon studies performed by the SCAT scientists and by other SMMR data users, the SCAT will recommend a new calibration scheme which will be the basis for an improved brightness temperature data set.

TIROS-N/NOAA Series

Dr. Joel Susskind
Code 611
NASA Goddard Space Flight Center
Greenbelt, MD 20771
(301) 286-7210 or FTS 888-7210

Project Objectives

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

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

Instrumentation

1) Advanced Very High Resolution Radiometer (AVHRR)
This scanning radiometer (4-channel on TIROS-N, NOAA-6, and NOAA-8 and 5-channel on NOAA-7, NOAA-9, and NOAA 10) 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, cloud cover, total ozone burden, and outgoing longwave radiation 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, NOAA-10 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 NOAA-10, 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 afternoon satellite in a 1430 LST ascending orbit at the equator. Both are in sun synchronous orbits at an average altitude of approximately 830 km with orbital periods of 102 minutes. Each satellite provides essentially global coverage twice daily. NOAA-9, launched in December 1984, is the current afternoon satellite, replacing NOAA-7 launched in 1981, and TIROS-N launched in 1979. NOAA-9 contains the 5 channel AVHRR and is the first satellite containing SBUV and ERBE. MSU on NOAA-9 failed in March 1987, seriously degrading the capabilities of the HIRS2 instrument. NOAA H is scheduled for launch in the Fall of 1987 to replace NOAA-9. NOAA-10, launched in September 1986, is the current morning satellite. NOAA-10 contains the 5 channel AVHRR and ERBE but does 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, M.D., and 4) readout of onboard recording selected highest resolution (LAC) data. AVHRR and TOVS data are archived at NOAA/NESDIS 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 December 1978 to present. Both tapes and picture imagery are available on request. SBUV and ERBE products are not yet available.

OCEAN TOPOGRAPHY EXPERIMENT (TOPEX)

Charles A. Yamarone, Jr., Topex Project Manager, Jet Propulsion Laboratory, MS 264-686, 4800 Oak Grove Drive, Pasadena, CA 91109; Phone (818) 354-7141 or FTS 792-7141

Robert H. Stewart, Project Scientist, Jet Propulsion Laboratory, MS 264-686, 4800 Oak Grove Drive, Pasadena, CA 91109; Phone (818) 354-3327 or FTS 792-3327

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

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

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

Current Status: Topex/Poseidon was approved by the US Congress in October 1986, and by the French government in early 1987. In anticipation of the approval of the program, NASA and CNES issued coordinated Announcements of Opportunity in July 1986 for research in oceanic circulation based on data from the mission. The proposals received in response to the announcement are being reviewed, and both agencies expect to select a team of Principal Investigators in September 1987.

The proposed mission includes a launch of the Topex/Poseidon satellite by Ariane in late 1991, a satellite designed to last three years with sufficient expendables for an additional two years, and a system to process and distribute data. The satellite will be based on existing designs, and the Jet Propulsion Laboratory is negotiating a contract with Fairchild Space Corporation for obtaining the Topex satellite. The satellite will operate in an orbit with an altitude of 1334 km and an inclination of 63.4°. The orbit minimizes the influence of tidal aliases on the measurements of sea level; it repeats exactly every ten days to minimize the influence of geoidal undulations on measurements of the temporal variability of sea level; and it passes directly over two planned calibration sites, one at Bermuda to be operated by NASA, and one near Dakar to be operated by CNES pending approval by the government of Senegal. Because the NASA and CNES altimeters will share a common antenna, the CNES altimeter will operate on a schedule agreeable to both NASA and CNES. Present plans call for the CNES altimeter to operate for one day out of twenty (for 5% of the time) while the NASA altimeter is turned off; but this arrangement will be reevaluated after launch when data from both altimeters are available.

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

Science Working Team: An Announcement of Opportunity (AO) soliciting proposals for scientific research utilizing data from the Topex/Poseidon mission was released in July 1986 by both NASA and CNES. Fifty-nine proposals were received by NASA and twenty-five proposals were received by CNES in response to the AO. These proposals covered a broad range of oceanographic, geophysical, and geodetic research topics. After completing the review process, the following investigators were selected by NASA:

Principal Investigator	Submitting Institution
Dr. George Born	University of Colorado
Dr. Derek Burrage	Australian Institute of Marine Science, Australia
Dr. Dudley Chelton	Oregon State University
Dr. John Church	Commonwealth Scientific and Industrial Research Organization, Australia
Dr. Bruce Douglas	National Geodetic Survey, NOAA
Dr. Lee-Lueng Fu	Jet Propulsion Laboratory, NASA
Dr. Eli Katz	Lamont-Doherty Geological Observatory, Columbia University
Dr. W. Timothy Liu	Jet Propulsion Laboratory, NASA
Dr. Roger Lukas	University of Hawaii
Dr. James Marsh	Goddard Space Flight Center, NASA
Dr. James Mitchell	Naval Ocean Research and Development Activity
Dr. Richard Rapp	Ohio State University
Dr. Braulio Sanchez	Goddard Space Flight Center, NASA
Dr. Jiro Segawa	University of Tokyo, Japan
Dr. P. Ted Strub	Oregon State University
Dr. Chang-Kou Tai	Scripps Institution of Oceanography, University of California, San Diego
Dr. Keisuke Taira	University of Tokyo, Japan
Dr. Byron Tapley	University of Texas
Dr. John Wahr	University of Colorado
Dr. Carl Wunsch	Massachusetts Institute of Technology

NASA SCATTEROMETER (NSCAT) PROJECT

Benn Martin
Jet Propulsion Laboratory, 264-325
Pasadena, CA 91109
(818)393-5926

The NSCAT Project is developing a backscatter Ku-band radar instrument and associated ground data processing system to produce frequent high-resolution measurements of near-surface vector winds over the global oceans. During the past year the Project accomplished a number of significant milestones, in spite of a large (60%) reduction in requested funding. This budget reduction was a consequence of a fifteen month delay in the launch of the N-ROSS (Navy Remote Ocean Sensing System) spacecraft, which will carry the NSCAT radar instrument. The Navy now plans to select the spacecraft contractor early next fiscal year and to launch in September 1990.

The NSCAT Science Definition Team (SDT) was formed and the first SDT meeting was held at JPL. All fourteen investigator teams, representing a broad range of oceanographic and meteorological research interests, participated; in addition, an N-ROSS representative was appointed by the Navy and was present. Six SDT subcommittees were formed to advise the Project on a range of subjects, including model function, data records, and geophysical validation.

The first formal NSCAT Project Reviews were conducted; the Project Requirements Review, and Instrument and Data Systems Preliminary Design Reviews, were well-attended and well-received. Approximately three dozen non-JPL individuals attended, including Bill Townsend (NSCAT Program Manager), Captain Neil Holben (N-ROSS Program Manager), and representatives from LaRC, GSFC, NOAA, NRL, RCA, and the NSCAT subcontractors.

As a consequence of the budget reduction, the contract for the instrument radio frequency (RF) subsystem could not be awarded as planned. Furthermore, due to the N-ROSS launch delay it was decided to select two contractors, one for the traveling-wave-tube (TWT) high-voltage power supply, and a second for the balance of the RF electronics. At present, contracts are in place for the instrument TWTs, antennas, high-voltage power supply, and RF electronics.

The architecture for the NSCAT ground data processing system has been established and detailed design is well underway. An algorithm development test bed is nearly complete with breadboard software developed for processing the raw data into sensor and geophysical data products, e.g., the final near-surface wind vectors. In addition, the development of the detailed technical performance requirements for competitive procurement of the large data processing computer has begun.

DMSP SSM/I Sea Ice Archive

Roger G. Barry, Director
Ronald L. Weaver
National Snow and Ice Data Center
CIRES, Campus Box 449
University of Colorado
Boulder, Colorado 80309-0449
(303) 492-5171

and

Charles S. Morris
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-8074

On June 19, 1987, a Defense Meteorological Satellite Program satellite was launched into polar orbit from Vandenberg Air Force Base. Carried onboard is the first of a new generation of passive microwave radiometers, the Special Sensor Microwave/Imager (SSM/I). Initial reports indicate that both the sensor and spacecraft are healthy and providing good data. Afer a 90-day impound period imposed by the Navy for initial evaluation, data from the SSM/I instrument will become available for general use. The National Snow and Ice Data Center (NSIDC) and the NASA Ocean Data System (NODS) have undertaken a joint effort to develop a processing and archiving system for SSM/I data of interest to sea ice researchers. NSIDC will have the long-term responsibility for processing and archiving the data using this system.

The starting point of this effort was the NODS archive system developed at JPL to provide easy on-line access to Seasat and GEOS-3 data. The archive system has been modified by NODS to permit the loading of SSM/I data on a routine basis. As part of the loading procedure, several different archives will be created. The SSM/I swath antenna temperatures received from NOAA's Satellite Data Services Division will be converted into swath brightness temperatures and stored in a Rapid Access archive. This archive will be used as input to create gridded (Level 3) products, including daily average brightness temperatures for each of the seven radiometer channels and three-day average sea ice concentrations (1st-year, multi-year, and total ice) mapped onto north and south polar grids. The brightness temperature grids will have a resolution of 12.5 kilometers (km) for the high resolution 85 GHz channels and 25 km for the other five channels. The ice concentrations will be displayed on a 50 km grid. In addition, there will also be daily ice edge location data with 12.5 km resolution derived from the 85 GHz channels and monitor area histograms which will provide a check on possible instrument drift. One "browse" image every six days on a 100 km grid will be available for each brightness temperature channel and sea ice concentration. These browse images are designed to allow researchers to rapidly scan the available data.

The available products from the DMSP SSM/I sea ice archive include images (Tektronix 4107 terminal required), browse images, contour plots, tabular data, and histograms. The data may be displayed or ordered interactively.

After the first six months of data processing by NODS, there will be a gradual shift in operational responsibility to NSIDC. NSIDC has been provided with the SSM/I data processing, archival, and distribution software developed at JPL and will continue to receive software updates as appropriate. During this period, NODS will distribute data to the NASA SSM/I Sea Ice Validation Team. NSIDC will distribute data to all other users. Approximately 15 months after the data become available, NSIDC will assume complete responsibility for the production, archival, and distribution of all SSM/I sea ice products.

Due to the vast amount of data involved, most of the SSM/I data archived by NSIDC and NODS will be stored on optical platters. Both NODS and NSIDC have optical drives for reading (many times) and writing (once) to the optical platters. NODS is currently purchasing an optical platter jukebox which will automate the mounting of platters on the drives and, thus, permit more rapid response to user requests. NSIDC is also planning to purchase a jukebox in the future.

Current Status - NODS:

The SSM/I specific software has been completed and tested using simulated SSM/I data. Optical disk drives have been purchsed and a jukebox should be in-house in the near future. SSM/I data loading procedures have been specified. NODS is working closely with the NASA SSM/I Sea Ice Validation Team to insure that their data needs are met. The NODS-NSIDC SSM/I Implementation Plan has been updated to reflect the actual launch date.

Current Status - NSIDC:

The Cryospheric Data Management System (CDMS) is the NSIDC version of the NODS system. During this past year, Version 3.0 of the NODS software was installed and pre-launch hardware acquisitions were all completed. Initial tests of the NODS software have been successfully completed on the CDMS VAX 11/750.

As a preparatory activity for the SSM/I data processing at NSIDC, NIMBUS-7 SMMR data are being integrated into the CDMS and will be available for distribution to the research community by the Fall of 1987. The seven year SMMR data set includes dual polarized 18 and 37 GHz data regridded into the SSM/I data format. The regridding procedure (carried out by the Goddard Space Flight Center Oceans and Ice Branch) simply involves rebinning of the slightly coarser 30 km SMMR data to the 25 km SSM/I grid, introducing slight distortion into the SSMR data. This disadvantage is outweighed by the advantage to the user in having more flexible access to the data via the CDMS and in a format that will facilitate direct comparison of SMMR and SSM/I data sets.

ALASKA SAR FACILITY (ASF)

Dr. F. D. Carsey
Mail Stop 169-236,
(818) 354-8163; FTS 792-8163
Dr. Young H. Park
Mail Stop 169-236
(818) 354-5170; FTS 792-5170 and
Jet Propulsion Laboratory
4800 Oak Grove Dr.
Pasadena, CA 91109
Prof. Gunter Weller
University of Alaska Fairbanks
Fairbanks AK 99775-0800
(907) 474-7371

The Alaska SAR Facility (ASF) Project has approval to place a receiving station and SAR data processing and archiving systems at a suitable site in Alaska in order to receive and process a total of up to 40 minutes per day of SAR data from the ERS-1 satellite of the European Space Agency, the ERS-1 satellite of the Ministry of International Trade and Industry of Japan, and the RADARSAT satellite of the Department of Energy, Mines and Resources of Canada. These satellites are scheduled to fly in the early-to-mid 1990s. The objective of the program is to support geophysical investigations with the SAR and Optical Sensor data from these satellites. At present scientific investigations are anticipated in polar oceanography, glaciology, geology, hydrology, and terrestrial ecosystems. Current planning calls for the station site to be on the University of Alaska campus on the edge of Fairbanks. The operation of the ASF is seen to evolve in 3 phases, Phase 1 will be restricted to E-ERS-1 data over Alaska; Phase 2 will include data from E-ERS-1 and J-ERS-1 covering the Alaska area and containing an uncertain amount of data from the remainder of the surface viewed by J-ERS-1 which carries a tape recorder; Phase 3 includes Radarsat and possibly E-ERS-2 and will be global in its observations.

The project elements which address SAR consist of project management including science program support, the Receiving Ground System (RGS), the SAR Processor System (SPS), the Archive and Operations System (AOS) and a Science Working Team (SWT) to conduct research with the data. Of these the first four elements are fully defined and budgeted, and the schedule for the SWT has been set at a selection in FY '89. The receiving station will receive and record SAR data (and OPS data if approved), the SAR Processor System will process the signal data into images of 3 basic sorts: a 1-look highest resolution complex phase image, a 4-look 30m resolution image, and a 60 look low resolution image. The output of the SPS will go to the AOS in tape and direct digital form. The geophysical products needed by investigators may be generated at ASF in a Geophysical Processing System to be defined in Fy 87-88 and implemented through proposals from outside ASF which are organized by ASF.

To provide scientific guidance to the ASF implementation effort in the period before the SWT is selected NASA has invited a group of scientists from the disciplines to receive substantial benefit from ASF data to form the ASF Prelaunch Science Working Team (PSWT). This group will monitor the utility of the Science Requirements, will track the progress of ASF and will advise on the prelaunch research program needed to optimize the utility of ASF data. The prelaunch research program includes the acquisition of airborne SAR data, the development of algorithms for geophysical processing of the image data, and other developments the PSWT feels are crucial.

In the period prior to approval a Science Working Group published a review of the benefits of an Alaska receiving station for SAR data, and concluded that the major applications would be in the area of sea ice geophysics with other applications in glaciology, geology, ecology, and oceanography. These findings are in *Science Program for an Imaging Radar Receiving Station in Alaska*, by G. Weller, F. Carsey, B. Holt, D. Rothrock and W. Weeks, JPL 400-207, Jet Propulsion Laboratory, Pasadena, CA 91109, 45p, 1983, and in *A Programme for International Polar Oceans Research (PIPOR)* by the PIPOR Group, B. Battrick, ed., ESA SP-1074, Paris, 42p, 1985. Other documents are now in process including *Science Plan for The Alaska SAR Facility* (by the PSWT), *Alaska SAR Facility Science Requirements: Receiving Ground System, SAR Processor System, and Archive and Operations System.* Analogous requirements for the Optical Scanner (OPS) on J-ERS-1 are now in the early stages of preparation. The science program management for the ASF also includes interactions with the flight agencies to secure access to the flight-instrument data in support of the SWT investigations. Proposals have been submitted to ESA ERS-1 for this data access, and selection results are due late in 1987.

NASA Ocean Data System (NODS)

J. Charles Klose
Victor Zlotnicki
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-5036

Data sets from past, present, and future ocean observing satellites represent a non-renewable national resource that must be preserved. The need for an information system that effectively curates and distributes these data sets has been identified by national and international scientific committees as an essential element in the flow of information from satellites to user. If a mature information system is to be in place in time to support NSCAT, TOPEX, ASF, and OCI data sets, we must continue to develop the NASA Ocean Data System. Common use of satellite data sets will not become a reality until effective access to these data sets can be provided.

PROGRAM OBJECTIVES: The objective of the NASA Ocean Data System (NODS) is to archive and distribute data sets from spaceborne ocean viewing sensors and, to a limited extent, data sets from in-situ measurement systems. NODS will provide a catalog of data sets relevant to ocean science that can be interrogated interactively. Interactive access will also be provided to a bibliography system which provides abstracts of documents relevant to data sets referenced in the catalog or held by the archive. NODS will archive data at various processing levels, ranging from levels 0, 1, and 2 swath-oriented data to levels 3 and 4 gridded data. NODS will produce and archive browse products which are designed to provide rapid response to users wishing to browse through data interactively. Users will be able to select data by time, region, project, sensor, data level, and measurement. Selected data can be displayed at the user's terminal, electronically transmitted to the user or written to magnetic or optical media for shipment to the requester.

APPROACH: NODS is designed to serve the data needs of researchers in NASA's oceanography program and in the wider community of NASA-associated ocean research programs (WOCE, TOGA, GOFS, etc.). NODS is a computer-based distributed system of archive and catalog "nodes" and user terminals or workstations, linked together by a computer network. NODS archive nodes contain data from NASA oceanographic spaceborne sensors, allied non-NASA oceanographic spaceborne sensors, and allied oceanographic in situ sensors. NODS refers to those components of the distributed system funded directly or indirectly by NASA. NODS will interface with other NASA disciplinary or interdisciplinary data systems (e.g. NCDS, CODD, etc.), data systems of other agencies (e.g. NOAA, NSF, USGS, etc.), and eventually may become integrated into an interagency ocean science or earth science data system. NODS may also develop network connections and data (or metadata) exchange standards and agreements with ocean-related data systems of other countries (e.g. Europe, Canada, Japan, etc.).

CURRENT STATUS: Major accomplishments in the past year are listed below.

1. Processed approximately 600 requests for Seasat and GEOS-3 data.

2. Delivered updated versions of the prototype GOLD catalog software system to eleven university and government laboratories.

3. Updated the DMSP SSM/I JPL NSIDC Operation Plan.

4. Made information about the JPL West Coast Satellite Time Series, the Miami AVHRR, the URI AVHRR, and the Scripps CZCS and AVHRR data sets available through the catalog system.

5. Completed development of the West Coast Satellite Time Series (WCSTS) data archive and distribution capability.

6. Delivered Version 3 of the archive system. Version 3 will support the archival of SSM/I, GEOSAT, TOPEX, and NSCAT data on digital optical disk storage devices.

7. Established a 15-node oceanographic computer communications network under SPAN and PSCN.

8. Published the User Requirement Document for Version 1 of the GOLD catalog.

9 Published an updated NODS User Handbook.

GEOSAT

Dr. Bruce Douglas
National Oceanic and Atmospheric Administration
National Geodetic Survey
N/CG11
11400 Rockville Pike
Rockville, MD 20853
(301) 443-8858

On 12 March 1985, the Navy's Geodetic Satellite, (GEOSAT), was successfully launched into a near circular orbit with an altitude of 800 km. The primary mission of GEOSAT (or Geodetic Mission) is to provide high density, intermediate and long wavelength gravity data over the global ocean for required improvements in the Navy's earth gravity models. The data from the geodetic mission is classified, although negotiations are underway to allow release of cross-over data from this period.

In October 1986, GEOSAT successfully completed eighteen months of its primary, classified mission. The satellite was then maneuvered into a 17-day exact repeat orbit whose ground track coincides with the previous Seasat altimeter tracks, allowing data from the Exact Repeat Mission (ERM) to be unclassified. The ERM officially became operational on 8 November 1986.

Under agreement reached with the U.S. Navy and the Johns Hopkins University Applied Physics Laboratory, the National Gedetic Survey of NOAA has assumed responsibility for generating the unclassified data sets from the ERM.

Raw data in the form of sensor data records (SDRs) are converted to finished geophysical data records (GDRs) by merging the altimeter data with an ephemeris provided by the Naval Astronautics Group and adding correction fields for tides, troposphere (wet and dry components) and ionosphere. The GEOSAT GDRs also provide global ocean significant wave heights and other ocean data derived from GEOSAT altimetry measurements.

Completed GDRs are made available to the public from the NOAA National Environmental Satellite Data and Information Service (NESDIS) in Washington, D.C. Data is presently being distributed to U.S. institutions only; non-U.S. citizens must request these data through the science officer of their country's embassy in the United States.

NESDIS receives GEOSAT data approximately 30 to 60 days after observation. A new data tape is received at NESDIS about every five weeks. Copies of the GEOSAT GDR data tapes are provided to customers on either an annual subscription or individual order basis.

Inquiries, Data Order Forms, User's Manual, etc., can be obtained from:

National Oceanic Data Center
User Services Branch
NOAA/NESDIS E/OC21
Washington, D.C. 20235
Telephone: (202) 673-5549 or FTS 673-5549
Electronic mail: OMNET, mailbox "NODC.WDCA"

NAVY REMOTE OCEAN SENSING SYSTEM (N-ROSS)

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

In November and December, 1986, the N-ROSS Program was reviewed jointly by the Assistant Secretary of the Navy for Research, Engineering and Systems, and a system acquisition panel composed of various deputies of the Chief of Naval Operations.

The review exposed a multi-million dollar cost overrun for the N-ROSS Program. The industry estimated cost for N-ROSS was nearly twice the initial estimates, and when viewed in relation to other priority war fighting system developments, the Navy determined N-ROSS to be unaffordable, and the Program was therefore cancelled.

In rebuttal, the U.S. civil oceanography community mustered a vigorous campaign to convince the Navy that the cancellation of N-ROSS would have a devastating impact on future national ocean research. Letters were sent to the Navy by, among others: Jim Fletcher, the Administrator of NASA; Eric Bloch, the Director of the National Science Foundation; Tony Calio, the Administrator of NOAA; Bill Graham, the Science Advisor to the President; and, several members of Congress.

These letters pointed out that N-ROSS had become a centerpiece for a major data collection effort scheduled for the early 1990s, supporting among other things the U.S. interest in the international WOCE and TOGA Programs. They also pointed out the potential advantages of combining N-ROSS with the other national and international satellite systems planned for flight during an overlapping time period.

After the cancellation, the Office of Naval Research (ONR), did a cost assessment for N-ROSS, trying to ascertain the reason for the large cost growth over the original budget and to look for modification to the N-ROSS plan that could save money. Suggestions were made to reduce the system cost while maintaining as much of the original desired capability as possible.

The Secretary of the Navy, John Lehman, reviewed the new ONR cost assessment in March. He was convinced N-ROSS could be built and operated for much less than the Navy had projected before the cancellation in December.

With these new reduced cost projections and the overwhelming support expressed by the civil oceanographic activities, the Secretary reversed his earlier decision and issued a directive to restart the N-ROSS Program. The Secretary signed the directive on April 10, the day he left office. One of the stipulations in the restart was that the remaining program development be capped at a total cost of $335 million. Ultimate N-ROSS Program responsibility also passed from the Navy to the Secretary of Defense for final review and approval.

The decision to reinstate the N-ROSS Program by the Secretary of the Navy must be put into proper perspective. What is inferred by such a directive is that the Program can be restarted if it can successfully compete for the limited funding available for all Navy development. The Program is now being considered in that light by the resource sponsors within Navy who will have to allocate funds to complete N-ROSS.

Even though the basis for the N-ROSS Program cancellation last December was cost, the Navy has since then performed an operational analysis review of the Program. This analysis attempts to show the overall effectiveness of N-ROSS in supporting Naval warfare. The outcome of the analysis did not show significant gains as a result of using a space oceanographic system, such as N-ROSS. The results are viewed by many Navy advocates as controversial. A major space system like N-ROSS has never been modeled for warfare simulation before, and, with several unknown variables, the accuracy of the algorithms and models used is questionable.

There are a series of things yet to be accomplished before a contract can be awarded to complete the development of N-ROSS. First, funds must be identified and reprogrammed. With available funding, the entire N-ROSS Program will be reviewed by the Assistant Secretary of the Navy for Research, Engineering, and Systems. This review is currently scheduled for Sept/Oct 87.

After that, the Program must undergo both a Defense Acquisition Board and a Defense Resources Board review, encompassing total program life cycle costs, acquisition strategies, and alternative programs. These reviews are under the purview of the Secretary of Defense for Acquisition and are scheduled for Oct/Nov 87.

After the N-ROSS Program was cancelled in December, NASA addressed options to protect our investment in NSCAT, the NASA scatterometer which is one of the proposed N-ROSS sensors. We are looking to identify other flight opportunities, other than N-ROSS.

One of these options is within the Department of Defense Space Test Program (STP). This program exists to provide flight opportunities for feasibility demonstrations and proof-of-concept for new potential space systems.

To obtain a flight opportunity in the STP, the NSCAT Program competed for a priority within Navy. It was ultimately ranked fourth out of twenty-one proposed experiments. When it later competed within all of DOD, it was ranked seventh. This is probably a high enough ranking in the STP to provide a flight opportunity in the 1991/1992 time frame. If the N-ROSS Program fails the DOD reviews this October and November, the Navy has the option of sponsoring and funding an NSCAT STP flight.

Two other flight options were considered for NSCAT if N-ROSS was not available. The first was to fly the scatterometer aboard TOPEX. Studies have been underway to ascertain the impact on both missions if the sensors were combined on one flight vehicle. The second was to fly NSCAT in the operational DMSP Program. In light of the reinstatement of the N-ROSS Program, no conclusions have been reached about either of these options.

In our final assessment, although we are very pleased that N-ROSS was reinstated by Secretary Lehman, we are very anxious to see the Navy identify adequate funding and the N-ROSS Program complete the DOD reviews this fall. The earliest N-ROSS launch now appears to be the first quarter of 1992. If, in the worst case, the Program fails to proceed to full scale development, we will solicit Navy assistance in readdressing the STP option and we will seriously consider our own option of flying NSCAT on TOPEX.

ERS-1: THE FIRST EUROPEAN REMOTE SENSING SATELLITE

Guy Duchossois, ERS-1 Mission Manager
European Space Agency (ESA)
8-10, rue Mario-Nikis
F-75738 Paris 15
France

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

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

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

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

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

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

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

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

- Spacecraft and payload control and mission management.

- Provision of SAR regional service, SAR operating time being limited to a maximum of ten minutes per orbit (i.e., duty cycle of 10%).

- Provision of low bit rate (LBR) global service thanks to the on-board tape recorder with a capacity allowing one complete orbit period (i.e., 100 minutes) of LBR data (i.e., data other than from the SAR sensor) to be stored.

- Generation and delivery within three hours from observation of a number of selected products called fast-delivery (FD) products, including SAR "Fast Delivery" images, wind speed and direction, wind speed at nadir, wave height at nadir, and wave image spectra.

- Archiving and generation off-line of precision and thematic products using national facilities provided to the Agency by some of its Member States (France, Germany, Italy, and UK).

To further promote and expand the utilization of ERS-1 data, ESA issued worldwide on May 20, 1986, an Announcement of Opportunity for scientific investigations, application demonstration experiments, and contributions to the geophysical data validation.

An unexpectedly large number of proposals (about 300) was received from 23 countries and five international organizations. Proposals address the whole spectrum of scientific and application research in the fields of ocean, ice, and land processes. The aim is to select Principal Investigators by the end of 1987.

MARINE OBSERVATION SATELLITE - 1 (MOS-1)

Koichi Ayabe
Earth Observation Center (EOC)
National Space Development Agency of Japan (NASDA)
1401 Ohashi, Hatoyama-Machi
Saitama, 350-03, Japan
telephone: (0492) 96-1611

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

Research Benefits: MOS-1 will provide information on water vapor contents, water surface temperature, distribution of ice floes, water chlorophyll concentration, detection of mineral and energy resources, land use classification, crop inventory, and so on.

Sensors: Three kinds of sensors are;

Instrument	Spectrum	Resolution	Sensor
MESSR	0.51 - 0.59 um	50 m	CCD
	0.61 - 0.69 um	50 m	CCD
	0.72 - 0.80 um	50 m	CCD
	0.80 - 1.10 um	50 m	CCD
VTIR	0.5 - 0.7 um	0.9 km	Si-Pin diode
	6.0 - 7.0 um	2.7 km, 0.5 K	HgCdTe
	10.5 - 11.5 um	2.7 km, 0.5 K	HgCdTe
	11.5 - 12.5 um	2.7 km, 0.5 K	HgCdTe
MSR	23.8 Ghz	32 km, 1 K	Dieke type
	31.4 Ghz	23 km, 1 K	Dieke type

In addition, Data Collection System Transponder is flown on board. Uplink/downlink frequency is 400/1700 MHz.

Product: CCT of five correction levels is available from NASDA/EOC.

Level 0	No correction
Level 1	Radiometric correction only
Level 2	Radiometric and geometric correction
Level 3	Precision correction (MESSR only)
Level 4	Precision registration (MESSR only)

Film or paper print of each band of each sensor and false color composite of MESSR are also available.

MOS-1 data will be distributed on a public non-discriminatory basis through the Remote Sensing Technology Center of Japan.

Launch Date: MOS-1 was successfully put into orbit by the N-11 launch vehicle on February 19, 1987, from Tanegashima Space Center off Kyushu Island. Three month in-orbit checkout shows both the satellite and instruments are working well as designed.

Current Status: MOS-1 is in 909 km sun-synchronous orbit with an inclination angle of 99 degrees. Recurrent period is 17 days. Time of descending node equator crossing is 10:05 a.m. NASDA Earth Observation Center is acquiring MOS-1 data and managing the mission control.

MOS-1 data will be acquired by Tokai University Space Information Center at Kumamoto, Japan; Japanese Antarctic station (Showa station at 69.00 S and 39.35 W); Thailand station in Bangkok; four ESA stations (Maspalomas, Fucino, Kiruna, and Tromsoe) ; and, Australian station at Alice Springs.

MOS-1 Verification Program (MVP) is performed to evaluate sensor performance, estimate the influence of atmosphere, and verify the effectiveness of sensor parameter. As the result of AO selection, 95 themes are accepted from 78 organizations where 18 organizations from 11 foreign countries are included.

As a successor of MOS-1, MOS-1b is requested to the Space Acitivity Committee to be launched in early 1989 when the design life of MOS-1 expires. MOS-1b is a refurbished prototype model of MOS-1.

EARTH RESOURCES SATELLITE - 1 (ERS-1)

Tasuku Tanaka
Director, Earth Observation Program Office
National Space Development Agency of Japan (NASDA)
2-4-1 Hamamatsu-cho
Minato-ku, Tokyo 105, Japan
telephone: (03) 435-6166

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

The mission lifetime will be two years.

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

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

Planned Launch Date: ERS-1 is planned to be launched in early 1992.

Current Status: In 1980, the basic study of ERS-1 was started by NASDA. Since 1985, under a task-share agreement, the Ministry of International Trade and Industry (MITI) has been responsible for the development of mission equipments (SAR, VNIR, SWIR, Mission Data Recorder, and Mission Data Transmitter) and NASDA for the development of bus equipments, integration of the mission and bus equipments into a satellite system, tests of the system, launch and tracking and control of the satellite.

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

Preliminary design of ERS-1 was completed in 1985. Critical design began in 1986 after the basic design.

SATELLITE OCEAN DATA SYSTEM SCIENCE WORKING GROUP (SODSSWG)

H. Frank Eden
Joint Oceanographic Institutions Inc. (JOI)
1755 Massachusetts Ave., N.W.
Washington, DC 20036
(202) 232-3900

Objective and Scope:

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

1) the conceptual design of a distributed data system to collect, archive, and distribute data from various flight projects (e.g., TOPEX, N-ROSS/NSCAT, NOAA/AVHRR & OCI, DMSP, SSMI, SAR). This system includes processing and analysis centers at oceanographic institutions, universities, and government facilities and national archives (both U.S. and foreign);

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

3) analysis of the relationship of this system to other systems planned for operational use of satellite data;

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

5) an identification of present and potential agency roles in the implementation of such a system.

Status:

SODSSWG was established in 1985 and consists of a central committee of approximately 20 members. These members and other representatives from government agencies, the academic community, and industry are organized into five panels which include:

- A NODS advisory panel that considers data sets to be added, deleted, and reprocessed, user needs and services, science inputs, and priorities and budgets for the NASA Ocean Data System (NODS). The chairman is Otis Brown, RSMAS, University of Miami.

- A panel on networking which considers existing and planned systems, such as SPAN and UNIDATA, and their interaction with PSCN, future costs, relationships to users both of satellite and non-satellite data, e.g., the TOGA/WOCE community. The chairman is Chet Koblinsky, Goddard Space Flight Center.

- A panel on archiving that considers central and distributed centers, types of products, validation, quality control and analysis tools, support levels for various data sets, distribution systems, relationships between NASA and NOAA Centers and between U.S. and European Centers. The chairman is Mark Abbott, Scripps Institution of Oceanography, and the Jet Propulsion Laboratory.

- A panel on non-NASA flight projects that considers how data from both U.S. and non-U.S. projects can be made available, the user needs at various levels and necessary in situ data for validation. The flight projects to be considered would include U.S. projects, GEOSAT, NOAA missions, N-ROSS and DMSP, and possible shuttle data such as SIR-A and B. Non-U.S. projects would include E-ERS-1, MOS-1, J-ERS-1, and possibly RADARSAT. The chairman is Frank Eden, Joint Oceanographic Institutions Inc.

- A panel on the cataloging of satellite and in situ data that considers how data should be standardized, documented, and inventoried and what requirements a cataloging system should meet. The chairman is Peter Cornillon, University of Rhode Island.

Each panel has held separate meetings and produced a report on its activities in 1986 which includes specific recommendations for system design and agency action. Semi-annual meetings of the general SODSSWG have also been held. The latest meeting in June 1987 was held in conjunction with NOAA in order to discuss the coordination of the NASA and NOAA data management systems. Reports from each panel, and minutes of the SODSSWG meetings may be obtained from JOI.

Anticipated Benefits:

The goal of the SODSSWG is to design a national system of ocenaographic data centers that can process, inventory, catalog, distribute, and archive oceanographic data from both satellite and in situ measurements. Implementation and operation of this national system will require the cooperation of NASA, other agencies, and the oceanographic research community.

A national oceanographic satellite data system is essential to the future of oceanographic research and global studies which depend heavily upon these data and related in situ data.

MODERATE-RESOLUTION IMAGING SPECTROMETER INSTRUMENT DEFINITION PANEL

Wayne E. Esaias, Chairman
Code 671, Goddard Space Flight Center
Greenbelt, MD 20771
(301) 286-5465

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

Requirements generated by the oceanographer members of the MODIS Panel are based on experience with the Nimbus-7 CZCS and NOAA/AVHRR data. This has resulted in a need for at least 17 spectral bands in the wavelength region from 0.4 to 1.0 micrometer with the visible bands having bandwidths less than 20 nanometers and signal-to-noise in excess of 600:1. The near-infrared bandwidth and signal-to-noise requirements are less restrictive since those channels are principally used for aerosol corrections. The ocean color requirement having the greatest impact on the system is the requirement to point up to 20 degrees fore or aft of nadir to avoid specular reflection (sunglint) from the ocean surface. To accommodate this requirement it was proposed that the optical component of the MODIS system be divided into two packages to be designated MODIS-T (tilt) and MODIS-N (nadir); the former containing the visible and near-infrared channels requiring fore or aft of nadir viewing and the latter containing those channels with no requirement for off-nadir pointing, including all of the infrared (IR) channels requiring cooled detectors.

In summary, MODIS, as presently conceived, is a system of two imaging spectroradiometer components designed for the widest possible applicability to research tasks that require long-term (5 to 10 years), low-resolution (0.5 to 1.0 kilometer), global, multispectral (52 channels between 0.4 and 12.0 micrometers) data sets. The system is described in a NASA document published in 1986 entitled: "MODIS - Instrument Panel Report," available from NASA HQ, Code EEC. An Announcement of Opportunity for the entire Eos, including requests for proposals utilizing MODIS observations, is scheduled to be issued by NASA Headquarters in late 1987. Proposals in response to this AO will be used to select members of the MODIS Science Team, which will serve as the scientific advisory group during instrument development and operation. Dr. Vincent Salomonson is the Goddard Science Team Leader, and Dr. William Barnes is the Sensor Scientist.

PRODUCTION AND ARCHIVAL OF A GLOBAL OCEAN BASIN CHLOROPHYLL DATA SET

Gene Carl Feldman
Code 636
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771
(301) 286-9428

and

Richard W. Eppley
Institute of Marine Resources
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, California 92093
(619) 452-2338

and

Blanche W. Meeson
Code 634
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771
(301) 286-9282

The Nimbus-7 Coastal Zone Color Scannner (CZCS) acquired nearly 66,000 images between October 1978 and June 1986. This data set, using a consistent sampling strategy and single processing technique, represents the most comprehensive source of ocean color measurements to date. For most of the world's oceans, the changes in ocean color that can be measured from space are directly related to changes in near-surface phytoplankton pigment concentrations. Phytoplankton, the microscopic plants that grow in the upper, sunlit regions of the oceans, form the base of the marine food web and knowledge of their distribution and abundance is critical for many branches of marine ecology and fisheries science. In addition, since the fixation of carbon in the ocean by photosynthesis is about equal in magnitude to that occurring on land, an understanding of the temporal and spatial distributions of phytoplankton biomass and primary production is necessary to better assess the role of the ocean in the global carbon cycle.

The Nimbus Project Office in collaboration with the NASA/GSFC Laboratory for Oceans and the University of Miami/Rosenstiel School of Marine and Atmospheric Science have undertaken to process all the CZCS imagery to produce a Global Ocean Basin Chlorophyll Data Set and to provide easy access to the data products by the oceanographic community via NASA's National Space Science Data Center (NSSDC).

An image processing/analysis system utilizing recent advances in digital optical disc storage technology has been developed and is now operational in a production mode. Approximately 3,000 - 4,000 CZCS images are being processed each month with the data products being archived on digital optical discs. The transfer to optical disc storage has a number of advantages. For instance, a significant reduction in data storage media has been achived. Approximately 150 - 200 1600bpi tapes containing the level-1 CZCS data can now be stored on a single 12 inch optical disc platter. With the incorporation of an optical disc autochanger (jukebox), the system will have online access to nearly 160 gigabytes of data which will greatly faciliate the data flow through the system. At the current rate of production, the entire CZCS data set will be processed within 2 1/2 years.

A number of significant advances in algorithm development have taken place as a direct result of the production of the first prototype global ocean color image. The implementation of a new multiple scattering atmospheric correction algorithm has greatly increased the latitudinal range over which valid chlorophyll retrievals can be made. A revised interchannel gain calibration has also been tested and successfully implemented.

The data products will be archived by NSSDC in coordination with the NASA Ocean Data System (NODS) and Pilot Climate Data System (PCDS). In addition to archiving the original Level-1 data, the NSSDC archive will also contain the Level-2 data products of the derived geophysical parameters at high resolution (1 km) in satellite swath coordinates and the Level-3 earth-gridded products of these parameters. Composites of the key parameters (pigment concentration and diffuse attenuation coefficient) over weekly through annual time scales will also be archived along with the relevent compositing statistics. A catalog and inventory will be maintained on-line for remote access, search and ordering of the data products. A portion of the data set, primarily the Level-3 composites will be maintained on-line by the digital optical discs.

An external committee, with members largely from academia, met on March 25, 1987, to review plans for processing and archiving of the CZCS dat set. The members of the committee were: Richard Eppley (Scripps), Richard Barber (Duke), Dennis Clark (NOAA/NESDIS), Robert Evans (Miami) and Phil Zion (JPL). The committee enthusiastically endorsed plans to prepare daily, weekly, monthly and annual composite images and to make these available in the new archive. They concluded that the new products will be most useful if the work can be done in the next 2-4 years. The committee also endorsed the concept of a video disk browse file and concluded that this format may promote a much larger audience for CZCS images that has appeared to date. Other specific recommendations were sent to E. Njoku and J. Yoder at Ocean Branch and plans for implementation are presently being developed

The archiving effort to support the Global Ocean Basin Chlorophyll data set at the National Space Science Data Center is just getting off the ground. As recommended by the Science Advisory Panel, near-term and long-term archiving plans have been developed. In the near-term, the GOLD catalog as implemented by NODS at JPL will be installed at NSSDC and will provide interactive access to information about the CZCS archive. With this tool scientists will be able to identify and order images based on the scientific parameters, and the time and place of collection. There will be both digital and analog (video) data products in the archive. The digital data will be distributed on magnetic tape and on optical disks. In the long term, the archive will be transitioned to a slightly different catalog and archive system. This system will provide the same functional capabilities but will be able to support the entire data set (alimitation of the near term system). This system will also provide access to correlative data such as, sea surface temperature, sunlight, winds, and ozone. Digital data may also be distributed in more than one format at that time.

Sea Surface Temperature Archiving Science Working Group

Peter Cornillon

Graduate School of Oceanography
University of Rhode Island
Kingston, RI 02881
(401) 792-6283

As the interest in satellite-derived sea surface temperature fields has increased, so has the demand for products associated with these. Unfortunately, however, current SST products are not well-defined, their quality is not accurately assessed, and access to them is not adequate. NASA with NOAA's help would like to begin investigating questions related to such products. To this end the Sea Surface Temperature (SST) Archiving Science Working Group (SASWG) was formed under the auspices of NASA's Oceanic Processes Program, Code EEC. SASWG held its first meeting on 19 May 1987 in Baltimore, Maryland to begin to plan a distributed archive of satellite-derived SST data products, to be used primarily by research oceanographers.

SASWG has the following objectives:

- *To define the science requirements.* What SST products do oceanographic researchers need?
- *To identify existing and potential SST products (domestic and foreign) that will meet the science requirements now and in the future.* What SST products are needed—raw data and/or processed SST fields and to what level if processed? What are the latency, time, space (regional or global), and accuracy, requirements? What algorithms are available or in development? Are these algorithms adequate? Can new technology such as optical discs be used for distribution?
- *To plan assessment and validation.* How can the SST products be validated? What confidence level in the products is needed?
- *To set archive requirements.* How should the SST products be archived? What time limits are necessary? What kind of access is needed—real-time or retrospective? Should ancillary data be included (e.g., ship reports)?
- *To outline the system (costs, schedules, etc.) needed to produce the identified SST products if the system does not already exits.*
- *To write a final, summary report.*

The report of the first meeting includes lists of existing satellite-derived SST products and current users of these products, questionnaires distributed to users and their responses, lists of the different algorithms, and tables comparing satellite-derived SST data sets obtained using different algorithms to calibrate the sensor.

OCEANOGRAPHIC WIDE FIELD SENSOR
(SeaWiFS)

Robert G. Kirk
Code 671
NASA Goddard Space Flight Center
Greenbelt, MD 20771
(301) 286-7895

The NASA ocean color mission objectives are governed by the scientific requirements established by the NASA Ocean Color Science Working Group in the MAREX Report, and by the Joint EOSAT/NASA Working Group in the SeaWifs Report. The SeaWiFs science project will provide measurements of ocean color from space to which will support research into: a) the character of ocean physical and biological processes; b) to assess the global oceanic biomass; and c) to better understand the role of oceanic processes in modulating the Earth's biogeochemical cycles, including the CO_2 cycle as it is affected by fossil fuel combustion. This research will be conducted by NASA as well as the outside scientific community through an Announcement of Opportunity process.

The MAREX Report recommended that NASA develop and fly an Ocean Color Instrument (OCI) mission, and it also furnished baseline scientific performance specifications. Goddard, then, studied several spacecraft alternatives for such a mission. The present work extends the previous work to study the feasibility of on ocean color mission using the proposed compact Wide-field Sensor (SeaWiFS) an the EOSAT Corporation's LANDSAT-6 satellite.

We conducted a Phase A study which defines a NASA Facility Data System and accompanying Science Program for the EOSAT Company's commercial ocean color instrument called "SeaWiFS" to be launched on board LANDSAT-6 at the end of 1990. Codes 670, 630, and 620 participated in the study. A current working group chartered jointly by NASA Headquarters and EOSAT is providing final baseline characteristics.

Next year a GSFC Study Project will work with EOSAT and the Joint NASA/EOSAT Working Group to integrate the commercial and science baseline and develop a detailed NASA plan for implementation of a Science Data System for a FY 91 SeaWiFS launch on LANDSAT-6

The proposed concept assumes NASA input to the SeaWiFS specification and operational scheduling, and the receipt of worldwide, continual taped ocean color data from EOSAT, as well as direct read out of East Coast real time coverage at GSFC. EOSAT will forward taped ocean color data to a data processing system at GSFC. GSFC, in turn, will process all received data to scientifically useful form on optical disk format and distribute it to the research community in conjunction with the NASA Ocean Data System. Research community users include:

NASA Principal Investigators
Announcement of Opportunity participants
Domestic and foreign researchers, through the NSSDC

The Earth Observing System (Eos) Project

Richard E. Hartle and Ralph Kahn
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
(301) 286-8234

One of the most exciting new directions in Earth Science is the recent effort to address, in quantitative terms, the interactions among the atmosphere, oceans, and land surfaces that shape the environment of our planet. The Earth Observing System (Eos) is a multidisciplinary mission planned to provide the observational and data handling capabilities needed to study the Earth as a system, with emphasis on understanding the global scale processes that operate at or near the planet's surface. The conceptual basis for the Eos Mission was developed by the Eos Science and Mission Requirements Working Group (SMRWG), which was chartered to consider the broad Earth Science objectives that could be studied from low Earth orbit in the 1990s, and to identify the specific observations and instruments that would be needed to meet these science objectives (Butler et al., 1984). Subsequently, the Eos Science Steering Committee (SSC) was established to develop an implementation strategy for the Mission based upon the concepts set forth by the SMRWG. As part of the SSC's effort, six Eos instrument panels and an Eos data panel were formed to refine the plans. The instrument package under consideration will observe at wavelengths ranging from ultraviolet to microwaves (see table below), allowing for the first time near-simultaneous, global scale measurement of many environmentally significant parameters.

A unique aspect of the Eos concept which will affect the scientific use of the data is that the Mission is viewed as an Earth Science information system. Data production, validation, archival, documentation, and dissemination to a wide community of scientists representing varied disciplinary and multidisciplinary interests are an integral part of the Mission itself (Butler et al., 1984; Arvidson et al., 1985; Hartle and Tuyahov, 1986).

The SSC strategy places the Eos instruments on polar platforms that will be developed and flown as part of the Space Station complex. The SSC plan includes both research and operational instrument packages. The operational instruments will be delivered by NOAA, which also assumes responsibility for acquisition, archival, and distribution of the data produced. The research payload will be selected by NASA through a competitive selection process. Ultimately, four or more platforms, in sun-synchronous orbits, will participate in the Eos project, including one platform provided by the European Space Agency and one provided by Japan. In-orbit instrument servicing and replacement is part of the Eos plan, allowing Mission life to extend up to 15 years, as is required to detect many climatically significant variations.

A preliminary instrument manifest and deployment plan is shown in the table below, along with instrument acronyms in a second table. The platforms will orbit at an altitude of 824 km with morning and afternoon crossing times.

The broad scope of scientific issues to be addressed by Eos provides a rich opportunity for international scientific cooperation. Implementation of the program aimed at understanding the Earth as a globally interacting system will require coordination of operations, data exchange, and analysis from orbiting remote sensing instruments, in-situ measurement programs, laboratory efforts, and modeling initiatives. The Eos project is taking critical steps toward meeting this goal.

Eos BASELINE DEPLOYMENT SCENARIO
824/824 KM*

PLATFORM	NPOP - 1	NPOP - 2	EPOP - 1	JPOP - 1
ALT/CROSSING	824 KM/1:30 PM	824 KM/1:30 PM	824 KM/9:30 AM	800KM/10-12:00 NOON
RESEARCH	MERIS (MODIS-T)	SAR	HRIS	OCTS
	MODIS - N	IR-RAD	ATLID	(MODIS - N)
	HIRIS	SUB-MM	GLRS	AVNIR
	ITIR	F/P-INT	SCATT - 2	LAWS
	AMSR		ALT - 2	AMSR
	SCATT - 1	MAG	SAR - C	(SAR - L)
	ALT - 1	MPD	ATSR +	SAR - X
	CR	PEM	CSR(ERBI SCANNER)	
	MAG	SUSIM	MAG	
	MPD	MLS	MPD	
			AMIR	
OPERATIONAL	AMRIR (2)		AMRIR (2)	
	GOMR		ERBI (NS)	
	ERBI (NS)		AMSU (2)	
	ERBI (S) (CSR)		SEM	
	AMSU (2)			
	SEM			
OTHER	ARGOS +	DB	ARGOS +	
	S & R	P/L-EXEC	S & R	
	DB		PPS-PODS	
	PPS-PODS		(DB)#	
	P/L-EXEC			

* REVISION 2 FROM INTERNATIONAL COORDINATED WORKING GROUP MEETING, OTTAWA, MAY 1987
# MASS IN S/C BUDGET
(2) REDUNDANT INSTRUMENTS
(ACRONYM) PROPOSED PAYLOAD

ACRONYMS ICWG SCENARIO

JULY 1987

ALT	RADAR ALTIMETER (1-NASA, 2-ESA)
AMIR	ADVANCED MICROWAVE IMAGING RADAR
AMRIR	ADVANCED MEDIUM RESOLUTION INFRARED RADIOMETER
AMSR	ADVANCED MICROWAVE SCANNING RADIOMETER
AMSU	ADVANCED MICROWAVE SOUNDING UNIT
ARGOS +	DATA COLLECTION SYSTEM (FRENCH)
ATLID	ATMOSPHERIC LIDAR
ATSR +	ALONG TRACK SCANNING RADIOMETER
AVNIR	ADVANCED VERY HIGH RESOLUTION RADIOMETER
CR	CORRELATION RADIOMETER
CSR	CONICALLY SCANNING RADIOMETER
DB	DIRECT BROADCAST
ERBI	EARTH RADIATION BUDGET INSTRUMENT (NS-NON-SCANNER) (S-SCANNER)
F/P-INT	FABRY PEROT INTERFEROMETER
GLRS	GEODYNAMICS LASER RANGING SYSTEM
GOMR	GLOBAL OZONE MONITORING RADIOMETER
HIRIS	HIGH RESOLUTION IMAGING SPECTROMETER
IR-RAD	IR RADIOMETER
ITIR	INTERMEDIATE THERMAL INFRARED RADIOMETER
LAWS	LASER ATMOSPHERIC WIND SOUNDER
MAG	MAGNETOSPHERE CURRENTS/FIELDS
MERIS	MEDIUM RESOLUTION IMAGING SPECTROMETER
MLS	MICROWAVE LIMB SOUNDER
MODIS-N	MODERATE RESOLUTION IMAGING SPECTROMETER-NADIR
MODIS-T	MODERATE RESOLUTION IMAGING SPECTROMETER-TILT
MPD	MAGNETOSPHERE CURRENTS/FIELDS
OCTS	OCEAN COLOR & TEMP. SCANNER
P/L-EXEC	PAYLOAD EXECUTIVE
PEM	PARTICLE ENVIRONMENT MONITOR
PPS-PODS	PRECISE POSITION SYSTEM-PRECISE ORBIT DETERMINATION SYSTEM
S & R	SEARCH AND RESCUE
SAR	SYNTHETIC APERTURE RADAR (C, L, & X BANDS)
SCATT	SCATTEROMETER (1-NASA, 2-ESA)
SEM	SPACE ENVIRONMENT MONITOR
SUB-MM	SUBMILLIMETER SPECTROMETER
SUSIM	SOLAR UV SPECTRAL IRRADIANCE MONITOR

GEOPOTENTIAL RESEARCH MISSION (GRM/GRADIO)

Edward A. Flinn
Geodynamics Branch
NASA Headquarters
Washington D.C. 20546
202-453-1675

and

David C. McAdoo
NGS/NOAA
Rockville, MD 20852
301-443-8528

Program Objectives: The paramount objective is measurement of the global gravity field and geoid to high resolution and accuracy: 3 milligal rms error in one-degree averages for the gravity field, and 5 cm rms error in geoid undulations, both for horizontal resolutions of 150 km. Gravity information of this quality is required for studies of solid-earth dynamics (in particular of subduction dynamics), of continental lithospheric structure and of orogenesis or mountain building. This gravity field would also be of great value to geodesy for high precision surveying and for high accuracy satellite orbit determination. It is also important for physical oceanography, since satellite altimeter measurements (e.g., TOPEX) must be referred to an accurate marine geoid. Another major objective of this mission is precise, high-resolution observation of the global magnetic field. Such a magnetic field is needed for studies of crustal structure and core dynamics, and to provide an international reference geomagnetic field for mapping and navigation.

Scope: GRM was planned as a system of two drag-compensated spacecraft in identical polar orbits at 160 kilometers altitude, the gravity information being obtained from inter-satellite microwave ranging. This mission has been studied since 1980 as an exclusively NASA mission. In early 1987 joint planning with ESA led to a new concept of an international, single-spacecraft mission with magnetometers and a gravity gradiometer system (GRADIO) flown on a spacecraft of GRM design. Such a mission would accomplish the original GRM objectives, at a very significantly reduced cost to NASA, and in addition, provide a prototype test flight for a much more sensitive cryogenic gravity gradiometer system being designed for flight in the late 1990's.

Status: In July 1987 ESA obtained funds for Phase A/B studies for GRADIO, and is retaining an option to join with NASA at the inception of phase B in 1988/1989. NASA must commit significant FY1989/1990 funds to carry out its contribution to this international GRM/GRADIO mission.

Launch: ESA's plan at present is to launch GRADIO/GRM piggybacked with ERS-2 on an Ariane vehicle, as early as 1993. GRADIO/GRM could also be launched on a Delta-2 launch vehicle.

RADARSAT

Dr. E. Shaw
Director, RADARSAT Project Office
110 O'Connor Street, Suite 200
Ottawa, Ontario
Canada K1A 0Y7
Tele. No. (613)-993-8900

RADARSAT, an earth observation satellite, is being developed by Canada in collaboration with the USA and UK. RADARSAT will be a low-orbiting spacecraft in a high polar, sun-synchronous orbit with a payload consisting of a C-band synthetic aperture radar (SAR), secondary sensor(s), a sensor data storage facility and a data transmission downlink. RADARSAT is designed to operate for five years after its launch, scheduled in 1994.

RADARSAT is conceived to meet needs of the remote sensing user community, especially those of operational nature, by providing an all-weather data acquisition capability with an end-to-end data delivery system. The SAR sensor onboard RADARSAT is a novel and flexible system being developed to provide a variety of choice in data acquisition to users. The many modes of SAR will provide options in selecting swath-width, resolution, and angle of incidence.

The primary SAR 'operational' mode will provide a swath-width of more than 100km with a spatial resolution of approximately 28m in azimuth and 30m in range with 4-looks. The 'high resolution' SAR mode will provide a swath approximately 55 to 90km, with a 1-look resolution as good as 8m. These 'operational' and 'high resolution' swaths can be selected from within an accessability swath of 500km, over incidence angles 20^o to 49^o. Two wide swaths (approximately 150km each) with approximately 40m resolution at 4 looks, over incidence angles 20^o to 40^o, will also be available. In addition, the 'scan' SAR mode will provide very wide swaths (300km and 500km) with a resolution of approximately 100m with 6 looks. This mode is intended to provide survey imagery of the whole 500km accessability swath at one time, if needed. Moreover, It will be possible to collect data between 49^o and 60^o for research purposes.

RADARSAT will supply timely ice or ocean information and land renewable (e.g. agriculture and forestry) and non-renewable (e.g. geology) resource data on a world-wide basis. RADARSAT will be an operational observation system providing processed sensor data to users within the time scales significant to them. To meet user needs, various levels of SAR products are being planned with each level having different specifications as to resolution, geometric/positional corrections applied, format and turn-around requirements.

The construction of RADARSAT was recently approved by the Canadian government subject to confirmation of contributions from the domestic as well as international partners (USA and UK). These confirmations of RADARSAT participants are due by the end of 1987.

SECTION III - INDIVIDUAL RESEARCH SUMMARIES

Individual research activities supported in full or in part by the NASA Oceanic Processes Program in Fiscal Year 1986 and 1987 are summarized in the following pages. The activities are listed alphabetically by senior principal investigator.

STUDIES OF OCEAN PRODUCTIVITY

Mark R. Abbott
Jet Propulsion Laboratory, 169-236
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-4658; FTS 792-4658

and

Scripps Institution of Oceanography, A-002
University of California
La Jolla, CA 92093
(619) 534-4791

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

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

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

Current Status: Analysis of CZCS imagery from Vancouver Island has concentrated on estimating decorrelation times as a function of length scale. There are large differences in these scales between coastal and open ocean waters. A paper detailing the large-scale pigment patterns during CODE-1 has been published. Temporal and spatial patterns of pigment were shown to be largely driven by the local wind field. All CZCS data from 1979 through 1986 covering the California Current have been processed, and analysis of these patterns is continuing. Filaments off California and Oregon appear after the spring transition, with filaments in the northern region appearing later in the spring than those in the southern region. In the south, they are also more variable in length and orientation. Filaments begin to disappear in early autumn. This work was partially supported by ONR.

Scatterometer Applications to Ocean Surface Analysis

R. Atlas, D. Duffy, H. M. Helfand and E. Kalnay

Global Modeling and Simulation Branch
NASA/Goddard Space Flight Center
(301) 286-3604

Long term interest: Utilization of satellite surface wind data to improve analyses over the ocean and to increase our understanding of physical processes at the air-sea interface.

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

Status: The entire 96-days of Seasat scatterometer data has been objectively dealiased. This data has been assimilated at 4° lat. x 5° long. resolution to produce global gridded fields of surface wind, wind stress and sensible and latent heat fluxes at 6 hour intervals from 0000 GMT 7 July to 0000 GMT 10 October 1978. Both the dealiased winds and the gridded fields have been made avaiable to the oceanographic community and are currently being used by investigators in the United States, Canada and Europe.

The objectively dealiased winds were evaluated through comparisons both with subjectively dealiased winds and with objectively dealiased winds obtained using a different method. In addition, the GLA objective method was also verified using simulated Seasat data. The results of these evaluations show good general agreement among the three methods but also indicate the regions where the dealiasing is most uncertain.

The global gridded fields of wind stress and sensible and latent heat flux were primarily evaluated through comparisons with previously published climatologies. The monthly mean analyses of wind stress and latent heat flux fields agreed well with known atmospheric and oceanic features. The monthly mean sensible heat flux fields differed substantially from climatology. But in a limited number of subjective comparisons with observed atmospheric features, instantaneous sensible heat flux fields were found to be reasonable.

Higher resolution (2° lat. x 2.5° long.) dealiasing and assimilation of SASS winds is currently being tested using the GLA Optimal Interpolation (OI) analysis scheme.

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

R.C. Beal, F.M. Monaldo, T.W. Gerling, D.G. Tilley
The Johns Hopkins University
Applied Physics Laboratory
Laurel, Maryland 20707-6099
(301) 953-5009

Long-Term Interests: Application of spaceborne microwave sensors to global monitoring of wind, waves, and currents.

Objectives: Determine the potential of SAR for measuring the directional wavenumber spectrum of the surface wave field. Investigate properties of the global wave field such as temporal and spatial decorrelation, which are relevant to the global sampling problem.

Approach: Using digitally processed SAR wave imagery collected coincidentally with NASA P-3 wave measurements, as part of the SIR-B experiment in late 1984, and more recently as part of LEWEX in early 1987, assess the potential of SAR for estimating the global ocean wave directional energy spectrum. Apply the results to refine models of wind wave development and infer viability of the various wind wave generation models. Extract statistical properties of the global wave field and determine the potential of SAR for accumulating global wave climate.

Status: Analysis and interpretation of the SIR-B Extreme Waves Experiment conducted off the coast of Chile is complete. We have analyzed four days of simultaneous aircraft and spacecraft estimates of the surface wave field, with sea states ranging from 1.5 to 5 m, and waves in various stages of development. Analysis of the LEWEX data set is in the early stages, but promises to yield new insight into the directional wave prediction problem. For each of the three high priority days, the significant wave height ranged between 3 and 5 meters, and the directional spectrum was usually bimodal or trimodal. Including all the anticipated wave hindcasts, a total of more than 100 directional spectra will be included in the comparison. LEWEX analysis is expected to extend through FY89.

Funding: This task is being conducted with joint support from the NASA SIR-B Announcement of Opportunity and from the Environmental Sciences Directorate of the Office of Naval Research.

DERIVATION AND ANALYSIS OF GLOBAL TROPICAL SEA SURFACE TEMPERATURE DATA FROM SATELLITE SENSORS: A COMPONENT OF THE TOGA HEAT FLUX PROJECT (THEP)

R. L. Bernstein
SeaSpace
5360 Bothe Avenue
San Diego, CA 92122
(619) 450-9542

Long-Term Interests: the upper ocean and its coupling with the atmosphere, with emphasis on the application of remote sensing techniques to advance the study and understanding of ocean variability.

Objectives: produce a multi-year satellite-derived sea surface temperature (SST) data set for the tropics, merge it with fields of surface wind speed, humidity, and solar insolation provided by other THEP investigators to produce ocean-atmosphere heat exchange maps. These and related materials will then be used to study the role of heat flux in the evolution of seasonal and interannual variability of the tropical ocean-atmosphere system.

Approach: AVHRR Global Area Coverage (GAC) data at 4 km resolution, and HIRS atmospheric sounder data at 30 km resolution, are at present the best sources of data for deriving SST. The approach is to (i) acquire these data for the entire global tropical band over a period of years; (ii) develop algorithms that are both fast and accurate, and continue to make improvements in them; (iii) validate results against high quality in situ data from specially instrumented ships of opportunity and buoys; and (iv) reprocess the entire multi-year data set when algorithmic improvements warrant. The processed data are then contributed to a research archive maintained by Timothy Liu at JPL, accessible by interested investigators.

Status: AVHRR GAC data for the tropical Pacific have been acquired for 1981-82, and will soon be extended through mid-1985. Processing algorithms to derive SST at 10 km spatial resolution have been implimented, and now require a reprocessing time of a few per cent of the duration of the data set. Thus a five-year data set can be completely reprocessed in a few months. Validation against high quality in situ data currently yields rms errors of 0.4 - 0.5 C. The 1981 data have been fully processed, and the 1982 - 84 data will be processed in the coming year.

This project is jointly supported by NASA, NOAA and NSF.

WEST ANTARCTIC GLACIOLOGY

Robert Bindschadler
Laboratory for Oceans
Code 671, NASA/Goddard Space Flight Center
Greenbelt, MD 20771
(301) 286-7611

Long-Term Interests: To understand the role of ice sheets in the climate system. In particular, how the ice sheets interact with the ocean and atmosphere and how they behave independent of climate forcings.

Objectives: 1) measure the mass balance of the Ross Sea drainage basin of the West Antarctic ice sheet. 2) Identify the controls on the ice flow in this basin, particularly the nature of ice stream flow and its interaction with the ice shelf. 3) Assess past and predict likely future behavior of this ice sheet by the use of numerical models.

Approach: Conduct field studies of the configuration and motion of the ice flow including accumulation rates, temperature, surface elevation and topography, ice velocity and deformation, ice thickness, and bed characteristics. Analysis of these data will indicate the current state of health of the ice sheet and the partitioning of driving and resistive forces which determine the motion of the ice. Satellite imagery will be used where available.

Current Status: Three seasons of field work have been completed. Portions of the ice sheet are growing while others are shrinking. The dynamics of the ice stream are dominated by the presence of an active subglacial drift layer which deforms rapidly. Dramatic changes in the ice sheet are currently underway but the forcing mechanism for these changes (i.e. climatic or internally induced) is not yet known. Satellite imagery of limited regions has been aquired.

Funding: This project is jointly funded by NASA and the National Science Foundation (DPP-8514543).

Altimetry Data Assimilation & Numerical Ocean Modeling

Dr. George H. Born
Dr. Robert R. Leben
Colorado Center for Astrodynamics Research
University of Colorado, Boulder
Campus Box 431
Boulder, Colorado 80309
(303) 492-8638

Long-Term Interests: This research program at the Colorado Center for Astrodynamics Research (CCAR) is dedicated to the investigation of data assimilation, error analysis, and methods to enhance the use of GEOSAT-ERM and TOPEX altimetry in numerical ocean models.

Objectives: Questions to be addressed in this study include: 1) what are feasible numerical methods for ingestion of altimetric data into numerical ocean models; 2) how do errors in altimeter data (geoid, orbit, and wet tropospheric) affect the accuracy of ocean circulation models; 3) can time variations in the sea surface topography relative to the geoid be effectively used as input to circulation models; 4) to what extent can the geoid be estimated as a part of the data assimilation procedure; and 5) what preprocessing of altimetry data is required prior to assimilation into circulation models.

In anticipation of the assimilation of altimetry data into ocean models, data sets at several day intervals will being be generated from GEOSAT-ERM altimetry data to provide the ocean modeling community surface topography which are better suited for model assimilation than topography maps at 17 day intervals.

Approach: A two-layer quasigeostrophic box ocean model has been selected for our investigations of ocean circulation modeling with altimetric data assimilation. Simulated altimetry data will be employed for initial studies of the proposed assimilation techniques. Subsequent work will be concerned with the incorporation of estimations for the geoid, and introduction of wet tropospheric correction and orbit errors into the simulated data used for the assimilation experiments. This will allow parametric investigations of the applications and limitations of the assimilation of GEOSAT-ERM and TOPEX/POSEIDON data into numerical ocean models.

Status: The QG model has been validated in benchmark tests on the Cyber 205 at Princeton and is being modified to use a vectorized multigrid elliptic solver for efficient execution. Assimilation experiments have been performed on the CCAR Pyramid, and initial implementation is in progress on the JVNC Cyber 205 and NASA Ames Cray 2.

GLOBAL OCEAN FLUX STUDY (GOFS): U.S. GOFS PLANNING

Peter G. Brewer
Department of Chemistry
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543
617-548-1400 Ext. 2896

Long Term Interests: The Global Ocean Flux Study is being planned as the principal ocean biogeochemical experiment of the 1990's. It will greatly expand our knowledge of the role of the ocean in controlling the chemistry of the planetary atmosphere, of the principal cycles of the biogenic elements within the ocean, and the linkage of such cycles to the sedimentary record. GOFS will most likely be a principal component of the International Geosphere Biosphere Program (IGBP); it is presently proposed as an international joint (JGOFS) program under the auspices of the Scientific Committee on Oceanic Research (SCOR). The U.S. Planning Office is acting to bring such a program into reality and help forge the links between satellite imagery and large scale ocean flux observations. The office receives joint support from NSF and NASA.

Objectives: The objective os such planning is to help create the scientific experiments required. GOFS will need components relating to the time series measurement of change and variability over the long term at key sites; the implementation of a global survey (in part in conjunction with the World Ocean Circulation Experiment (WOCE); and the emplacement of process specific studies at key sites around the world. In addition to these field components strong modelling efforts and data management practices are required. The objective of careful planning is to foster such activities, to identify the needs, and to provide the links between the component parts; in particular the utilization of satellite ocean color products in combination with the field programs is to be planned for.

Approach: The approach to achieving these goals has been to form a U.S. Steering Committee with P. G. Brewer as Chairman, and J. McCarthy (Harvard), E. Eppley (Scripps Institution of Oceanography), and K. Bruland (U.C. Santa Cruz) as Executive members. The Steering Committee has met regularly, and created working groups in key areas. A published account of progress is to be found in EOS (1986), 67, 827-837.

Status: Planning activities for GOFS have resulted in the publication of 3 reports. Three more reports are in press. An International Meeting, held in Paris, February 1987 has produced a report recommending formation of an international program with contributions from U.S., Canada, France, Germany, U.K., The Netherlands, Japan and China. It is anticipated that further progress will follow.

IMPROVEMENT OF CZCS ATMOSPHERIC CORRECTIONS AND APPLICATION TO A MULTI-YEAR STUDY OF SPRING BLOOM

NASA NAGW-273

Annual Report

Co-Principal Investigators
Dr. Otis B. Brown[1]
Dr. Robert H. Evans[1]
Dr. Howard R. Gordon[2]

[1]Division of Meteorology and Physical Oceanography
Rosenstiel School of Marine and Atmospheric Science (RSMAS)
University of Miami
4600 Rickenbacker Causeway, Miami, FL 33149
Telephone (305) 361-4018

[2]Physics Department
University of Miami
Coral Gables, FL 33124
Telephone (305) 284-2323

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) develop a scheme for atmospheric correction employing a model for the water leaving radiance as a function of the pigment concentration for Morel Case I waters; (b) use models to study the ramifications of the El Chichon aerosol and modify the present algorithm to account for its effects as necessary; (c) extend the Lw-C model to include the influence of detached coccoliths with the goal of increasing the accuracy of pigment retrievals in cocolithophorid blooms; (d) develop a better understanding of shelf-Slope biomass and productivity differences and similarities with respect to the onset, magnitude and simultaneity; (e) determine Spring background pigment levels in shelf, Slope, Gulf Stream and Sargasso Sea regions; and (f) compute variations in the provincial biomass concentrations between the above regions.

Approach: Results of in situ measurements and Monte Carlo models will be used to develop and test radiative transfer models for improvement of atmospheric corrections and for development of an analytically based bio-optical model which can account for the effects of coccolithophorids on the upwelled radiance/ pigment relationship. The test area chosen to carry out the study is the Middle Atlantic Bight, a region of intense study in 1982 and 1985 by virtue of the Warm Core Rings Experiment (WCRE) and the BIOWATT experiment. WCRE and BIOWATT investigations yield the ancillary surface data (surface current, surface pigments, thermal structure, etc.) needed for comparison with CZCS imagery. These data will be useful in testing the satellite-based techniques, which can then be extended to other time periods and locations.

Status: Incorporated the results of a multi-scattering, polarization dependent Rayleigh model and implemented an improved sensor calibration and degradation model into the operational CZCS computational procedure. A primary result of these improvements is extension of pigment retrievals to 70° from the solar equator, a difference of some 10° over standard methods. Concurrently a method for objectively screening clouds has been developed which permits nearly automatic generation of image composites for both temperature and color time series. Seasonal time series have been assembled for validation of these results. Sufficient progress has been made on these problems to enable initial screening of "global time series" data from early 1979 and generation of global pigment maps by NASA/GSFC investigators. A number of publications dealing with these topics are in the process of submission.

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

Principal Investigator: Prof. R. A. Brown
Dept. of Atmospheric Sciences AK-40
University of Washington
Seattle, WA 98195
Phone: (206) 543-8438

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

Objectives: This project is an investigation of the mesoscale structure of midlatitude fronts using the Seasat A Satellite Scatterometer (SASS) data. We are analysing North Pacific fronts viewed by Seasat, collecting all ancillary data. Since we have been 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 are checked against known flow patterns around fronts and cyclones from STREX and other such data to evaluate wind algorithms in regions where there are high winds and strong variation in boundary layer stratification. The results are simultaneously incorporated in a PBL model so that the value in forecasting capability and large scale flux parameterizations is evaluated.

Current Status: The semi-objective analysis scheme has been completed and was presented in a paper by G. Levy and R. Brown (JGR, 91, C4, 5143f). Comparisons with SMMR data here revealed mesoscale details. We are studying the character of vorticity and divergence across a front. The PBL model was used to produce surface pressure fields from SASS data which are comparable to NWS fields (Brown and Levy, MWR, 114, 11, 2197f). Our current investigation is centered on the effect of the inertial terms in the force balance for the PBL.

ANALYSES OF THE WIND-DRIVEN RESPONSE OF TROPICAL OCEANS

Antonio J. Busalacchi
Oceans and Ice Branch, Laboratory for Oceans
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771
(301) 286-9502

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

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

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

Status: Among the efforts of the past year, a multi-mode linear model of the tropical Pacific has been forced by three different analyses of the surface wind field for 1979-1983. Both model and observational depictions of the mean seasonal cycle for the upper ocean thermal field were analyzed along the major ship tracks in the western, central, and eastern tropical Pacific. Model solutions were also used to address array design questions in observing system simulation experiments. Subsequent analyses of the solutions for the 1982-83 El Nino will be performed with repsect to differences from the mean seasonal cycle, as well as differences in the three wind products.

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

Dr. Janet W. Campbell
Bigelow Laboratory for Ocean Sciences
West Boothbay Harbor, Maine 04575
(207) 633-5723

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

Objective of this specific research task. To investigate the feasibility of estimating primary productivity from satellite measurements of chlorophyll, sea surface temperature, surface irradiance and diffuse attenuation.

Approach utilized for this task. A large data set consisting of carbon uptake rates, chlorophyll concentrations, incident and underwater light (PAR) and sea surface temperature was analysed for empirical and theoretical relationships. The data were obtained at 1047 stations on the northwest Atlantic continental shelf between 1978 and 1982 as a part of the NMFS MARMAP program.

Status and progress. Surface chlorophyll was highly correlated with mean euphotic chlorophyll and moderately correlated with mean euphotic productivity. Knowledge of the depth of the euphotic zone, or equivalently, the diffuse attenuation coefficient for PAR, is needed to estimate integral chlorophyll or productivity. In considering theoretical models of the relationship between productivity, chlorophyll and light, we found that parameters in such models are highly variable. Efficiency of light utilization was maximal in the lower half of the euphotic zone, but declined near the surface. Light saturation and photoinhibition existed at all times of year but were more pronounced in the summer. Consequently, seasonal increases in surface irradiance were not met by proportionate increases in production. We concluded that estimation of primary production from satellite measurements requires improved techniques for estimating light absorbed by phytoplankton. A paper on this work (Campbell and O'Reilly, 1987, in press) will appear in Continental Shelf Research.

THE IMPACT OF NSCAT WINDS ON TROPICAL OCEAN MODELING

Mark A. Cane
Lamont-Doherty Geological Observatory
Palisades, NY 10964
914-359-2900

Long-Term Interests are the effects of winds on the tropical oceans with special attention to aspects which are important to ocean-atmosphere interaction.

Objective The overall objective of this research task is to assess the value of NSCAT winds for improving our ability to specify the state of the upper layers of the tropical ocean via numerical ocean models. Attention will also be given to the impact of NSCAT winds on dynamical prediction of the El Nino-Southern Oscillation (ENSO) cycle with a coupled atmosphere-ocean model. The anticipated payoffs of the proposed research are (i) an assessment of the benefits of NSCAT winds for numerical modeling of the tropical ocean; (ii) an understanding of how best to use NSCAT data in numerical models. The principal issues are the degree and nature of the temporal and spatial averaging to apply, and the procedures for using NSCAT data in conjunction with other products.

Approach The focus of the research is (i) to characterize the structure and magnitude of errors in operational and quasi-operational wind products, particularly NSCAT; and (ii) to understand how the errors in the specified wind stress propagate through model calculations into errors in oceanic quantities such as sea level or sea surface temperature (SST). A description of the wind errors in terms of their impact on oceanic variables will follow from (i) and (ii).

Current Status

An issue related to (i) presently under investigation is the systematic biases in ship wind reports. The hypothesis under investigation is that failure to account for the height of the ship anomometer has introduced a long term trend in this data set. We are presently calculating the covariance of sea level errors as a function of wind error under various simple assumptions about the wind error covariance. This work will be extended to more realistic wind errors, taking account of the distribution of observations. The primary influence of wind on SST is local or quasi-local: via evaporative fluxes, Ekman (or other surface layer) currents and upwelling. These will be analyzed before moving on to larger scale, remote influences.

MODEL STUDIES OF THE EFFECTS OF WINDS AND HEAT FLUX ON THE TROPICAL OCEAN.

Mark A. Cane
Lamont-Doherty Geological Observatory
Palisades, NY 10964
914-359-2900

Long-Term Interests relevant to this project are to develop an understanding and ability to model the processes which determine sea surface temperature in the tropical oceans. We are particularly concerned with the interaction between wind-driven dynamical processes such as horizontal advection, upwelling, and adiabatic changes in subsurface temperature structure, and non-adiabatic processes, notably surface heating and wind-induced turbulent mixing.

Objective of the present research task is to develop a sufficient understanding of the processes listed above which influence SST to enable us to model them effectively. We seek the simplest description of the upper ocean's forced response. Our analysis is especially concerned with the feedbacks in the surface heat budget which make it inadequate to consider processes individually

Approach We are developing a suite of numerical models and model parameterizations appropriate for the upper layers of the tropical ocean. The goal is to model SST; because of our interest in the coupled ocean atmosphere system we focus on those features of the tropical SST field which influence the atmosphere. The simplest model [that of Zebiak and Cane (1987)] has linear dynamics, a highly parameterized subsurface thermal structure, and a fixed depth surface layer. The most complex is a fully 3-dimensional primitive equation model which will incorporate sophisticated mixed layer parameterizations.

Status A new primitive equation model has been developed. It uses 4th order finite differences, variable grid resolution, and a general vertical coordinate (currently implemented as a sigma coordinate). Tasks in the near future include extension to realistic geometry and experimentation with various formulations for vertical mixing.

The simple model is being extended to a multi-mode version which consistently combines a frictional surface layer with linear dynamics summed over an arbitrary number of vertical modes. A new surface heat flux parameterization has been developed which needs only surface winds and cloud cover as input data. This is being tested in a number of models for the Atlantic and Pacific.

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

Dr. K. L. Carder
Department of Marine Science
University of South Florida
St. Petersburg, FL 33701
813-893-9130

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

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

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

Current Status: The optical and electronic components of the spectral instrument and a machine-language, CMOS microprocessor (80C85) has been programmed and integrated to control the operation and data storage and retrieval aspects of the instrument. A magnetic bubble memory data storage module has been installed, and initial field sampling in the central Pacific has been successfully completed. Minor modifications to the program controlling the instrument and calibration improvements are underway with final tests and data acquisition set for summer 1987 in the Gulf of Mexico and Straits of Juan de Fuca.

A remote sensing reflectance model for Case I and Case II waters has been developed and tested in the Gulf of Mexico, Tampa Bay, the oligotrophic north Pacific, and the Straits of Juan de Fuca. It simulates the optical effects of chlorophyll-like pigments, gelbstoff, detritus, and a colloidal ferric precipitate indigenous to the Puget Sound/Straits of Juan de Fuca region. Fluorescence quantum efficiencies have been calculated from field reflectance data which appear to detect phytoplankton populations stressed due to nutrient limitation/photo-inhibition. The effects of dissolved humic and fulvic acids on remote sensing have also been evaluated and found to explain much of the variability seen in comparisons of measured and remotely sensed chlorophyll concentrations.

IMAGING RADAR STUDIES OF SEA ICE

Dr. F. D. Carsey
Mail Stop 169-236
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-8163; FTS 792-8163

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

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

Approach: The approach is to examine the Seasat data set and data from SIR-B, Landsat, other satellites, instrumented aircraft such as the C-band data from the CCRS CV-580 over LIMEX and other platforms, notably buoys. The types of analysis in use are:

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

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

ARCTIC STUDIES WITH PASSIVE MICROWAVE SATELLITE OBSERVATIONS

Dr. Donald J. Cavalieri
NASA Goddard Space Flight Center
Greenbelt, MD 20771
(301) 286-2444 FTS 888-2444

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

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

Approach: Archived satellite and aircraft data are used to define the capability of existing algorithms to map regions of new ice production. Data from the upcoming DMSP SSMI and from associated aircraft underflights planned for next year will be used to determine the potential of the dual-polarized 85 GHz radiances for use in thin ice algorithms and for application to processes studies. In the Arctic polynya study, which is a joint project with Professor Seelye Martin of the University of Washington, sea ice data from the Nimbus 7 SMMR as well as station weather data are used to calculate heat and salt fluxes, and ice production rates for the winter months of 1978 through 1982.

Status: Comparison of coastal polynya open water areas computed from SMMR data and from analyzed NOAA visible satellite imagery and USGS aircraft data is near completion and will provide both a qualitative and quantitative assessment of passive microwave sea ice algorithms for mapping regions of new ice production. Primary sites of sea ice production in polynyas along the Siberian continental shelf region have been identified using monthly SMMR 37 GHz polarization variance maps. Open water areas, ice production rates, heat and salt fluxes for these polynyas are currently being computed.

NASA Sea Ice Validation Program for the DMSP Special Sensor Microwave Imager (SSM/I)

Dr. Donald J. Cavalieri
NASA Goddard Space Flight Center
Greenbelt, MD 20771
(301) 286-2444 FTS 888-2444

In June 1987 a new generation passive microwave sensor called the Special Sensor Microwave Imager (SSM/I) will be launched as part of the Defense Meteorological Satellite Program (DMSP). The SSM/I will provide daily passive microwave coverage of the polar regions at 19.35, 22.24, 37.0, and 85.5 GHz with a swath width of almost 1400 km. A spatial resolution of 12.5 km at 85.5 GHz will improve greatly the utility of passive microwave imagers for operational applications and for polar research. The value of the SSM/I to polar research was recognized early on and a program was initiated by NASA for the acquisition and archiving of these data for the research community.

For the purpose of providing the science community with quality data for studying the role of sea ice in the global climate system and for understanding the interaction of ice-ocean--atmosphere processes, NASA established a DMSP-SSM/I Sea Ice Research Science Working Group in 1982 to prepare a coherent program to acquire the SSM/I microwave radiance data, to convert the data into useful sea ice parameters, and to archive the data for the research community. The NASA Ocean Data System (NODS) node at the Jet Propulsion Laboratory in Pasadena, California was assigned the task of developing the software to process and to map the SSM/I sea ice parameters. The responsibility for the long term processing and archiving of these data was given to the National Snow and Ice Data Center (NSIDC) in Boulder, Colorado.

In 1984, Robert Thomas, then NASA Manager for Polar Oceans, formed a Sea-Ice Algorithm Working Group for the purpose of implementing the recommendations of the NASA DMSP SSM/I Sea Ice Research Science Working Group. The algorithm group was charged with the following tasks: first, to evaluate the current state of passive microwave sea ice algorithms; second, to select an algorithm for initial processing of the SSM/I data; third, to provide quidance to NODS for the implementation of the selected algorithm and finally, to develop and implement a plan for validating the algorithm and for identifying potential algorithm improvements. By 1985 an algorithm for processing the SSM/I data by NASA had been selected and a report outlining the rationale for its selection was published (Swift and Cavalieri, 1985).

In 1986, Kenneth Jezek, NASA manager for Polar Programs, established a program to implement the validation of the NASA algorithm, to monitor the performance of the sensor, and to quality check the SSM/I data products before distribution by NSIDC to the research community. The validation program is outlined in a plan prepared by the NASA DMSP SSM/I Sea Ice Algorithm Validation Team. This validation plan is divided into prelaunch and postlaunch activities. The prelaunch activities include the necessary software development to process the data, site selection for validation and calibration testing, and identification of comparative data sets. Postlaunch activities include SSM/I data acquisition and distribution to the NASA validation team, an assessment of sensor performance, validation of the NASA sea ice algorithm, and quality control of the data products before archival.

The validation of the sea ice algorithm itself consists of three key components: first, the selection of SSM/I algorithm constants, second, analysis and intercomparison of the derived sea ice parameters with other data, and third, an aircraft field program. Following the selection of algorithm constants, an analysis of the derived sea ice parameters will be made for several regions in both the Arctic and Antarctic. The intercomparison of sea ice parameters will involve the use of other satellite imagery, including SMMR if the sensor is still operational, aerial photography, active and passive aircraft microwave imagery, and surface measurements from ships, buoys, and ice stations.

The aircraft program involves a series of NASA aircraft underflights in the Arctic during winter. These flights are needed to acquire coordinated observations from the SSM/I and aircraft sensors. Measurements made with the aircraft allow high resolution SAR and imaging radiometer measurements of sea ice concentration and ice type to be compared with corresponding measurements made from the satellite over several footprints thus providing a direct check on the spacecraft algorithm over selected regions of the Arctic. Further, analysis of coincident aerial photography allows an independent (non-microwave) determination of the ice parameters.

The end goal of the NASA DMSP SSM/I validation program is to provide the polar research community with a usable and accessible passive microwave data set which has been quality checked as well as with a report which will document the accuracy of the sea ice parameters derived from the SSM/I and the degree to which these parameters meet the observational requirements as specified by the polar science community.

ANALYSIS OF AVHRR, CZCS AND HISTORICAL IN SITU CHLOROPHYLL OFF THE U.S. WEST COAST

Dudley Chelton and Ted Strub
College of Oceanography
Oregon State University
Corvallis, OR 97331
(503)754-4017; (503)754-3015; (503)754-3504

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

Objectives: 1) to characterize the seasonal cycles and interannual variability in SST and pigment concentration off the U.S. west coast by forming monthly composite fields from individual satellite images obtained from the NOAA AVHRR and the NASA Nimbus-7 CZCS; and 2) to explore the statistical relationships between these fields and fields of zooplankton biomass and surface wind stress.

Approach: Satellite data from the JPL West Coast Satellite Time Series will be used to explore methods of compositing the individual partially cloud-covered images into monthly mean fields, attempting to minimize the influence of daily cloud contamination and inaccuracies introduced by the atmospheric correction algorithms and by sampling errors from observations unevenly spaced in time. In parallel, we are statistically examining historical zooplankton and wind data along the west coast of the U.S. to investigate the relation between chlorophyll and biological productivity at higher levels in the food chain, and the relation between biological variability and physical forcing.

Current Status: Acquisition of the image processing equipment necessary to conduct the satellite component of this research is not yet complete so the effort thus far has focused on analysis of historical data. A study of seasonal and interannual variability of zooplankton biomass from the 35-year CalCOFI data set has recently been completed. A detailed analysis of meteorological data from the eastern North Pacific is in progress. Analysis of satellite data is expected to begin in July 1987, when the image processing system becomes operational.

EFFECTS OF MEASUREMENT AND SAMPLING ERRORS ON NSCAT FIELDS OF VECTOR WINDS, WIND DIVERGENCE, WIND STRESS AND WIND STRESS CURL

Dudley Chelton, Steve Esbensen and Frank Wentz
College of Oceanography
Oregon State University
Corvallis, OR 97331
(503)754–4017; (503)754–3504

Long-Term Interests: To use spatially and temporally averaged fields of vector winds, wind divergence, wind stress and wind stress curl to investigate the characteristics of atmospheric varibility in the lower atmosphere and the surface forcing function for ocean circulation. These wind fields will be used as input to statistical and numerical models of ocean circulation and to study the dynamics of processes related to convergence in the lower atmosphere.

Objectives: To understand the limits in accuracy of NSCAT wind fields imposed by measurement and sampling errors. Most applications of NSCAT data will involve both spatial and temporal averaging of individual NSCAT observations. Clearly, measurement errors (due to instrument errors and errors in model function formulation) introduce inaccuracies in the averaged winds. Sampling errors due to infrequent NSCAT sampling (typically 1–3 observations per day) at a given location also introduce inaccuracies by the inability to resolve short time scale variations. An additional objective is to develop an optimal estimation model to improve the accuracy of spatially and temporally averaged NSCAT wind fields.

Approach: The approach to examining the accuracies of NSCAT wind fields is to conduct two parallel studies: the measurement error component is investigated using simulated and aircraft scatterometer data; the sampling error component is investigated from synthetic time series of winds generated from observed open-ocean wind spectra and generated by mesoscale resolving atmospheric models. These essentially continuous time series are then sampled at satellite overpass times and spatially and temporally averaged wind time series constructed from the "satellite observations" are compared with the true averages constructed from the continuous time series. The approach to generating more accurate wind fields from NSCAT data is to develop a series of optimal interpolation models which combine NSCAT vector wind observations in the two off-nadir swaths with SSM/I wind speed observations from across the nadir gap.

Current Status: A first order examination of measurement vs. sampling errors indicates that the latter are far more important in spatially and temporally averaged wind fields. Unresolved high frequency variability places a lower limit on the accuracy of spatially and temporally averaged NSCAT wind fields. A first order optimal interpolation model has been developed to quantify errors in NSCAT winds interpolated across the nadir gap.

This study is being conducted through the auspices of the NSCAT Announcement of Opportunity.

TEMPORAL AND SPATIAL VARIABILITY OF SEA SURFACE WINDS

Dudley Chelton
College of Oceanography
Oregon State University
Corvallis, OR 97331
(503)754–4017; (503)754–3504

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

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

Approach: The approach for determining the usefulness of the SMMR data has been to examine the brightness temperatures measured as a function of frequency, incidence angle, and time and identify calibartion drifts and cross-scan biases. These problems are then removed to develop internally consistent data sets which can be used to construct monthly average fields of SST, wind speed, water vapor and atmospheric liquid water. The approach for analysis of scatterometer data is to generate spatially and temporally averaged wind fields from the vector winds and study space-time variability of the global wind field.

Current Status: The SMMR brightness temperatures have been examined and several calibration bias problems have been identified. Some of the problems could not be corrected at the brightness temperature level. Consequently, it has been necessary to reprocess all of the data from the antenna temperature level. Presently, brightness temperatures are being processed to estimate geophysical parameters. During this fiscal year, monthly average maps of SST, wind speed, water vapor and liquid water will be generated for the period 1979–1985.

In the scatterometer study, global average fields of a number of wind parameters have been generated for the period July–October 1978. These global fields have been analyzed to identify features poorly resolved in conventional wind data. A detailed examination of the spatial and temporal variability of the near surface wind field over the Southern Ocean has also been completed.

REMOTE SENSING OF MARINE PRIMARY PRODUCTION

Dr. Donald J. Collins
Jet Propulsion Laboratory
m/s 183-301
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-3473; FTS 792-3473

Long-Term Interests: The goal of this research is the use of remote sensing for the determination of primary productivity of the oceans, and the investigation of the relationships between the physics and the biology of the upper mixed layer.

Objectives: The objective of this research is to develop models describing the primary productivity of the ocean in terms of the distributions of chlorophyll abundance, incident solar radiation and sea-surface temperature and to develop techniques for the remote assessment of global primary production.

Approach: The approach is to explore physiological relationships between the near-surface concentration of chlorophyll _a_ and the primary productivity of the upper mixed layer. These relationships permit an assessment of the primary production through the remote sensing of the visible and infrared spectra of the ocean. The research includes spectral studies of the fluorescence, absorption and scattering of marine phytoplankton, and investigations of the taxonomic and photoadaptation effects required to interpret remotely sensed data obtained from the ocean.

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. A physiological model has been developed for the assessment of the productivity of the ocean based on the near-surface distributions of chlorophyll _a_ and of the photosynthetically usable radiation (PUR). The model has been tested against _in situ_ data and algorithms are under investigation for the assessment of primary production of the ocean from remotely sensed data.

MICROWAVE REMOTE SENSING OF THE POLAR REGIONS

J. C. COMISO
LABORATORY FOR OCEANS, CODE 671, NASA/GSFC
GREENBELT, MD 20771
TELEPHONE: 301-286-9135

Long-Term Interests: Optimal utilization of satellite microwave data in the study of sea ice cover. Quantify errors in the determination of various ice parameters and investigate role of sea ice in various ocean and atmospheric processes.

Objectives: (a) Investigate multispectral microwave emissivities of various ice types and surfaces using Nimbus 7-SMMR and DMSP-SSM/I data in conjunction with field, aircraft, and submarine observations, (b) Develop or improve techniques for deriving geophysical ice parameters from satellite data and (c) study long-term physical processes associated with the ice edge, polynya formations, and ice extent.

Approach: Field measurements in the Weddell Sea and at CRREL and aircraft experiment over the Arctic will be analyzed to determine emissivities of various ice types and establish which types can be unambiquously identified. An algorithm based on results of these analyses and the multispectral capability of satellite data will be developed. Long time series of brightness temperatures will be used to study oceanic, atmospheric, and biological processes in the polar regions.

Current Status: A controlled experiment at CRREL and a field experiment in the Weddell Sea have been performed. A P3 aircraft experiment over the Central Arctic, Fram Strait and Greenland Sea is in progress. A data set of gridded daily polar brightness temperatures using SMMR from launch date in 1978 to present has been generated and is presently utilized for processes studies.

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

Peter Cornillon and Everett Carter

Graduate School of Oceanography
University of Rhode Island
Kingston, RI 02881
(401) 792-6283

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

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

Approach: (a) The approach to the **edge detection** problem has changed over the last year. Instead of using a technique based on the Kalman filter, we are now using an approach based on the distribution of data within small windows. From the shape of the distribution we can determine whether or not there is an edge in the window and at what temperature it is found. (b) **Paired vortices** are first to be located in low resolution satellite–derived SST fields and are then to be studied in detail with the full resolution SST fields.

Status: (a) **Edge Detection**– Thus far we have coded a frontal detection algorithm based on histograms of the satellite–derived SST field. Algorithm steps are: (1) the image is divided into (overlapping) square windows; (2) for each window, an unsupervised learning and clustering technique is used to define two populations; (3) using methods derived from the Analysis of Variance and the theory of Markov Random Fields, the validity for the existence of the two clusters is checked for each window (in this case, the existence of two populations means the presence of a front in the window); and, (4) the results of neighboring windows are combined together in such a way as to obtain coherent edges throughout the whole image. We are now completing this algorithm which entails the addition of several steps, optimization of the code and further analysis of the statistics used for the separation of populations. (b) **Paired Vortices**– The sea surface temperature (SST) field immediately to the north and south of the Gulf Stream and west of $57°W$ has been examined in approximately 7,000 low resolution images ($\approx 3km$) of the western North Atlantic for occurrences of large paired vortices (modons). Twenty–three possible paired vortices have been identified in these images. Sufficient coverage of five of the 23 existed for them to be definitely identified as cyclone–anticyclone pairs. Final analysis of these using high resolution images is now in progress.

Optimal Combination of Wind Stress Data with Sea Surface Temperature Data for the Western Atlantic

Peter Cornillon, David Evans and Everett Carter

Graduate School of Oceanography
University of Rhode Island
Kingston, RI 02881
(401) 792-6283

Long–Term Interests are a better understanding of the relationship between wind forcing and near surface oceanographic mesoscale phenomena using satellite–derived sea surface temperature (SST) fields. The particular phenomena of interest are large scale currents, Mode Water formation and the location of the Subtropical Front(s).

Objectives: To establish the relationship between wind stress on a regional and basin wide scale and meandering of the Gulf Stream and Brazil Currents, the position and angle at which these currents leave the continental shelf, Mode Water formation and the location of fronts in the Subtropical Convergence.

Approach: Using satellite–derived SST fields we will quantify long term trends in parameters associated with the phenomena listed above and then examine the wind stress field of the Atlantic for similar trends.

Status: To date we have spectrally analyzed Gulf Stream meandering over a four year period and have detected trends in the integrated spectral power over this period. These trends vary with downstream distance from Cape Hatteras, increasing over the first $\approx 500km$ and decreasing over the next $\approx 500km$. We have begun the next step in this research: quantification of the wind stress field as a function of time for the North Atlantic for the same four–year period. The ATOLL (Atlantic Tropical Ocean Lower Level) winds for the North Atlantic covering the period from October 1984 to June 1986 have been acquired and we are at present deriving mean (averaged in both space and time) wind stress fields. We are also calculating the wind stress curl from these winds.

This work is being conducted through the auspices of the NASA NSCAT AO.

EXAMINATION OF CHUKCHI ICE PROCESSES

John P. Crawford
Mail Stop 169-236
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354- 6471, or FTS 792-6471

Long-Term Interests: Using spaceborne SAR and passive microwave observations to address the geophysical issues associated with the Bering/Chukchi Sea in particular and the polar oceans in general.

Objectives: The objective of this research is to advance our understanding of the geophysical processes of the Chukchi/Bering Sea system and its seasonal changes in ice cover. This research is also aimed at developing relationships between derived geophysical parameters from active and passive microwave remote sensing observtions and actual surface conditions. The issues concerning the Chukchi Sea involve understanding the effects of heat transported by bathymetrically channelled flow northward through the Chukchi, the processes influencing the ice edge, and the role of the shelf break during ice retreat.

Approach: The approach being taken in examining the above issues involves analyses of historical microwave data from Seasat, specifically the SAR and SMMR observations, in conjunction with in-situ oceanographic and atmospheric measurements, and regional bathymetry. Analogue Seasat SAR data is registered to a coordinate system and analyzed to derive ice concentration. This information is subsequently entered into a digital cartographic data base and compared with bathymetry and other variables to determine relationships between the various processes.

Status: Recent activity has included the construction of a digital cartographic data base for the Chukchi Sea using JPL's Digital Cartographic Facility. The data base includes bathymetry digitized from available USGS charts converted into image format. Progress is being made in analyzing the ice conditions and edge location of more than 70 Seasat SAR passes over the Chukchi during 1978 and entering these analyses into the data base. Once in the data base, the ice concentrations can be statistically examined with bathymetry and other variables.

COMPARISON OF SATELLITE AND AIRCRAFT OBSERVATIONS

Jane A. Elrod
Oceans and Ice Branch
Laboratory for Oceans
NASA/GSFC
301-286-9503

Long-term interests: The distributions, variability, and interrelationships of chemical, physical and biological properties of the ocean, as observed through the use of remote sensing tools.

Objectives: To undertake a comprehensive comparison of Coastal Zone Color Scanner (CZCS) parameters with parameters from two airborne sensors, the Airborne Oceanographic Lidar (AOL) and the Multichannel Ocean Color Sensor (MOCS).

Approach: CZCS scenes for days on which AOL data were available and which were cloud-free over at least part of the flight track were processed to level 3, applying Rayleigh and aerosol corrections to the three radiance channels and determining pigment concentrations. The CZCS parameters were then extracted from under the AOL flight track and compared to the AOL data and to the MOCS data, if available.

Status: CZCS scenes from 1981, 1982, and 1984 have been processed and comparisons are underway with the aircraft data, in collaboration with W. Esaias, F. Hoge and R. Swift. Results show that CZCS pigment correlates well with AOL chlorophyll fluorescence or MOCS pigment in Case 1 waters, but not at all in Case 2 waters. However, curvature algorithms look useful for deriving pigment in some types of Case 2 waters. This analysis shows the importance and utility of aircraft sensors in future satellite sensor validation efforts.

ASSESSING OCEAN PRODUCTIVITY FROM SATELLITE MEASUREMENTS

Richard W. Eppley
Institute of Marine Resources
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, California 92093
(619) 534-2338

Long-Term Interests: Plankton production in the oceans, phytoplankton physiology, nutrient relationships, and the relation between production in surface waters and the sinking flux of biogenic particles to deep water.

Specific Task Objectives: Develop relationships between phytoplankton chlorophyll measured by the Coastal Zone Color Scanner and the rate of primary production in the euphotic zone.

Approach: Existing data collected from ships are used to study relationships between depth integrated primary production (mg Cm^{-2} day^{-1}) and near-surface chlorophyll-like pigments (mg m^{-3}). The West Coast Time Series of CZCS images, 1978-1981, has now been prepared by M. R. Abbott and P. M. Zion. CZCS pigment values have been extracted, corresponding to ship sampling locations, for use in the model development.

Current Status: Empirical models have been published for primary production-surface pigment relationships in the Southern California Bight and the Eastern Tropical Pacific. Prompted by the assertions of T. Platt (Bedford Institute) and others, that analytical models are preferred to empirical ones, the Southern California data set has been re-examined with a view to creating an analytical model. An interesting result is that the chlorophyll content of the water column within one optical depth interval is relatively stable and predictable in this area. Thus the depth profile of chlorophyll concentration can be reconstructed from the surface value measured by the CZCS. Considerable variability in the data remains to be explained by the model and this is probably due to photoadaption-the adjustment of the photosynthetic mechanism in response to ambient light. Collaborators are Drs. W. M. Balch and M. R. Abbott.

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

Paul G. Falkowski
Oceanographic Sciences Division
Department of Applied Science
Brookhaven National Laboratory
Upton, NY 11973
(516) 282-2961 or FTS 666-2961

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

This specific research task is involved with constructing a xenon flash fluorometer which would simultaneously estimate ongoing photosynthetic rates as well as phytoplankton biomass in the ocean. In pursuing this objective, basic lab and field experiments were conducted to test general principles which describe the functional relationship between photosynthesis and fluorescence.

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

We have constructed a microprocessor controlled pump and probe fluorometer. The prototype fluorometer is a bench top version which is used for laboratory experiments and at sea for discrete samples. We are now constructing a submersible instrument which will be compatible with a CTD data acquisition system for use at sea. The submersible version will be field tested and used in the second SEEP field program in the spring of 1988.

WIND/WAVE STUDIES

Michael H. Freilich
Jet Propulsion Laboratory, 169-236
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 393-7801; FTS 977-7801

Long-Term Interests: To use satelite scatterometer data to study wind forcing of the ocean on small and medium scales. To develop dynamically based models describing wave-induced water motions in the nearshore region.

Specific Objectives: (1) Examine and quantitatively characterize errors inherent in scatterometer wind data, including both measurement errors and sampling-related errors (collaboration with D. B. Chelton of Oregon State). (2) Model the two-dimensional evolution of waves in the shoaling region, including nonlinear and refractive effects, generation of low-frequency alongshore currents, and wave-induced enhancement of low-frequency energy inside the break zone (with R. T. Guza of SIO and S. L. Elgar of Washington State).

Approach: Simulations, using realistic scatterometer orbits, measurement swaths, and time-varying winds are used to determine the magnitudes of errors in spatial/temporal averaged quantities as a function of geographical location, averaging areas and time, and scatterometer measurement accuracy. Comparisons between different scatterometer systems, and enhanced accuracies possible through combining scatterometer data from separate scatterometers on-orbit, can be determined quantitatively. (2) Existing 1-D nonlinear shoaling models are extended to include 2-D wave fields on smooth (but arbitrary) bottom topography. Detailed bispectral and directional analyses of existing data (spanning a variety of wave and beach conditions) are used to guide the development and test the accuracy of the extended shoaling models.

Status: (1) The simulation capability developed in previous years has been used to characterize potential errors in ERS-1 wind measurements, in order to determine their utility for large-scale studies associated with WOCE. Based on analyses of the 2-D spatial variability of winds, the simulation capability is being extended to allow characterization of errors in spatial/temporal averages of wind stress curl. (2) The 1-D shoalng model of Freilich and Guza has been transported to the SDSC CRAY, and 13 additional data sets have been analyzed using the model on the CRAY. Detailed analyses of directional data (using arrays and two different depths) have demonstrated conclusively the existence of (and probable dynamics underlying) "nonlinear refraction" of waves through the shoaling region.

The shoaling waves studies are sponsored jointly by NASA and NSF.

OCEAN CIRCULATION FROM SATELLITE ALTIMETRY

Dr. Lee-Lueng Fu
Jet Propulsion Laboratory, 169-236
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-8167; FTS 792-8167

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

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

Approach: (1) Altimetric crossover differences (differences between measurements made at the ground track intersection) are used to construct spatial arrays of time series of sea level variations. The procedure involves least-squares optimization for both error reduction and time series estimations. (2) Differences in sea surface height between observations along repeat ground tracks are used to study the statistics of global mesoscale variability. (3) Orbit errors, the dominant errors in altimetric measurement, are modeled in terms of a Fourier series with its coefficients determined by a least-squares method.

Status: (1) A new technique has been developed to recover satellite orbit errors from altimetric crossover differences. The thrust of the new technique is the ability to solve for the Fourier coefficients of orbit error without the need for any auxiliary constraints that would distort the resulting ocean topography. This technique will be applied to the newly available Geosat ERM data. (2) We are beginning data processing work on the Geosat ERM data. Near-term science plans for the data include studies of the global mesoscale variability, temporal variability of the Gulf Stream and the Antarctic Circumpolar Current.

THE ROLE OF WIND STRESS IN DETERMINING THE GENERAL OCEAN CIRCULATION

Dr. Lee-Lueng Fu
Jorge Vazquez (CoI)
Jet Propulsion Laboratory, 169-236
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-8167; FTS 792-8167

Long-Term Interests: The long-term objective of this project is to understand the role of wind stress in determining the barotropic component of the time-mean circulation of the ocean (especially the regions away from boundary currents and intense recirculations). The emphasis will be placed on the exploration of the utility of the NASA Scatterometer (NSCAT) wind measurement in improving our knowledge of the ocean's general circulation.

Objectives: Near-term objectives are to investigate the degree of consistency of the ocean circulation estimated from hydrographic data with the climatological wind stress data in the context of linear vorticity dynamics (the Sverdrup relation).

Approach: Based on the assumption of linear vorticity dynamics, geostrophic velocity in the ocean can be estimated from hydrographic data using the method of beta spiral or the inverse method. The barotropic component of the velocity is also constrained by wind stress and bottom topography. The impact of this latter constraint will be investigated and its effects will be incorporated in the estimation of ocean current velocity.

Status: Gridded bathymetry data from NGDC have been analyzed and processed into a form that can be used with hydrographic data and wind stress data in a calculation of the barotropic velocity in the ocean. Present efforts are directed toward a study of the circulation of the North Atlantic Ocean.

This task is funded by the NSCAT Project through a NASA Announcement of Opportunity.

A MULTI-SENSOR REMOTE SENSING APPROACH FOR MEASURING PRIMARY PRODUCTION FROM SPACE

Dr. Catherine Gautier
Scripps Institution of Oceanography, California Space Institute
University of California at San Diego
La Jolla, CA 92093
(619) 534-4936

Long Term Interests: Our aim is synoptic global assessment of marine primary productivity. Success of the CZCS in producing maps of phytoplankton pigments inspires us to develop remote sensing methods for measuring primary productivity. Applications include fisheries management and monitoring the response of primary productivity to long and short term climatic fluctuations through carbon cycle modelling and sedimentation studies.

Objectives: We have proposed to develop a multi-sensor remote sensing method for computing primary production from space. This method is based upon our existing capability to measure - from space - the prime environmental parameters that regulate photosynthesis. These are the instantaneous shortwave radiation, the radiation experienced by the phytoplankton in the recent past, and the nitrogen availability.

Approach: Our model will incorporate data from three satellite sensors. The photosynthetically active radiation (PAR) is obtained from the VISSR on the GOES satellites. Nutrient concentrations will come from nitrate regressions on sea-surface temperature (SST), measured by AVHRR on the NOAA satellites. Biomass can be estimated from the Nimbus-7/CZCS as mentioned above. With knowledge of the interrelationships between primary production and the controlling parameters, we shall develop an empirical, multivariate approach, then progress toward a more physically based semi-empirical algorithm based on estimating phytoplankton biomass, nutrients and PAR in the water column. This work is in collaboration with Dr. M.J. Perry (University of Washington, Seattle).

Current Status: Our computing capabilities have expanded rapidly in the past year. A remote sensing workshop here this summer will test and further augment our system. We have evaluated and are implementing various pigment algorithms for CZCS processing. We have inserted our new formula for computing PAR into our existing image processing software. The 1987 BIOWATT field program provides us with ground verification of the formula. We have obtained and are processing GOES imagery corresponding to these cruises. Algorithms for mapping sea-surface temperatures from AVHRR are near completion. We have initiated an investigation of nitrate-SST relationships and data has been identified and gathered for study of relations among primary productivity and its forcing parameters.

Effects of a Large-Scale Wave-Field Component On Scatterometer-Derived Winds

Roman E. Glazman

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Dr.
Pasadena, CA 91109
Tel. 818-354-7151

Long-Term Interests: To understand geophysical and hydrodynamical phenomena that introduce biases in microwave remote sensing measurements of wind, wave height and sea level. A particular type of bias under consideration is correlated with the "generalized wind fetch", defined as $\frac{\rho_w g <\zeta^2>}{\rho_a U_{10}^2}$. We believe that this bias is controlled by the degree of the wind wave development.

Objectives: The main objective for 1986-87 is to investigate the fetch-induced bias in SEASAT scatterometer measurements of wind speed. In order to understand the physical mechanism responsible for this bias, an investigation into the sea surface geometrical features, deemed likely to cause the corresponding errors in SASS measurements, is being conducted. The attention is focused on intermittently occurring events of steep and breaking wavelets that belong to the range of gravity waves.

Approach: The SASS-NDBO collocated data set of wind and wave measurements is used to analyze trends in the SASS errors and relate them to various measures of the degree of wind-wave development. The theoretical part of the research is carried out employing results recently reported in the literature on statistical geometry of random fields.

Status: The task was initiated in 1986. Preliminary analysis of the SASS wind measurements has been performed and revealed a well-pronounced fetch-induced bias. A hypothetical explanation of the bias is being proposed based on a model developed by Zakharov et.al., 1975 through 1983, that yields an inverse energy cascade in the equilibrium range of wave spectra when the sea is sufficiently well developed.

A SUMMER ICE/OCEAN MICROWAVE REMOTE SENSING AND MESOSCALE MODELING EXPERIMENT FOR MIZEX/EAST'84

Per Gloersen and Erik Mollo-Christensen
Laboratory for Oceans
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771
301-286 6362

Long-Term Interests: Utilize microwave radiometric and radar data obtained from spacecraft and airborne instruments to study the role of air-sea-ice interactions in global weather and climate.

Objectives: 1) Understand better the physical ocean/ice/atmosphere interactions occurring in the marginal ice zone (MIZ). 2) Validate and improve the algorithm for obtaining sea ice concentration and age from such data.

Approach: Analyze multispectral microwave radiance data acquired by airborne radiometers and radars in combination with simultaneous and similar data acquired from the SMMR on board the Nimbus-7 spacecraft and surface observations during MIZEX'84.

Status: This is the last year for this effort. This analysis resulted in the writing of four papers, two of which have been accepted for the special MIZEX issue of JGR. The other two are in review. The most significant results may be summarized as follows: 1) During the several freeze/thaw cycles encountered during MIZEX'84, there was no significant difference between the sea ice concentrations obtained from either the multispectral microwave radiometers on board the NASA CV-990 or the SMMR data down to the melt point of the ice. 2) The disappearance of the multiyear sea ice signature near the melt point was correlated more with the presence of cloud cover than above- freezing air temperatures. 3) The appearance of ocean eddies as manifested by floating spirals of ice was correlated to low wind conditions in the MIZ; high winds invariably resulted in producing a smooth ice edge. 4) The wind was more important than the ocean current in determining the ice edge structure over the Yermak Plateau; the reverse was true for the Molloy Deep. 5) As before, reduction of ice concentration within the sea ice pack was correlated to winds with a strong off-ice component.

GLOBAL OCEAN WAVE SPECTRAL INFORMATION FROM SPACE

Hans C. Graber
Department of Ocean Engineering
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
(617) 548-1400

Vincent C. Cardone
Oceanweather, Inc.
5 River Road
Cos Cob, CT 06807
(203) 661-3091

Mark Donelan
Canada Centre for Inland Waters
867 Lakeshore Road
Burlington, Ontario L7R 4A6, Canada
(416) 336-4879

Long Term Interests: The goal of this program is to: (a) provide a clear statement of the relevant science issues pertaining to modelling and monitoring of surface wave processes on regional and global scales utilizing wave spectral information from space, and (b) propose a program which subsequently addresses these issues within a multi-year time frame.

Objectives: Although the issues of this study embrace a broad range of potential research activities, we will specifically focus on: (i) evaluation of wave remote sensor capabilities; (ii) global and regional wave model performance and underlying physical formulation; (iii) remote wind and wave data assimilation in NWP/GCM atmospheric models and numerical spectral ocean-wave type models; (iv) optimum system design for remote ocean sensing of surface wind speed, wind stress, and wave properties.

Approach: Evaluate the present state of wave modelling and monitoring techniques of ocean wave properties. The review will also include an assessment of what is known about (post-SASS) scatterometer model functions and the stress dependence on sea state, of the effect of present assimilation schemes and data sources on oversmoothing wind fields and wave hindcasts, and of the practical rquirements of operational global and regional wave models. In addition, we plan to keep close contact with the SCOR affiliated Wave Modelling Project (WAM) to expand our collaborative activities in WAM and begin to address directly the science issues above through an independent program of research and experimentation which may or may not necessarily mesh with WAM.

Current Status: This study just began and primary efforts are to gather relevant material on the above issues.

MICROWAVE EMISSION FROM POLAR SURFACES

Thomas C. Grenfell
Department of Atmospheric Sciences AK-40
University of Washington, Seattle WA 98195
(206) 543-9411

Long Term Interests: To investigate the emissivity properties of the prevalent types of sea ice and to relate these to the physical properties of the ice in order to optimize the use of satellite imagery in understanding the large scale structure of sea ice and its environment.

Objectives: To obtain accurate surface based radiometric data of the full range of ice types present in selected regions together with the physical properties of each type. These measurements should be coordinated with aircraft and satellite overflights and used to extend the distance scales to those of the accuracy of the satellite retrievals. Since ice signatures vary with geographical location and show a strong seasonal dependence, a range of ice types must be sampled during different times of the year.

Approach: We observe sea ice emissivity together with integrated downwelling radiation from the atmosphere at vertical and horizontal polarization as a function of frequency from 6 to 90 GHz and nadir angle from 0-80^{o}. This selection of angles and frequencies covers the full range of operating parameters of both SMMR and SSM/I. In addition, our field programs also include measurements of the physical properties of the ice and snow which affect the emissivities. Our data analysis is done in close cooperation with other NASA sea ice investigators to carry out the comparisons with aircraft and satellite data sets.

Current Status: Our principal activities during the past year have involved analysis of data from studies of artificial sea ice grown at CRREL, and from studies of natural sea ice types in the Fram Strait and northern Greenland Sea. The details are described in several papers and include: (a) the microwave signatures of young growing sea ice from 0 to 30 cm thick; (b) signatures of late spring and summer ice types in the Greenland Sea marginal ice zone; and (c) comparisons of ice concentration in the MIZ derived from different sensors covering microwave, visible, and near infrared wavelengths. We find excellent agreement for specific ice types between our averaged values and the results of airborne radiometry.

Our theoretical emissivity model is now being tested and will shortly be applied to our existing data sets. Presently we are able to represent emissivity and backscattering cross sections for homogenous snow packs and granular sea ice below 37 GHz. At higher frequencies, the assumed ice absorption is too large and/or the calculated amount of scattering is too small. This work has been sponsored jointly with the Office of Naval Research under contract N00014-81-K-0460.

WEDDELL SEA PASSIVE MICROWAVE EXPERIMENT

Thomas C. Grenfell
Department of Atmospheric Sciences AK-40
University of Washington, Seattle WA 98195
(206) 543-9411

Long Term Interests: To investigate the emissivity properties of the prevalent types of sea ice and to relate these to the physical properties of the ice in order to optimize the use of satellite imagery in understanding the large scale structure of sea ice and its environment.

Objectives: To obtain accurate surface based radiometric data in the Weddell Sea of the full range of ice types present together with the physical properties of each type. These measurements have been coordinated with satellite overflights and carried out over a wide area to sample distance scales comparable with those of the satellite images. Since ice signatures can also show a strong seasonal dependence, the sampling period was extended to six months.

Approach: Observations were carried out from late June through mid-December 1986 during the first winter transects to and along the Antarctic coast by the icebreaker F/S Polarstern. The radiometers were mounted on the ship's rail and measurements were made at frequencies of 6, 10, 18, 37, and 90 GHz in both vertical and horizontal polarization, covering the range of both the SMMR and SMM/I satellite imagers. The corresponding physical properties including depth profiles of salinity, temperature, density, and crystal size and geometry of both the ice overlying snow were sampled at regular intervals.

Current Status: Surface types observed ranged from open water through first-year ice with 50 to 80 cm of thermal growth whose total thickness was often several meters thick due to ridging and multiple overthrusting. Emissivities at 50^{o} nadir angle ranged from low values for calm water which were within 5% of theoretical predictions to values near unity with a slight positive spectral gradient for the thickest undisturbed ice. Values for thin growing ice fell between these limits. A heavy cover of dry snow usually associated with ridging and rubble fields had little effect at the lowest frequencies but resulted in a slightly negative spectral gradient as a result of volume scattering coupled with low absorption in the dry surface layers.

Dual frequency cluster plots showed two major clusters corresponding to open water and thick "white" ice, but several other clusters were also observed which corresponded to young ice in various stages of development. These latter clusters are not co-linear with those for thick ice and open water suggesting that they should be distinguishable in satellite imagery of selected parts of the polar regions where young ice types are abundant. Present results suggest that the microwave signatures observed for ice in the Weddell Sea are consistent with observations made in the Arctic during MIZEX West in the Bering Sea and NORSEX.

LARGE SCALE AIR-SEA INTERACTIONS

David Halpern
Jet Propulsion Laboratory, M/S 169-236
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-5327; FTS 792-5327

Long Term Interests: Using satellite and *in situ* measurements, determine the dominant physical processes contributing to large scale sea surface temperature (SST) and near surface chlorophyll-*a* variations, emphasizing the role of upper ocean horizontal and vertical currents.

Specific Objectives: Satellite ground truth studies; describe spatial and temporal scales of tropical surface wind fields; describe annual cycles of surface wind and upper ocean current and temperature fields in Atlantic and Pacific equatorial zones; evaluate relationship between equatorial currents (*e. g.*, SEC and EUC) and and large scale SST variations; evaluate physical control of near surface phytoplankton abundance patterns in equatorial regions.

Approach: Statistical analyses of SEASAT, GEOSAT, NIMBUS-7, and TIROS-N measurements and *in situ* measurements, comparing observational results with model data.

Current Status: Data analyses project initiated during FY86 at the University of Washington, and then moved to JPL. Some preliminary results of continuing analyses are: (1) prominent (amplitude ≈ 0.4 m s), near surface, relatively narrow-band 20-day period current oscillations propagate westward along the Pacific equator with seasonal modulation, creating SST fluctuations with longitudinal wavelength of ≈ 1000 km; (2) magnitude of wind variability along the equator is twice as large in the Atlantic than Pacific; (3) annual cycle of near surface zonal current component in equatorial Pacific contains substantially more eastward flow than in the Atlantic.

Collection of *in situ* data was sponsored by NOAA. Analyses at the University of Washington was also supported by NSF.

OCEANIC REMOTE SENSING LIBRARY (ORSL)

Jeffrey E. Hilland
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-4787, FTS 792-4787

Long-Term Interests: To obtain, archive, catalog and distribute research and development publications related to physical and biological oceanography, sea ice, and air-sea interaction studies. To provide a comprehensive collection of internal reports relevant to ocean science and technology.

Objectives: To provide contemporary literature on and related to remote sensing of the oceans. Also, to provide a full complement of services for researchers who are the patrons of the Oceanic Remote Sensing Library (ORSL). To implement labor-saving methodologies for the management and distribution of literature.

Approach: The objectives of this task are met by the ORSL librarian. Organization, maintenance, and distribution of 185 titles and a bibliography containing more than 1800 entries are the main tasks. The focus of the literature collection is high quality oceanographic periodicals and NASA, DOD, NOAA, and ESA internal documents ("grey" literature). An on-line, computer based bibliography provides search and order capabilities to all users of the NASA Ocean Data System. Services provided to patrons consist of: document loan, interlibrary loan, literature search, and document acquisition. Requests for service are made via mail, telephone, visitation, and the NASA Ocean Data System bibliography.

Current Status: In response to patron requests, and to provide an up-to-date reference library, new titles were added to the collection of books, atlases and periodicals. Also, periodicals that were rarely used were eliminated to reduce subscription costs. The bibliography was expanded by approximately 26%. More than 450 documents were distributed to researchers. The "ORSL Observer" newsletter was compiled and distributed on a bi-monthly basis. Finally, a study of bar code systems was performed to determine if documents can be managed more efficiently.

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

Eileen E. Hofmann, Co-PI
Department of Oceanography
Texas A&M University
College Station, TX 77843
(409) 845-3501

Charles R. McClain, Co-PI
Oceans and Ice Branch/Code 671
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
(301) 344-5377

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

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

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

Current Status: Available CZCS images for the southeastern U.S. continental shelf have been analyzed with statistical methods to obtain correlations between the pigment data and flow and temperature fields. Also gradient and gradient changes have been computed for selected images and these results compared to equivalent results obtained from simulated pigment fields derived from a numerical model. Numerical experiments with the Lagrangian particle tracing model that include CZCS data have been performed. Present effort is focused on interfacing CZCS data with a coupled physical-biological model.

APPLICATIONS OF LASER TECHNOLOGY

Frank E. Hoge
NASA/Goddard Space Flight Center, Wallops Flight Facility
Wallops Island, VA 23337
(804) 824-1567 or FTS 889-1567

Long Term Interests: To improve the basic understanding of primary production processes in the world's oceans through application of airborne laser technology to the quantitative measurement of water column constituents and sea surface phenomena. Included is use of airborne laser and passive radiometry in the advanced development and calibration of satellite ocean color scanners.

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

Approach: The NASA Airborne Oceanographic Lidar will be flown in cooperative, multi-institutional, oceanographic field investigations such as the National Science Foundation's Warm Core Rings, the Department of Energy's Shelf Edge Exchange Processes and Spring Recovery Experiment field efforts, and the Office of Naval Research's optical variability and bioluminescence studies (BIOWATT). These past (and some ongoing) field programs involve numerous universities and oceanographic institutions. Comparing airborne laser derived chlorophyll _a_ measurements with moored fluorometer, shipboard, and available Coastal Zone Color Scanner data is considered high priority for understanding phytoplankton dynamics and estimating primary productivity.

Status: Airborne laser-induced chlorophyll _a_ and phycoerythrin fluorescence data have been obtained, analyzed, and supplied to cooperating institutions. Corroboration with participating scientists in the analysis of the data and publication of important findings is an ongoing activity. During the past several years, numerous papers have been published on oceanic lidar applications to airborne measurement of chlorophyll, phycoerythrin, tracer dye concentration, oil film thickness and identification, monomolecular films, front mapping, water depth, and sea surface backscatter characteristics. Several papers have been recently published on active-passive (laser-solar) airborne ocean color methods for phytoplankton pigment concentration measurement, chlorophyll algorithm development, and general ocean color spectral variability studies. Promising on-wavelength subsurface scattering layer measurements have recently been obtained, and show potential for depth-resolved phytoplankton measurement.

MICROSCALE OCEAN SURFACE DYNAMICS

N. E. Huang
Code 671, NASA/Goddard Space Flight Center
Greenbelt, MD 20771
(301) 286-8879

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

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

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

STATUS: Our study is a continuous effort within the air-sea interaction program. In the last year, we have obtained the following results: (1) We found that the sea state can effectively modify the surface roughness structure especially in the low ($U^*<30$cm/sec) wind speed range. (2) We found that wave breaking can modify the spectral form, and established an analytic model for it. (3) We started an experiment series on wave current interaction.

FASINEX P-3 FLIGHTS

F. C. Jackson and E. J. Walsh
NASA/Goddard Space Flight Center/671
Greenbelt, MD 20771
(301) 286-5380

Long term interests: The high mobility and large-area, rapid mapping capability of NASA's airborne ocean wave sensors make them ideal 'surface truth' instruments for other airborne and satellite remote sensors. In the case of satellites, aircraft underflights with well calibrated, high resolution ocean wave sensors can considerably speed up the calibration and validation phase of a mission; in the case of aircraft measurement programs, full advantage is taken of the limited air time by trading temporal sampling for spatial sampling.

Objectives: In February, 1986, the NASA Wallops Flight Facility P-3 aircraft, equipped with the Surface Contour Radar (SCR), Radar Ocean Wave Spectrometer (ROWS) and Airborne Oceanographic Lidar (AOL), made five flights in the Frontal Air-Sea Interaction Experiment (FASINEX) for the purpose of providing directional wave spectrum data to support the JPL airborne scatterometer measurements. The objective was to determine the effect of non-equilibrium wave fields on scatterometer measurements of the wind vector/stress vector.

Approach: The SCR, as prime instrument, was to measure wave field on both sides of the front while flying in tandem with the scatterometer. The ROWS and AOL were to serve mainly as backup instruments. While in the aircraft 'elephant line', the ROWS would obtain near-nadir, relative cross-section data to support and complement the scatterometer measurements.

Status: Quality directional wave data were obtained on all five flight days. Although the SCR failed on two flights, backup ROWS and AOL star pattern data were obtained which largely compensate for the loss. All sensor data from the mission have been processed. Some of these data were shown at the Woods Hole workshop. SCR spectra processed with full and fractional swath resolution using carefully edited INS data have been produced for the 18th and a tape of these spectra has been sent to JPL. ROWS near-nadir cross section data have been analyzed for mean square wave slope. These data will be further analyzed in terms of available wind/wind stress data and other field data in collaboration with D. Weissman of Hofstra University.

MICROWAVE RADAR OCEANOGRAPHIC INVESTIGATIONS

F. C. Jackson
NASA/Goddard Space Flight Center/Code 671
Greenbelt, MD 20771
(301) 286-5380

Long-Term Interests: Global-scale, satellite measurements of ocean surface wave directional spectra have been shown to be feasible with the radar ocean wave spectrometer (ROWS) technique developed under this RTOP. My long term interest lies in seeing data from a ROWS type instrument in space used in a multi-sensor, wind and wave model mix to accurately determine air-sea fluxes and to improve operational weather and sea state forecasting.

Objectives: (1) To continue the low level-of-effort ROWS space sensor definition studies. (2) To further refine and validate the measurement technique. (3) To apply the ROWS aircraft data for wave spectra and surface mean square slope to basic wave physics and phenomenology investigations.

Approach: Space sensor definition studies will focus on specific flight opportunities sucn as RADARSAT. Our role will be limited essentially to providing technical guidance. ROWS data from six missions provide an adequate data base for quantitatively assessing ROWS performance. The reference spectra for the last five missions are mainly surface contour radar (SCR) spectra. Directional buoy data from the March 1987 LEWEX experiment provide additional data for assessing ROWS performance. As well, these data provide a check on SCR performance. The potential of ROWS near-nadir cross-section and rear-face spectral measurements for wind stress determination will be tested with February 1986 FASINEX data.

Status: Processed data sets from five missions are in various stages of analysis and in the queue for publication. Examples of ROWS data from three missions can be found in Measuring Ocean Waves from Space, edited by R. C. Beal, JHU/APL Tech. Digest, Vol. 8(1), 1987. The SCR comparison for the MASEX bimodal spectrum shown therein provides some of the strongest evidence we have for high fidelity in the ROWS directional response. Correction for saturation of the six-bit A/D has led to a more reasonable, linear E-x fetch relation for the MASEX data; however, direct verification is difficult because only a limited amount of colocated SCR data exists for the mission. A new computer-controlled ROWS data system will be assembled this June and flight tested by September.

AIR-SEA INTERACTION STUDIES

Principal Investigator: Kristina B. Katsaros, Associate Professor
Department of Atmospheric Sciences
Seattle, Washington 98195
Phone: (206) 543-1203

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

Objectives of this specific research: Our objectives were to extend our previous findings on wavenumber spectra of short waves to higher wind speeds and various atmospheric stability cases; to study wave generation under light winds; and to build statistics of breaking waves to search for detection and prediction criteria for these events.

Approach: Surface roughness can best be described by wavenumber spectrum of short waves. Therefore, we measured wave heights and calculated the frequency spectra which were then converted to wavenumber spectra by correcting for Doppler shift caused by long wave orbital velocities and surface currents. For the cases of wave generation by light winds, Doppler correction is not required. A parameterization of surface roughness in terms of environmental conditions can be sought by relating the time-averaged wavenumber spectra to atmospheric and oceanic variables, such as friction velocity, atmospheric stability, water temperature and long waves. Wave breaking can have significant effects on surface roughness and transport phenomena across the air-sea interface. However, due to their turbulent nature, breaking events can not be studied with the above approach. Therefore, these events were identified and excluded from the analyses by using a technique we developed earlier. Statistical methods are employed to determine detection/prediction criteria for these events as well as their temporal and spatial characteristics. The findings can be verified by using our video records of the water surface.

Current status: Data analysis techniques were developed and tested by applying to limited field data. The results up to this stage are summarized by Ataktürk and Katsaros (1987; JGR-Oceans, in press). We have collected new data sets in Lake Washington which cover various cases of wind speeds (2 to 10 m/s), water temperatures (15 to 25°C) and air-sea temperature differences (-4 to 4°C). These data sets are currently being processed.

LIGHT ABSORPTION, FLUORESCENCE, AND GROWTH OF PHYTOPLANKTON: STUDIES IN SUPPORT OF REMOTE SENSING

Dale A. Kiefer[1] and Janice Beeler SooHoo[2]
[1]Department of Biological Sciences, [2]Allan Hancock Foundation
University of Southern California, Los Angeles, Calif. 90089-0371
[1](213) 743-6911 [2](213) 743-2934

Long Term Interests: Our long term interests include contributing to the understanding of global marine primary production by defining synoptic basin and/or regional patterns of primary production from satellite imagery and then understanding the temporal and spatial patterns of primary production in these images in the context of chemical and physical parameters.

Objectives: The primary objective of the tenure of this study is the development and continued refinement of a model for the estimation of marine primary production from satellite images of sea surface pigments, temperature, and incident irradiance. In particular, we have focused our efforts on deriving a model based on first principles of photophysiology of microalgae in the hope that such a model will be more global in its applicability than regionally-derived correlations between chlorophyll a and primary production. Included in the refinement of the model are laboratory and modeling studies aimed at understanding the changes in light harvesting capability of individual algal cells as well as natural assemblages as a function of photoadaptive state and taxonomic composition. We are applying derivative analysis, spectral deconvolution techniques, and emprical orthogonal function analysis to *in vivo* absorption spectra measured on laboratory cultures and field-collected samples of phytoplankton.

Approach: We have extended the fundamental model of Kiefer and Mitchell (1983) for application to the euphotic zone in the ocean. Refinements include conversion of a model based on photosynthetically available radiation (PAR) to the more physiologically meaningful photosynthetically usable radiation (PUR). We continue to accumulate a large data base of shipboard measurements of light, chlorophyll, primary production and hydrography from the world's oceans against which we can test our model's ability to estimate primary production.

Status: The validity of the primary production algorithm has been tested with sea truth data from the North Pacific, upwelling regions of Peru and central California, Southern California Bight and Weddell Sea. We hope to add additional data from the equatorial Pacific and Bering Sea. Despite the wide range of locales and oceanographic regimes represented by these data, the correlation coefficients for measured and predicted primary production are greater than 0.75. Images of primary production from the Pt. Conception, California upwelling center have been made for a period in spring of 1983, and compared to measurements of primary production made during the OPUS study.

OCEAN CIRCULATION STUDIES WITH SATELLITE ALTIMETRY

Chester J. Koblinsky
NASA/Goddard Space Flight Center
Code 621
Greenbelt, Maryland 20771
(301) 286-2880

Long-Term Interests:

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

Objectives:

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

Approach:

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

Status:

An extensive analysis of wind fields and current measurements in the North Pacific has been carried out to understand the wind forced circulation. Several measurement locations indicate the presence of a direct wind forced response. An estimate of the global distribution of wind forced mesoscale variations has been made and a simple diagnostic model developed. Comparisons between the data and numerical ocean circulation models are in progress. Two presentations of this work were given this past year and a manuscript is in preparation. This topic will be pursued with GEOSAT altimeter data, bottom pressure measurements, and general circulation models over the next few years.

A study has been carried out of sea level change in the Northwest Atlantic using GEOS-3 and SEASAT altimeter data. Two techniques have been used extract the large scale, low frequency sea level fluctuations. Results from both techniques over an 18 month subset of the GEOS-3 data compare favorably with hydrography and tide gauge measurements at Bermuda. Simple models for some of the causes of sea level change (atmospheric forcing and surface heating) are being developed and tested with these measurements. A manuscript is in preparation discussing the results from the complete data set.

SUB-TEN CENTIMETER AIRCRAFT POSITIONING USING THE GLOBAL POSITIONING SYSTEM

William B. Krabill
Code 672 - Observational Science Branch
Laboratory for Oceans
Goddard Space Flight Center
Wallops Flight Facility
Wallops Island, VA 23337

Long Term Interests of the Investigator. Develop and apply the technology and algorithms required to provide aircraft trajectories with an accuracy of sub-ten centimeters. This trajectory accuracy is relative to a fixed site, with separation distances of up to 200 km, or perhaps more.

Objective of this Specific Research Task. To provide a precise reference position for airborne remote sensing systems including specifically laser and radar sensors. This technology will be applied to oceanographic measurements, including the possibility of detecting and measuring geostrophic currents, and for the collection of sea surface condition data for calibrating satellite radar and laser altimeters. The capability will also be applied to the collection of measurements over ice and snow .

Approach Utilized for this Task. This project will make use of techniques developed for geodetic applications in which the phase of the GPS L-band carrier is tracked to provide ultra precise, but ambiguous pseudo-ranges. The technique works very well for receivers at fixed locations, but is somewhat more difficult for a mobile application.

Status and Progress. A preliminary test was conducted in 1985 in which 10-12 cm. results were demonstrated utilizing receivers not designed to function in an aircraft. The project has recently procured two receivers from Motorola which are intended for mobile operation, and were used on a recent mission of the NASA P-3 to the north pole. Data from this project are now being analyzed, and early indications are that performance of the GPS receivers was well within specs.

OCEAN SURFACE WIND STRESS MEASUREMENTS IN SUPPORT OF SCATTEROMETRY STUDIES

William G. Large
National Center for Atmospheric Research
Boulder, Colorado 80307
(303) 497-1364

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

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

Approach: The approach is to obtain coincident measurements of τ_0, and NRCS over a wide range of conditions, then investigate the empirical relationships that emerge. The results should place useful constraints on theoretical studies. No presumption is made that NRCS is more closely related to wind stress, only that since wind stress is the parameter of most interest at the sea surface, an attempt should be made to directly relate it to measureable quantities such as NRCS. Airborne scatterometry is to provide the NRCS data, thus relieving the severe sampling constraints of a satellite system while maintaining the mobility to sample different geographical regimes.

Status: Data from the intensive phase (10 Feb–10 Mar 1986) of the Frontal Air–Sea Interaction Experiment (FASINEX) continue to be analyzed and interpreted. Direct measurements of τ_0 from the R/V Endeavor have proven to be reliable and a paper describing the instrumentation, and the measurements has been submitted for publication. These data, and direct stress and wind velocity from the NCAR Electra are being used in a case study of Feb. 18, along with NRCS from the NASA Ames C130B aircraft. Preliminary results (presented at the fall AGU in San Francisco) indicate that the marked decrease in backscatter on the cold, downstream (northern) side of a strong ($\sim$ 1.5° C) sea surface temperature front could only partially (50%) be explained by the change in wind speed and atmospheric stability. The remainder could be explained by a change in surface roughness or in the neutral 10 m drag coefficient. such that the entire change could be interpreted as following the surface wind stress. Contour wave radar data from the same period show that indeed the surface wave is very different on the two sides of the front. This work, in collaboration with F. Li (JPL) is being prepared for publication.

Instrumentation for the Field Measurements of Dielectric Constant at 18, 35, and 94 GHz

Richard W. Larson
Environmental Research Institute of Michigan
Advanced Concepts Division
P. O. Box 8618, Ann Arbor, MI 48107
(313) 994-1200

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

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

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

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

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

ADVANCED SCATTEROMETRY

F. K. Li
Jet Propulsion Laboratory
4800 Oak Grove
Pasadena, Ca 91109

Long Term Interest: To develop advanced technique and technology that will improve the performance of future spaceborne scatterometers as a remote sensor of oceanographic and meteorological variables.

Objectives: To develop a new airborne research scatterometer facility that can be used for geophysical research and as a test bed for new technology development. A second objective is to develop and analyze new system design concepts that can be applied to the next generation spaceborne scatterometers.

Approach: We are in the detailed design/early fabrication phase of a new airborne 14 GHz scatterometer (NUSCAT). This system is designed to be inherently flexible so that we can modify many aspects of the system operation without major changes. For example, several system receiver bandwidths are used to allow for pulse compression schemes and the raw radar echoes will be digitized and recorded using high density digital tapes. This system is planned to operate over an altitude range of 1500' to 45,000'. Using a frequency hopping scheme, the relative σ_0 measurement accuracy is expected to be ~ 0.3dB for 0.5-sec integration intervals. These accuracies should allow careful studies of σ_0 vs. oceanic winds in various geophysical research experiments.

We are also examining new system concepts that can potentially provide wind measurements superior to the NSCAT-class scatterometers. The key areas where improvements are desired include wider swath, higher wind direction ambiguity removal skill, etc. We are examining the use of conically scanning pencil-beam antennas, operating at medium to high incidence angles, to achieve these performance improvements.

Status: The functional requirements for NUSCAT has been documented. The procurement of major long-lead items will be completed in FY87. The development of the computer controller software will also be initiated. The mechanical/electrical interfaces with the C130 will be documented. For the advanced scatterometer concept, a computer program to simulate its performance is under development.

OCEAN SCATTEROMETER RESEARCH

F. K. Li
Jet Propulsion Laboratory, T1206D
4800 Oak Grove Drive
Pasadena, CA 91109
(818)354-2849; FTS 792-2849

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

Objectives: Improve the present scatterometer geophysical model function by comparing the radar backscatter at Ku band to ocean wind and wind stress, and to other auxiliary geophysical variables.

Approach: We will conduct a series of experiments to collect σ_0 and associated geophysical parameters over a wide range of atmospheric and oceanographic conditions and use this data set to guide the development of a physically based model function relating σ_0 to ocean winds. In FY86, we collected ~ 22 hrs. of σ_0 data during the Frontal Air-Sea Interaction Experiment. Two case studies using these data sets have been completed. The first indicated that the locations of the azimuthal modulation minima were significantly offset from the cross-wind direction. The offset was more pronounced for horizontal than for vertical polarization data. The second case study concentrated on the data across the sea surface temperature front collected on 02/18/86. An 3dB change in σ_0 was observed across the front and the wind stress measurements also showed a similar change of a factor of ~ 1.5. These results will aid in the development of the σ_0 vs. wind stress model. In FY88, we plan to conduct backscatter measurements during the Ocean Storms Experiment. The purpose is to collect a similar set of comprehensive data in the high wind speed regime.

Status: The FASINEX data set is being reduced to calibrated σ_0 using the recently measured antenna gain pattern and other instrument parameters. A final report on the σ_0 results and associated geophysical interpretation will be prepared. An engineering test flight of AMSCAT is being planned for July/August in order to prepare for the Ocean Storms Experiment. Six to seven flights are planned for Ocean Storms during October/November 1987.

REMOTE SENSING OF AIR-SEA EXCHANGES IN HEAT AND MOMENTUM

W. Timothy Liu
Jet Propulsion Laboratory
Mail Code 169-236
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-2394; FTS 792-2394

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

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 annual and interannual variabilities in the tropical Pacific.

Approach: (1) Demonstrate the feasibility of determining latent heat flux to a useful accuracy using Seasat SMMR data. (2) Determine a global relation between precipitable water and the surface-level humidity (3) Evaluate and correct precipitable water, sea surface temperature, and surface wind speed measured by Nimbus/SMMR and use these data to examine the annual and interannual variabilities in the tropical Pacific. (4) Examine and modify bulk parameterization models to use satellite data. (5) Using Nimbus/SMMR data to determine surface latent heat flux in the tropical Pacific and relate the flux variabilities to oceanic and atmospheric thermodynamics. (6) Combine the latent heat flux with shortwave radiation to examine ocean surface heat balance.

Current Status: Steps (1),(2),(3), and (4) described above have been completed. Steps (5) and (6) are still in progress.

Ana!ysis of Satellite-Tracked Drifting Buoys in the North Pacific

Dr. Douglas S. Luther

Scripps Institution of Oceanography, A-030
La Jolla, California 92093
Tele: (619) 534-4739

Long-Term Interests: Dynamaics of ocean fluctuations on time scales of 1 hour to 1 year, including free wave characteristics, wave-mean flow interaction, forcing and dissipation mechanisms.

Objectives: In collaboration with G.J. McNally, extract and interpret, from drifting buoy trajectories, the kinematic and some dynamic properties of a variety of near-surface oscillations, including free inertial waves (peak periods between 18 hours and 5 days), forced evanescent sub-inertial waves at mid-latitudes (periods of ~1-10 days), and mid-frequency oscillations in the tropics (periods of ~10-60 days) that are probably generated by mean flow instabilities or the interaction of the mean flow with topography.

Approach: Statistical and spectral analyses are employed, many of which have been modified to account for the irregular space-time sampling that is characteristic of drifitng buoy trajectories.

Status: In fiscal year 1986, we accomplished the following:
1) A variety of mid-frequency fluctuations in the tropical Pacific have been documented and their frequency-wavenumber characteristics estimated. One kind of oscillation, found between the equator and 5^{o}N, has characteristics consistent with perviously observed oscillations (Legeckis waves) that are believed to be generated by an instability involving the South Equatorial Current just north of the equator. Another oscillation, at 5^{o}-10^{o}N, has twice the period and wevelength of the Legeckis wave, while yet another oscillation in this latitude band, in a different season, appears to be a stationary lee wave downstream of the Line Is. Strong oscillations occur at the equator in the spring when the SEC is weak (and probably stable). And strong eddy activity is found around several island arcs.
2) Using vector cross-spectral analysis, the time lag of surface current behind surface wind stress has been clearly separated from the vector rotation of the surface current relative to the wind in mid-latitudes where good surface wind products are available from FNOC.
3) The vertical decay scales and rotary horizontal current structures of forced, sub-inertial waves at mid-latitudes have been estimated and compared with model predictions.
Manuscripts have been submitted or are in preparation.

OCEAN CIRCULATION AND TOPOGRAPHY

James G. Marsh
Chester J. Koblinsky
Goddard Space Flight Center
Greenbelt, MD 20771
(301) 286-5324

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

Objectives

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

Approach

Techniques for the computation of regional and global mean sea surfaces have been further refined. Improved values for geodetic parameters such as the earth's gravity model, tracking station coordinates, polar motion, earth rotation and earth and ocean tides have been incorporated into the orbit computations for Seasat.

Status

Global mean sea surface computations based upon the total sets of Seasat and Geos-3 satellite altimeter data have been continued on a 1/8° grid. Sea ice data in the southern oceans which have not been previously analyzed, have been processed using waveform retracking techniques. The mean sea surface coverage has been extended by several degrees in this region. Computer imaging techniques for displaying the mean sea surface data have been refined and new maps have been produced using edge enhancement techniques.

The use of the new GSFC GEM-T1 earth gravity model and associated geodetic parameters has resulted in a factor of two improvement in the accuracy of the Seasat orbits. Orbit accuracy for Seasat is now in the 50 cm. range. Previously with the best Seasat tailored model PGS-S4 orbit errors were about 1 m. Further improvements are anticipated in the next few months when altimeter data are included in the GEM-T1 model.

TOPEX Gravity Model Development and Precision Orbit Determination Technique Development

James G. Marsh
Goddard Space Flight Center
Greenbelt, Maryland 20771
(301) 286-5324

Long Term Interests

To develop a new earth gravity model and associated geodetic parameters which will provide computation accuracies for the TOPEX satellite at the decimeter level. Precision orbit techniques and computer programs are being developed to support this activity. Tracking system accuracy investigations are being conducted in order to insure adequate observational support.

Objectives

The computation of radial orbit position information for a satellite at an altitude of 1300 km to an accuracy of a decimeter has never been accomplished heretofore. The primary limitations have been errors in the geodetic models used for the orbit computations (e.g., primarily the earth gravity model, and also atmospheric drag, solar radiation pressure as well as the models for the earth and ocean tides). Other factors which require consideration are tracking system accuracy and computer program efficiency. The objectives of this work are to develop the geodetic force models and parameters required to support the decimeter accuracy goal for TOPEX.

Approach

A major recomputation of the earth gravity model was initiated over 2 years ago. This new geodetic solution has included models for (or the ability to solve for) all effects which would significantly affect the orbit accuracy for TOPEX. Where possible, highly accurate geodetic results from the NASA Crustal Dynamics investigations have been incorporated. Tracking system support is also under investigation. Investigations to date of the Doppler (Baseline system) have revealed serious questions as to whether that system would be able to provide the consistency and accuracy required. These investigations are being pursued.

Status

A new earth gravity model based upon a multi-satellite solution containing 17 satellites has been computed. This model (complete to (36,36)) is designated GEM-T1. The solution also provided for a comprehensive solution of global ocean tides and earth orientation. Accuracy assessments indicate that a factor of 2 improvement over the best previous models has been achieved. During the past year detailed analyses of SEASAT and GEOSAT Doppler data have been conducted. These investigations have revealed serious problems (e.g., cycle slips) with these data and cast serious doubt as to whether the Doppler system will actually support the decimeter accuracy goal. Additional GEOSAT Doppler data have been received and are under investigation.

The accuracy of the NASA laser tracking data is currently about 2 cm. The use of this system as a baseline system for Topex is being investigated.

A Satellite Study of Polynyas in the Arctic Ocean and the Sea of Okhotsk Using the SMMR and the SEASAT Data Sets

Seelye Martin
School of Oceanography WB-10
University of Washington
Seattle WA, 98195
(206) 543-6438

Long Term Interests: Our interests are in the use of satellite and related surface data to obtain information about deep and bottom water production in the Arctic and North Pacific Oceans.

Objectives: Our major objective is to estimate the production rate of oceanic intermediate, deep and bottom water from polynyas in ice-covered oceans. We also plan to use satellite measurements to understand the polynya surface properties.

Approach: To determine the production rates of the various oceanographic water types, we use a combination of SMMR data, NCAR 6 hour weather station data, Bakin wind data and oceanographic data. This work is being done in two separate areas: the Siberian shelf and the Sea of Okhotsk. The Siberian shelf work is a joint effort with Donald Cavalieri of the Goddard Space Flight Center; the Okhotsk work is a Masters thesis project being done by Michael Alfultis at the University of Washington. The Siberian work allows us to estimate the production of deep and bottom water in the Barents and Kara Seas. The Okhotsk work has two results. First, we have identified a new polynya which occurs in the Okhotsk over a topographic rise called the Kashevarova Bank. Second, we have calculated the flux of dense water from the polynyas which occur on the northwest Okhotsk shelf, and have shown that this flux makes a substantial contribution to a 700 m thick layer of cold intermediate water which is unique to the Okhotsk. Our calculated flux rate for this water is 1-2 x 10 m s or 3-6 x 10 km year , which gives a replacement time of about 5-10 years, a result consistent with oxygen measurements.

Status: During the past year, we completed our study with JPL on a passive and active microwave comparison of the Weddell Sea pack ice using the SIR-B observations. Also, at the fall 1986 AGU in San Francisco, we presented a preliminary version of the Siberian Shelf work. The Sea of Okhotsk work is presently available as a Masters thesis, it will be available as either a Technical Report or a paper by 1 July 1987.

INVESTIGATIONS OF MESOSCALE PHYSICAL AND BIOLOGICAL OCEANIC PROCESSES

Charles R. McClain
Oceans and Ice Branch, Code 671
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
(301) 286-5377

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 distributions. It is often possible to differenciate the effects of various forcing mechanisms by the pigment patterns produced. Studies that quantify the coupling between physical and biological fields can lead to improved insight into both physical and biological processes.

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

APPROACH: In order to study a number of oceanic systems, collaborations with on-going multidisciplinary field programs have been initiated and arrangements for several university collaborators to work at GSFC have been made. Whenever possible, CZCS and AVHRR data are collected during cruises in order to tie the imagery to high quality in situ measurements for interpretation. In order to understand variability on seasonal and interannual time scales, time series of images are processed and composited into seasonal mean and variance fields. Much effort is devoted to the development of user-friendly interactive image analysis software.

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

*Partially supported by the Department of State.

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

Principal Investigator:

Robert E. McIntosh
Department of Electrical and
Computer Engineering
University of Massachusetts
Amherst, MA 01003
(413) 545-0709

The Microwave Remote Sensing Laboratory (MIRSL) at the University of Massachusetts has been studying the feasibility of measuring ocean surface currents with frequency–agile, dual–frequency radars. This technique may have application for synoptically measuring ocean currents over large areas of the ocean from geostationary platforms in space. The MIRSL has also begun to develop a scatterometer to measure wind speed and direction above the ocean surface. In the next few years we will work cooperatively with JPL and NASA–Ames to measure microwave scattering from the ocean surface at C–Band. These measurements will be used to interpret ERS–1 data which will be available after 1990.

During fiscal year 1986, the MIRSL studied the reliability of measuring ocean surface current with the Laboratory's C–Band Step–Frequency Delta–K (SFDK) radar. The instrument was modified to enhance its capabilities to monitor the resonant "ΔK" peak of the cross product spectrum between two scattered microwave signals. Field measurements were made at North Truro (Cape Cod), MA during periods of changing sea state.

Preliminary SFDK measurements show effects that surface winds have on the measured surface currents. Consequently, we will continue the North Truro measurements to better quantify the relationship between surface current and wind speed and direction for a wider variety of ocean surface conditions. However, most of our emphasis during the coming year will be directed towards our scatterometer work owing to the importance of underflying ERS–1 and correctly interpreting scatterometer data.

ADVANCED RADIO TRACKING SYSTEM (ARTS)

William G. Melbourne
Telecommunications Science and Engineering Division
Jet Propulsion Laboratory, Mail Stop 238-540
4800 Oak Grove Drive, CA 91109
(818) 354-5071 or FTS: 792-5071

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

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

Approach: The system concept entails the concurrent tracking of GPS satellites by a global network of GPS terminals and by the TOPEX receiver. The global network includes three NASA/DSN sites and several other sites operated by the DMA, NOAA and other foreign agencies. The data streams from the DSN sites plus site specific tropospheric data will be compressed and transmitted at a rate of roughly 700 bps to a central ground data processing facility. The data from the non-NASA sites will be transferred on a non-real time basis. High accuracy orbits for TOPEX and the GPS satellites and also ground site positions and geoidal information will be obtained. A flight experiment with this GPS-based tracking will be conducted over the first two years of the TOPEX mission.

Status: A Geodynamics sponsored GPS-based geodetic system development continues. Several major experiment campaigns have been conducted to evaluate improvements in system performance and to obtain first epoch crustal deformation measurements. New instrumentation, data analysis software and data reduction strategies have established our capability to determine GPS orbits from ground data and to recover baselines at an accuracy of around 0.1 ppm with a repeatability in some components of about 0.03 ppm. Experiments in FY88 should demonstrate repeatability to about 0.01 - 0.03 ppm or about 3 cm on baselines of less than a few hundred kilometers length. Motorola has been selected to develop the TOPEX GPS flight receiver with the contract starting in late FY87. The functional design of the ground data processing system is nearly completed and the design of the precision orbit determination software has begun. Carrier phase observations in conjunction with a dynamic treatment of the TOPEX orbit, including tuning of the medium to long wavelength gravity terms, provide the most accurate performance. Other data processing techniques including combined use of carrier phase and pseudorange observations in a geometric mode to reduce dynamical modeling errors are being investigated.

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

Berrien Moore III
Institute for the Study of
Earth, Oceans, and Space
University of New Hampshire
Durham, NH 03824
603-862-1792

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

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

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

STATUS: We have been testing a constraint matrix for the Atlantic Ocean model with which we will encode the qualitative color patterns from CZSC data. These tests, using current estimates on new primary production, have been successful, and they were presented in a paper entitled, Modelling the Global Carbon Cycle: Ocean Circulation and Marine Production at COSPAR during July 1986 in Toulouse, France. We (B. Moore, B. Bolin, A. Bjorkstrom, and K. Holmen) presented additional results at the meeting of the European Geophysical Union during August 1986 in Kiel, Germany in a paper entitled, The Circulation of the Atlantic Ocean as Deduced by Using Hydrographic Data and Tracer Data in Combination, and Some Comments on the Role of the Atlantic Ocean for the Uptake of Excess CO2. A paper that addresses the details of the inverse method as applied to physical and chemical data in the context of a three dimensional model of the Atlantic Ocean has been completed (Bolin, Bjorkstrom, Holmen and Moore) and will be submitted shortly. A preprint will be available by mid-June 1987. Finally, a paper (Ringo, Copeland and Moore) that considers explicit methodological issues has been completed, and it answers a question posed recently by Fiadeiro and Veronis. In the future, we shall begin work on a more spatially (and possible temporally) detailed model of the Atlantic Ocean north of 15 degrees N. Lat. using spectral/inverse modelling techniques. This should resolve some of the issues uncovered in the development of the current Atlantic Ocean Model. We will then consider the CZCS annual data for this area as a set of side constraints for the inversion. If successful, we should be able to refine our understanding of new primary production for this region. In honesty, we do not think that this spectral model will be completed during this next year, but we should be able to make a major step toward its realization.

INVESTIGATION OF PROPERTIES OF RADAR BACKSCATTER FROM SEA ICE

Richard K. Moore
Radar Systems and Remote Sensing Laboratory
The University of Kansas
2291 Irving Hill Rd.
Lawrence, KS 66045
913-864-4832

Long-Term Interests

Over the long term we are interested in determining the properties of radar backscatter from sea ice and their causes. The ultimate objective is use of spaceborne radar for better monitoring and forecasting of sea ice properties for navigation and exploration and for meteorology and climatology.

Objectives

(1) Describing the radar scattering coefficient σ° of sea ice and its snow cover; (2) improving understanding of the physics of radar-ice and radar-snow-ice interactions; (3) comparing signatures from different sensors to improve discrim-ination of ice features; (4) developing methods to apply signature knowledge to ice surveys; (5) determining best radar system parameters for ice monitoring; (6) establishing improved automated methods for ice radar image interpretation using techniques of artificial intelligence.

Approach

Measurements have been made of σ° in different seasons using both helicopter-mounted and sled-mounted microwave spectrometers. The most recent measurements were made in the summer in the marginal ice zone (MIZ). Analysis consists of correlation of σ° observations with surface measurements of physical properties to determine ice radar response vs frequency, angle of incidence, polarization, ice wetness, ice type, snow cover, snow wetness, and surface roughness.

Quasi-laboratory measurements at CRREL and measurements in a cold-room laboratory with very-fine-resolution radars allow discrimination of the different sources of scattering and comparison with more complete snow-ice measurements than possible in the field. This approach offers many exciting possibilities for controlled experiments.

Working with operational radar ice interpreters, a knowledge base is being developed. The tools of AI will then be used to develop an expert system for automated interpretation.

Status

Reduction of MIZEX data is complete, and full analysis is underway. A preliminary analysis was accepted for publication. Analysis of a spring 1983 experiment is complete. Analysis of the 1985 CRREL experiment is complete and published. Preliminary analysis of the 1987 CRREL experiment shows clearly how the fine-resolution radar permits isolation of sources of scat-ter in the snow and ice. The cold-room ice sheet is growing, and measurements are being made. Most of the knowledge base for the expert system has been compiled. Simulated radar images are being produced from σ°data and typical floe shapes.

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

W.D. Nowlin, Jr.
Department of Oceanography
Texas A&M University
College Station, TX. 77843
409-845-1443

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

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

Approach: A U.S. WOCE Science Steering Committee (SSC) has been constituted with W. Nowlin (TAMU), chairman. The SSC has formed working groups on the ocean surface layer, air-sea exchange, geochemistry, numerical modeling, technology development and velocity (floats and drifters). A joint WOCE/TOGA data management working group was formed with the goal of creating a single data management working group was formed to create a single data management system to aid both programs. A U.S. WOCE Planning Office has been established to carry forward the activities of the SSC and to coordinate the efforts of the working groups.

Status: Planning activities for WOCE intensified in 1986 with a series of subject/process meetings held as a follow on to the sector meetings of 1985. These included meetings which addressed: interbasin exchanges, gyre interactions, deep circulation/topography, and heat flux. A summary of these meetings was published as U.S. WOCE Planning Report 5: WOCE Discussions of Physical Processes: Reports of U.S. Subject Meetings. WOCE Planning Report 4: A Primer on the U.S. Contribution to the World Ocean Circulation Experiment was prepared by Melbourne Briscoe on behalf of the SSC. Also, a U.S.-Japan Workshop on WOCE planning was held in Tokyo in March 1986. A second U.S.-Japan Seminar will be held at the University of Washington in June 1987.

This task is jointly sponsored by NSF, NASA, and NOAA.

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

John D. Oberholtzer
NASA/Goddard Space Flight Center, Wallops Flight Facility
Wallops Island, VA 23337
(804) 824-1241 or FTS 889-1241

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

Objectives: There are two objectives to the investigation. First, the MOCS can be used to study new algorithms for the detection and measurement of ocean parameters related to spectral radiance upwelling from the surface. Second, with the demise of the Coastal Zone Color Scanner on Nimbus 7, it is important that an ocean color instrument be available to take part in cooperative studies of ocean productivity. The MOCS is an aircraft mounted instrument that can provide a synoptic map of the chlorophyll concentration in an area around research ships and in other limited areas where needed.

Approach: The MOCS has shown that chlorophyll a concentration can be measured reliably off the mid-Atlantic coast. This has been accomplished by using the spectral curvature algorithm and collecting data at an aircraft altitude of approximately 150 m (500 ft). This will continue to be the preferred mode of collection; however, as opportunities to correlate with other instruments occur, extending the algorithm to different altitudes will be attempted. The MOCS will be available for use in cooperative studies with oceanographic research programs both to provide limited synoptic chlorophyll measurements and to extend those measurements into other water types.

Status: The MOCS is now operating with its new data collection system in place. Data were collected over the Microbial Exchanges and Coupling in Coastal Atlantic Systems, Chesapeake Bay mouth, site last year, and a paper describing the results is in preparation. Coverage of the BIOWATT II area is in progress in cooperation with the Naval Oceanographic Research and Development Activity, with flights on Navy P3's from the Patuxent Naval Air Station.

INSTRUMENTATION FOR THE FIELD MEASUREMENTS OF DIELECTRIC CONSTANT AT 18, 35 AND 94 GHz

Robert G. Onstott
Environmental Research Institute of Michigan
Advanced Concepts Division
P.O. Box 8618, Ann Arbor, MI 48107
(313)994-1200

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

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

Approach: Design and fabricate instrumentation for the *in situ* measurement of critical parameters adequate to describe the scattering surface areas. The construction of instrumentation for the *in situ* measurement of dielectric constant at frequencies of 94 GHz, 35 GHz and 18 GHz and the field testing of these instruments has been largely accomplished on this program. Support for construction of additional instruments for dielectric constant measurements at 10 GHz, 6 GHz, 5 GHz, 4 GHz, 3 GHz, 1.7 GHz, 1.2 GHz, 500 MHz and 100 MHz have been provided from other sources.

Current Status: During the past year a significant portion of the instrumentation for the *in situ* measurement of dielectric constant at 94, 35 and 18 GHz has been completed. A broad spectrum of dielectric materials has been assembled and measurements of dielectric constant at several lower frequencies will be used to derive correct field procedures and models that will be utilized in determining dielectric values from the 94, 35 and 18 GHz data. The remaining instrumentation is near completion and initial testing is scheduled to be accomplished during the summer months of 1987.

MICROWAVE RESPONSE OF ARCTIC SEA ICE

Robert G. Onstott
Environmental Research Institute of Michigan
Advanced Concepts Division
P.O. Box 8618, Ann Arbor, MI 48107
313-994-1200 Ext 2590

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

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

Approach: A successful microwave investigation of sea ice and water has just taken place in the Fram Strait during the Winter Marginal Ice Zone Experiment. Backscatter measurements were made in coordination with observations with an X-band SAR and a complement of ship and surface-based radiometers. Site characterization and dielectric measurements were also conducted. A variety of new, first-year, and multiyear ice forms were observed.

The comparison of coincidently acquired SAR and passive microwave data is continuing.

Status: Data acquired during MIZEX-87 is being reduced. Existing data is used to support signature analyses and the intercomparison of the near-surface microwave sensors, SAR, passive microwave imagers, and ice characterization measurements. Results were discussed in four papers presented at IGARSS '86. A paper which discusses the evolution of the microwave signature of sea ice during summer has been accepted for publication in JGR Oceans.

TIME DEPENDENT ALTIMETER STUDIES

Principal Investigator: M. E. Parke
Jet Propulsion Laboratory
4800 Oak Grove Drive 169-236
Pasadena, California 91109
FTS: 792-2739
Commercial: (213) 354-2739

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. 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. This work is aimed toward the analysis of Topex/Poseidon data.

Specific Objectives:

(1) Topex/Poseidon: To support the development of the Topex/Poseidon mission by providing scientific input into the mission design and verification studies.

(2) 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.

(3) Global Tide:

a. With new high precision orbits that are now becoming available, partial determination of the M2 tide from Seasat and Geosat data should be possible.

b. The models of Shwiderski and Parke and Hendershott are being compared to determine areas of disagreement. Understanding the source of disagreement should be useful for future modelling efforts and as a guide for future measurements.

Status:

A paper has been written on the choice of orbits for Topex/Poseidon to study ocean circulation and tides. The choice of orbits is dependent on the choice of calibration sites in a fashion that is not simple. For calibration sites at Bermuda and Dakar, it is suggested that the nominal orbit be moved to 1335 km altitude and 64.8° inclination.

Models of the Patagonian shelf have been developed on the Sun computer purchased last fiscal year. A paper comparing the M2 tide along the Seasat locked orbit with the model results will be submitted later this fiscal year.

A preliminary Geosat data set has been received, and initial statistical checks are underway. When six months of data have been received, a preliminary study of the deep water tides will be undertaken.

A joint paper has been written on the seasonable variability of the Gulf Stream using GEOS-3 data.

Northern Hemisphere Sea Ice from Passive Microwave Observations

Claire Parkinson, Josefino Comiso, H. Jay Zwally
Donald Cavalieri, Per Gloersen, William Campbell
(Code 671, NASA/Goddard Space Flight Center
Greenbelt, MD 20771, 301-286-6507)

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

Objectives: The central purpose of this work is to utilize the 1973-1976 data of the Nimbus 5 Electrically Scanning Microwave Radiometer (ESMR) to determine and analyze the annual cycle of Northern Hemisphere sea ice and to produce a high-quality volume presenting the data and analysis.

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

Status: Data reduction, compilation, plotting, and analysis have been carried out and an atlas of Arctic sea ice from the ESMR data is in press. Quality-control on the printing is being done with the help of NASA Headquarters and the Government Printing Office. The atlas overviews the role of sea ice in climate and the surrounding oceanographic and atmospheric conditions in the Arctic as well as presenting in detail the microwave properties of sea ice, the interpretation of the ESMR data, and extensive analysis and plots for monthly averaged brightness temperatures and derived sea ice concentrations. A magnetic tape of the data is being prepared for distribution to data centers, along with documentation.

ADVANCED OCEAN SENSOR DEVELOPMENT

Chester L. Parsons
NASA/Goddard Space Flight Center, Wallops Flight Facility
Wallops Island, VA 23337
(804) 824-1390 or FTS 889-1390

Long Term Interests: RTOP 161-10-06 is dedicated to the development of advanced satellite altimetry instrumentation and techniques within the programmatic interests of NASA's Oceanic Processes Program and its future flight opportunities.

Specific Objectives: This program is currently entering the third and final year of research about increasing the swath width of conventional altimeters. The completion of these studies is the immediate goal of the RTOP at this time.

Approach: The general approach being taken has been described in reports from the previous 2 years.

Current Status: The modularized aircraft testbed radar system, the Aircraft Multibeam Radar Altimeter, is entering system integration. Within this year, the system will be installed aboard the NASA Wallops P-3 research aircraft for initial deployment and verification missions. The degradation of tracking precision with off-nadir look angles up to 12 degrees will be measured over the ocean. Candidate tracking algorithms will be tested to optimize the performance of the altimeter at these angles.

The Earth Observing System (EOS) Altimetry Panel report on "Altimetry and Precision Orbit Determination" has been completed and will be published in the near future. This document will be used as a basis for an Announcement of Opportunity to be issued by the end of this calendar year. An advanced altimeter will be called for that uses wide swath viewing.

Three Master's degree candidates are basing their research around instrument science issues resulting from altimetric remote sensing at off-nadir angles. These efforts will continue to be supported this year.

ORIGINAL PAGE IS
OF POOR QUALITY

CALCULATION OF OCEANIC WAVE AND WIND STRESS DISTRIBUTIONS

(Co-Investigator with M. A. Donelan of the Canada Centre for Inland Waters)
Contract 957714-02/CIT/JPL

Willard J. Pierson Jr.

CUNY Institute of Marine and Atmospheric Sciences
The City College of The City University of New York
Convent Ave. at 138th Street
New York, N.Y. 10031. Tel. (212) 690-8315.

Long Term Interests: To use NROSS data to develop improved wave specification and forecasting models and wind stress models.

Objectives of Present Research: To participate as a member of the Science Definition Team especially with reference to the Model Function Subcommittee so as to develop a better model for backscatter from ocean waves and better algorithms to recover wind speed and direction from NSCAT data.

Approach: Study the SEASAT-SASS Mode 4 data so as to learn about the variability of simultaneously obtained V-pol and H-pol data. Interpret previously obtained theoretical results in terms of present NSCAT design.

Current Status: Various internal documents have been prepared for the subcommittee with reference to the potential errors in wind recoveries and algorithms for recovering the wind. Also the effect of swell in the presence of a wind wave spectrum for low winds has been studied. A major breakthrough for the interpretation of NSCAT backscatter estimates in terms of statistics that define a random interval with a preassigned probability of enclosing the expected value of the backscatter (such as would be predicted by a model) has been made. The meaning of negative estimates of the received power has been obtained. A paper on the application of these results is in preparation based on NSCAT preliminary design data.

ORIGINAL PAGE IS
OF POOR QUALITY

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

Willard J. Pierson Jr.

CUNY Institute of Marine and Atmospheric Sciences
The City College of the City University of New York
Convent Ave. at 138th Street
New York, N.Y. 10031. Tel. (212) 690-8315

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

Objectives of Present Research: (1) See current status. Numerous scientists are checking out the new model given in the references. (2) Plans for a new wave forecasting model are under development. (3) Work on a new boundary layer model is progressing. (4) Completed but not yet published.

Approach: The study of radar theory and backscatter data is continuing. Recent results from France (R. Ezraty) confirm some of C. M. Tchen's theories for the boundary layer. The study of these results in greater detail may be possible.

Current Status: (1) A paper by M. A. Donelan and W. J. Pierson has been published. A paper by C. M. Tchen and W. J. Pierson "A group-kinetic theory with a closure by memory loss for modeling turbulence in the atmosphere and the oceans" has been accepted for publication in a special issue of Meteorology and Atmospheric Physics (Springer-Verlaq-Wien) to appear in 1988 as a memorial volume for Bernhard Haurwitz. Efforts will continue to simplify the paper on the study of errors in ship reports of winds. An abbreviated version by Dischel and Pierson appears in Proc. MDS '86 (Marine Tech. Soc., New Orleans).

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

Willard J. Pierson Jr.

CUNY Institute of Marine and Atmospheric Sciences
The City College of The City University of New York
Convent Ave. at 138th Street
New York, N.Y. 10031. Tel. (212) 690-8315.

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

Objective of Present Research: To analyse Challenger SIR-B data obtained for passes over Cuba, in the Bahamas (over Nassau) and for Mikawa-Wan (a bay on the Pacific Coast of Japan).

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

Current Status: Analysis of the SIR-B data has been disapointing but the characteristics of winds around Puerto Rico have been will documented. The SIR-B data for the Japan pass show important L-Band backscatter features for the rivers entering the bay and for the bay itself for light winds. A final report to JPL will be finished by the end of June 1987.

COMMITTEE ON CLIMATIC CHANGES AND THE OCEAN

Dr. Roger Revelle
University of California, San Diego
La Jolla, CA 92093
(619) 452-4849

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

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

The SCOR/IOC Committee on Climatic Changes and the Ocean has been active, primarily through its panel, in continuing planning for WOCE for the development of an ocean observing system and design of ocean data management for the oceanic aspects of the WCRP. A detailed proposal has been prepared for an ocean CO_2 program consisting of measurements and other studies of the components of the carbon systems in the ocean. It is proposed that many of the measurements would be carried out in cooperation with WOCE and the proposed international Global Ocean Flux Study (GOFS), while others would be undertaken by individual national groups of marine scientists.

The Panel on Paleoclimatology has been actively reviewing data on past climatic variability and change, obtained from studies of ice and marine sediment cores, tree rings, pollen distribution, and other natural records. Working with the Scientific Committee on Antarctic Research (SCAR), the CCCO has concerned itself with seasonal and interannual variations in the extent of sea ice in the Southern Ocean and in the Greenland Sea.

The annual meeting of the CCCO was held in January 1986 at UNESCO headquarters in Paris, France. The committee met from 25 to 29 May 1987 at the Oceanographic Institute in Kiel, FRG.

The secretariat in Paris is the essential base for the activities of the Committee on Climatic Changes and the Ocean. It is supported by several countries, including France. Mr. Bert Thompson, the secretary, retired in June 1987, after several years of outstanding service. He is replaced by Dr. Ray Godin of the U.S. Navy Oceanographic Office.

THE RESPONSE OF THE ANTARCTIC CIRCUMPOLAR CURRENT TO WIND FORCING: SPATIAL VARIABILITY AND HEAT FLUX

James Richman, Dudley Chelton and Roland deSzoeke
College of Oceanography
Oregon State University
Corvallis, OR 97331
(503)754-4017; (503)754-3160

Long-Term Interests: To investigate the dynamics of wind-forced ocean circulation in the Southern Ocean and to determine the various components of meridional heat flux across the Southern Ocean.

Objectives: There are three objectives of this study: 1) the development of a numerical model of the dynamics of the Antarctic Circumpolar Current; 2) to investigate the structure and variability of wind stress and wind stress curl over the Southern Ocean, where conventional wind observations are particularly sparse; and 3) the determination of the wind-driven component of meridional oceanic heat flux (Ekman heat flux) in the Southern Ocean from NSCAT winds.

Approach: A periodic channel model is being adapted for application to the Antarctic Circumpolar Current. In the early stages, this model is being forced by very simple, idealized winds. As this model development proceeds, more general time-varying winds will be used. Ultimately, the model will be forced by observed NSCAT winds on time scales of a month and longer and the mechanisms responsible for oceanic eddy heat flux will be explored. In parallel, Ekman heat flux in the Southern Ocean is being examined from Seasat scatterometer data and historical meteorological data supplied by the Australian Bureau of Meteorology (ABM).

Current Status: The channel model has been transferred from the NCAR CRAY computer to a MicroVAX at OSU. The model has been run successfully on the MicroVAX using steady winds. In preparation for more general wind forcing, wind fields constructed from the ABM sea level pressure fields have been compared with Seasat scatterometer winds observed from July to October 1978. The two winds fields differ considerably in detail, but the ABM data are of surprisingly good quality on long time scales and large spatial scales. This encouraging result indicates that ABM data can be used to force the channel model with realistic time-varying winds while the model is prepared for assimilation of NSCAT observed winds.

This study is being conducted through the auspices of the NSCAT Announcement of Opportunity.

TOPEX RADAR ALTIMETER ADVANCED TECHNOLOGY MODEL

Laurence C. Rossi
NASA/Goddard Space Flight Center, Wallops Flight Facility
Wallops Island, VA 23337
(804) 824-1590 or FTS 889-1590

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

Specific Objectives: In the pre-project era, to participate with the 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, the planned data processing algorithms, and to assist them in the development of an overall TOPEX mission plan. To establish resource estimates for the TOPEX Flight Project Radar Altimeter, its associated data processing algorithm specification development, and flight mission support.

Approach: The stringent 2-centimeter precision requirement for ocean topography determination necessitated examining the applicability of existing Radar Altimeter designs for their applicability towards TOPEX. As a result, a system configuration has evolved using some flight proven designs in conjunction with needed improvements, i.e., a second frequency or channel to remove the range delay or apparent height bias caused by the electron content of the ionosphere; higher transmit pulse repetition frequencies for correlation 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: The TOPEX Advanced Technology Model Radar Altimeter under development by The Johns Hopkins University/Applied Physics Laboratory (JHU/APL) over the past 3 years was completed. Partial testing provided evidence that 2-centimeter precision altimetry is achievable with the design concept chosen for the flight Radar Altimeter to be used for the TOPEX Mission. A radio-frequency compatibility test with the TOPEX Radiometer Engineering Model was successfully completed to ascertain that no harmonic frequencies from the Radar Altimeter C-Band channel interfered with the 21 and 37 giga hertz channels of the Radiometer. The contractual documentation for use between The JHU/APL Laboratory and the GSFC for the development of the Flight Project Radar Altimeter was developed and submitted to NASA for review. The GSFC overall TOPEX Radar Altimeter Implementation Plan was initiated.

SAR AND MICROWAVE REMOTE SENSING OF SEA ICE

Drew Rothrock
Applied Physics Laboratory
University of Washington
Seattle, WA 98195
206-545-2262

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

Objectives: The goals of this research are to be prepared to extract useful geophysical data when ERS-1 and other SAR satellites are launched, and to demonstrate the applicability of these data to polar scientific problems. Our immediate objectives are to develop techniques to extract ice velocity, deformation, concentration, and concentration change from sequential imagery; to describe the spatial and temporal statistics of ice velocity, deformation, and concentration for development of efficient SAR sampling schemes; to investigate the relation between ice deformation and concentration change for parameterization in ice models; and to investigate the applicability of both continuum and non-continuum models of the ice velocity field to the interpretation of kinematic data and to the construction of ice models.

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

Status: Ice displacements measured by cross-correlating small areas on sequential images are accurate to several pixels on the rigid, slowly rotating pieces of ice in the central arctic winter pack. In deforming regions, improvements are needed and will likely be achieved by taking into account local rotations of the ice before cross-correlating. In fragmented ice, typical of the margins of the pack, techniques are being pursued for defining the boundaries of individual floes and recognizing them in sequential images regardless of their orientation. Spatial statistics show that ice velocity has no spatial derivative, although mean deformation over areas on order 100 km square can be defined, and its spatial variability measured. Observations of open water formation and loss and their relation to deformation have been made from SAR images. Each pixel is classified as ice or open water. The image is subdivided into many small areas, and the changes in the number of pixels of open water are counted in each area. Increases and decreases are separately summed. Automated measurements are accurate to about 20%. Comparison is made with parameterizations of open water change used in ice models.

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

COUPLED OCEAN-ATMOSPHERE DYNAMICS

Paul S. Schopf, Laboratory for Oceans
Max J. Suarez, Laboratory for Atmospheres
Code 671, Coddard Space Flight Center
Greenbelt, MD 20771 (301) 286-7428

Long Term Interests: The long range goal to which this study is hoped will contribute is the improved understanding of the interaction between the global oceans and atmosphere on interannual and decadal timescales, and the development of skill in analyzing and simulating these interactions, eventually leading to long term prediction.

Objectives: The primary objective of the effort in FY86 was to see if a deterministic oscillator could describe the El Niño/ Southern Oscillation (ENSO) phenomenon, and if so, what were the important physics of the oscillator.

Approach: A coupled numerical model of the global atmosphere and tropical Pacific was integrated, producing ENSO vacillations quite similar to those observed. Analysis of the model results, and construction of simpler analytic models formed the basis for the study.

Current Status: The numerical model was determined to vacillate via a non-linear delayed action oscillator which operates through wave delays and coupled instability of the ocean-atmosphere system in the central to eastern Pacific. This oscillator can be re-constructed through use of a simple ocean-wave model with localized SST sensitivity to the thermocline thickness. The wave model has been solved with many meridional modes of response and wave reflections from both western and estern boundaries, without affecting the basic physics of the oscillator. The inclusion of higher modes strengthens the oscillator, as does the addition of an eastern boundary. Both effects increase the period of the oscillation, overcoming a minor shortcoming in the simplest theory. The effects of the annual cycle have been examined, and we find that such processes lead to phase-locking, but do not materially alter the physics. Random external perturbations, such as might be expected from intruding mid-latitude storms, induce spectral broadening and provide more realistic simulations.

INVESTIGATION OF SOUTHERN OCEAN MESOSCALE VARIABILITY FROM SEASAT ALTIMETRY

Frank Sciremammano, Jr.
Department of Mechanical Engineering
Rochester Institute of Technology
One Lomb Drive
Rochester, New York 14623
(716)475-6819 or (716)475-2162

Long Term Interests: To develop techniques for obtaining synoptic, global scale mapping of mesoscale ocean currents from altimeter data and to utilize this to understand the low frequency dynamics of the Southern Ocean and other sparsely sampled ocean areas.

Objectives: The primary task is to develop and refine statistical techniques to identify and characterize the physical structure and intensity of mesoscale oceanic features, including a comparison of the use of a global mean sea surface instead of the collinear mean as a reference level. In addition, a comparison is being made of altimeter derived and in-situ currents where suitable current meter records are available.

Approach: A previously derived wavenumber eddy detection technique is being extended to the identification of the physical structure of the eddies by examining statistical measures of the surface spatial patterns of common oceanographic mesoscale features. In addition, the use of a global mean sea surface is being investigated for use as a reference level for this analysis. In places where two altimeter ground tracks intersect at a high latitude, two nearly orthogonal components of the surface geostrophic current can be derived for and compared with concurrent current meter data to assess the effectiveness of the altimeter at detecting the oceanic variability.

Status: Simulations of collinear altimeter data from known mesoscale physical features is progressing and being compared to the altimeter eddy signatures from the SEASAT records. Results using a global mean sea surface as a reference surface indicate that, with some important exceptions, the mean sea surface does provide a suitable reference for eddy detection. Finally, three sets of current meter data were identified which were collected during the SEASAT collinear sampling period near ground track crossover points. Preliminary results show that the altimeter derived and directly measured currents are in good agreement when a strong signal is present, but that caution must be used for quiet periods and in areas with strong topographic gradients.

SAR OCEAN WAVE IMAGING STUDIES

Co-principal Investigators: Dr. Robert A. Shuchman
Dr. John R. Bennett
Dr. David R. Lyzenga
Advanced Concepts Division
Environmental Research Institute of Michigan
P.O. Box 8618
Ann Arbor, MI 48107
(313)994-1200, ext. 2590

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 compared with actual images and spectra.

Status: Data sets currently under investigation include several aircraft SAR data sets collected during the 1984 SARSEX experiment, as well as the SIR-B data collected near the coast of Chile. Both data sets include surface or near-surface measurements of wave conditions coincident with the SAR data collections. These measurements have been used as inputs for the simulation model, and preliminary comparisons have been made with the actual SAR image spectra.

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 top be made from SAR imagery.

Bio-Optics, Photoecology, and Remote Sensing

Dr. Raymond C. Smith
UCMBO, Department of Geography
University of California at Santa Barbara
Santa Barbara, CA 93106
(805)961-2618

Long Term Objectives

The long term objectives of this research are: to study the fundamental processes influencing the distribution and variance of phytoplankton biomass and primary productivity in the oceans; to further the development and utilization of buoy, 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 primary production; and to increase our understanding of the interrelationships between physical, optical and biological processes in the upper layers of the ocean.

Specific Objectives

Specific objectives include: (1) 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 (Smith and Baker, 1985; Evans et al., 1985; Brown et al., 1985); (2) bio-optical modeling aimed at predictively linking ocean optical properties, pigment biomass and primary productivity (Smith et al., 1987); (3) the deployment of bio-optical sensors on a long-term deep-sea mooring for the study of temporal variability (including the vertical distributions) of pigment biomass and corresponding optical properties and to assess the degree to which vertically distributed primary production can be estimated using data from satellites and moorings.

Approach

Our approach is to describe quantitatively and to model mathematically 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 and mooring oceanographic equipment and methodologies; the development of data handling procedures for the merging of contemporaneous ship and remotely sensed data (Smith and Baker, 1986); the development of models with which to link optical properties, pigment biomass and primary productivity (Smith et al., 1987); the development of numerical models for the assessment of flow fields from remotely sensed data (Stow, 1985); and the quantitative analysis of ship and satellite time series data (in progress). Our research also emphasizes collaborative work with several universities and NASA research groups.

Status

For the SCB we are in the process of analyzing several years of CZCS and ship data in order to provide a quantitative assessment of the spatial and temporal variability of pigment biomass in this region. A thesis on this topic will be finished this year. A publication (Smith et al., 1986) and a thesis (Dunlap, 1985) on the mesoscale ecology of cetacea in the California Current were completed. For our research in WCR several articles have been published (Evans et al., 1985; Brown et al., 1985; Smith and Baker, 1985) and others are in progress. A quasi-synoptic shipboard bio-optical sampling strategy for assessing phytoplankton in highly variable ocean regions was developed, utilized in a California frontal region, described and accepted for publication (Smith et al., 1987). In collaboration with Biospherical Instrument Inc. a bio-optical moored sensor has been developed and several of these instrument were deployed on the Biowatt deep-sea mooring in February 1987.

ASSESSMENT OF ALTIMETER SATELLITE ACCURACY

Robert H. Stewart

Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093
(619) 534-2140

Long-Term Interests: The usefulness of the next generation of altimeter satellites for oceanographic studies will depend critically on the accuracy and precision of the measurements of sea level made by the radar altimeters carried on these satellites. The goal of this one-year study is to summarize the present understanding of the errors influencing altimeter accuracy using, in particular, published results of Seasat investigations and the design studies for Topex/Poseidon.

Specific Objectives: The specific tasks include: (1) summarizing the results of the Seasat mission, including the work based on the Seasat altimeter observations of sea level; (2) describing the methods that will be used for minimizing the errors in measurements of sea level that will be made by the proposed new Topex/Poseidon altimetric satellite mission; (3) describing the work leading to the selection of the orbit for Topex/Poseidon.

Status: The study began in March of 1987; and the third task has been completed. A paper describing the criteria for the selection of an altimeteric satellite's orbit was written with Michael Parke, David Farless, and David Cartwright and it has been submitted to the Journal of Geophysical Research for possible publication. Work on the remaining tasks has started, and they are expected to be completed by the end of the study. A bibliography of papers pertinant for studies of the accuracy of satellite altimeter measurements of sea level has been compiled, and a preliminary assessment of Seasat results has been completed.

RADAR STUDIES OF THE SEA SURFACE

Robert H. Stewart

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354 3327 FTS 792-3327

Long-Term Interests: Radio signals scattered from the sea surface carry information about processes operating at the sea 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: The specific objectives of the investigation, developed over a period of several years, were (1) document the methods that enable spaceborne radars to be used for studies of oceanographic phenomena, (2) study the accuracy and usefulness of synthetic-aperture radar measurements of oceanic waves and other phenomena; (3) investigate techniques that might be used for calibrating satellite observations of rainfall, especially acoustic signal generated by rain falling over an area at sea; (4) teach graduate students at the Scripps Institution the methods of satellite oceanography so they would be prepared to use data from the next generation of NASA ocean observing satellites and instruments; and (5) summarize the results of the Seasat mission.

Status: The tasks described above are nearing completion, and the contract ends with this fiscal year. Hence it is appropriate to list the major results of the work. They are: (1) a monograph on the *Methods of Satellite Oceanography* published by the University of California Press in 1985; (2) a series of papers with John Vesecky on the usefulness of the synthetic aperture radar on Seasat for studies of ocean waves based on the analyses of Seasat observations of the Jasin experiment and other areas of the ocean; (3) a thesis by Nystuen on the theory and observation of subsea noise generated by rain; (4) the development of a graduate-level course on methods of satellite oceanography taught on alternate years at the Scripps Institution of Oceanography; and (5) several papers documenting the recent results of Seasat and other oceanographic satellite observations plus a Jet Propulsion Laboratory Technical Document on the results of the Seasat mission.

MICROWAVE REMOTE SENSING MEASUREMENTS OF OCEANS AND ICE

Calvin T. Swift
Department of Electrical and Computer Engineering
University of Massachusetts
Amherst, MA 01003
(413) 545-2136

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

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

Approach: Statistical inversion techniques, which have been successful for remote sensing of the atmosphere are being applied to microwave remote sensing of oceans and sea ice. To this end, a weather correcting sea ice algorithm has been developed and tested using SeaSat SMMR data. In addition, this technique was used to develop a passive microwave windspeed algorithm, which has been successfully used in remote sensing of hurricanes and will form the basis of an alternate SSM/I algorithm.

Status: Over the past year, our activity has focused on the SSM/I, which may have been launched prior to the date of this Annual Report. Validation plans have been drafted for both the sea ice and ocean windspeed data products. In preparation for the verification of ocean surface windspeed, we have developed software to co-register coincident satellite and NOAA buoy data to validate the in-place algorithm and to assess a possible replacement algorithm. The weather correcting sea ice algorithm has also been modified to accept SSM/I frequencies.

DETERMINATION OF OCEAN CIRCULATION AND THE GEOID USING SATELLITE ALTIMETRY

Chang-Kou Tai
Scripps Institution of Oceanography A-030
La Jolla, California 92093
(619) 534-6358

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

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

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

Status: (1) The error analysis (mentioned in last year's report) has shown that the estimation error in the least-square procedure is comparable to the estimated error in the dynamic topography, therefore rendering the results in doubt. (2) However, the same error analysis has pinpointed aliasing as the culprit. (3) Spherical harmonic expansion procedure which is accurate up to degree 180 (the old procedure is accurate up to degree 36) and various smoothing techniques (such as smoothing the edges of each region) are being employed to eliminate aliasing. (4) An aliasing-free result will be produced in three months.

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

Prof. John F. Vesecky (Principal Investigator) (415) 723-2669
Prof. Ronald N. Bracewell (Co-Investigator) (415) 723-3545
STAR Lab, Electrical Eng. Dept., Stanford Univ., CA 94305-4055

Long-Term Scientific Interests: Sea ice covers some 20×10^6 km^2 of the ocean surface influencing weather and climate, both locally and globally. It is also a dominant factor at high latitudes for both commercial and military activities. The importance and variability of sea ice, coupled with the hazards and difficulties of in situ observations make aircraft and satellite remote sensing of sea ice cost effective as well as valuable. Remote sensing observations are most useful when they can be accurately and consistently interpreted as corelevant measurements for sea ice science and applications. Automated algorithms for such interpretation are essential for making use of SAR data from long-term remote sensing satellites.

Research Task Objectives: Remote sensing using satellite synthetic aperture radar (SAR), such as with instruments aboard the SEASAT (NASA), ERS-1 (ESA), JERS-1 (Japan) and RADARSAT (Canada/USA) spacecrafts, provides an excellent means for observation of sea ice motion and deformation. Radar images can be collected day or night and through clouds, thus giving SAR significant advantages over photography. NASA is installing a tracking station at Fairbanks, Alaska to receive SAR sea ice data from the ERS-1 satellite (1989). However, tracking sea ice features over a series of co-spatial images separated in time is a tedious and time consuming process to do manually, even when computer assisted. Thus a key component in the utilization of ERS-1 SAR data for ice science and applications is an automated algorithm to extract sea ice movement and distortion information efficiently and accurately from SAR image pairs.

Research Approach: The fundamental data set is a pair of SAR images of the same geographical region collected a few days apart. These images are about 100 km square at 25 m. resolution. The first step is an averaging process to reduce the resolution and make the number of sample points tractable. Two approaches for subsequent processing are being investigated. The first concentrates on particular types of features, such as lead-floe boundaries. SAR images of sea ice are reduced to a collection of such features, thus reducing the search space. For example, a 16,000 point image would be reduced to a set of about <100 features, each containing some tens of points. Leads are allowed to expand or contract by appropriate cutting of lead-floe boundaries. Boundary segments are classified according to their suitability for use as tracking features (tie points). A guided correlation scheme is used to search a 'test' image for matching features. Ice velocity and distortion estimates are obtained by considering the displacement and rotation of features. The second approach involves an image processing algorithm called image pyramid area correlation (IPAC) or simply hierarchical correlation. An image is first highly averaged to lower the resolution and make a straightforward block correlation algorithm tractable in terms of computation time. The ice velocity field established from the low resolution correlation is then used to guide further correlations at higher resolution. Results of these two fundamentally different approaches are to be compared, with their strengths and weaknesses noted. Several approaches may be integrated into a single robust algorithm.

Current Status: Progress during 1986 can be summarized as follows: (1) Image pyramid (hierarchical correlation) algorithm developed, including rejection of low confidence ice velocity estimates and replacement with interpolated values; (2) Application of above algorithm to SEASAT SAR image pairs from the Beaufort Sea and favorable comparison with manual ice tracking results; (3) Feature tracking algorithm developed and applied to SEASAT SAR image pairs; (4) Error assessment algorithm developed using image reconstruction and subtraction; (5) Qualitative comparison of image pyramid and feature tracking algorithms made; (6) Research results reported at IGARSS'86 meeting and submitted for publication in **IEEE Trans.Geoscience & Remote Sensing.** Research task objectives for 1987 are summarized as follows: (1) Improve image pyramid ice tracking algorithm by improving error detection and correction and rotational invariant correlation in order to provide a more robust ice motion estimate. (2) Improve feature tracking algorithm by adding pressure ridges as features to be tracked so that feature tracking can provide ice motion information away from floe-lead boundaries. (3)Test ice motion algorithms over a variety of ice scenes provided by JPL in order to find weaknesses and ways to correct them. (4) Develop rotation invariant correlation methods to track rotating individual ice floes in the marginal ice zone (MIZ) so that ice motion can be sensed in the MIZ. (5) Begin integration of several techniques into a robust algorithm.

This research is also supported by the Office of Naval Research.

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

Tyler Volk
Department of Applied Science
26 Stuyvesant St.
New York University
N.Y., N.Y. 10003
(212) 998-8995

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

Objectives: To simulate ocean biogeochemical property distributions for the deep ocean along with surface chlorophyll concentrations for comparison to GEOSECS property distributions for the Atlantic and Pacific Oceans and CZCS large-scale patterns of surface chlorophyll concentrations. A key emphasis is the North Atlantic basin because of the availability of good seasonal surface pCO_2 data and the upcoming CZCS time-series of this region.

Approach: A two-dimensional, meridional model has been constructed, which incorporates mixing processes and bottom water formation and includes internal source terms for organic tissue oxidation and calcium carbonate dissolution. For surface chlorophyll concentration prediction, biological processes (such as growth rates and grazing) and physical processes (such as horizontal and vertical advective and diffusive circulations) are mathematically resolved at a comparable levels. Two-dimensional profiles of total carbon dioxide, dissolved oxygen, nitrate, carbon-14, alkalinity and silicate are produced and tested against global data. Simpler box models are also being run to provide preliminary indications of the relative importance of biological and physical processes for particular regions. These indications, derived from isolating and perturbing basic processes, serve as hypotheses to be examined with the more complex model.

Status: This research is in its second year under the Interdisciplinary Research Program in Earth Science: Ocean Basin Carbon Fluxes. The work indicates fundamental differences between the equatorial Atlantic and Pacific in the processes behind the positive pCO_2 pressure difference (surface water minus atmosphere) in these regions. Basically, the equatorial Atlantic's CO_2 outgassing is caused by temperature alone and the nutrient concentrations act counter to the outgassing. The nutrients, by contrast, are an important component in the equatorial Pacific, and perhaps even dominate the outgassing. A manuscript, "Limiting controls on largescale surface ocean carbon dioxide sources and sinks: temperature, surface nutrients", is in press in the new AGU journal, *Global Biogeochemical Cycles*.

APPLICATION OF SURFACE CONTOUR RADAR (SCR) TO OCEANOGRAPHIC STUDIES

Edward J. Walsh
NASA/Goddard Space Flight Center, Wallops Flight Facility
Wallops Island, VA 23337
(804) 824-1000 ext. 2526 or FTS 889-2526

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

Objectives: Continue analysis and dissemination of SCR data sets while designing system upgrades to greatly improve data quality.

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

Status: A paper by Walsh et al. entitled "Evolution of the Directional Wave Spectrum from Shoreline to Fully Developed" has already caused a stir in the international oceanographic community, even though it is still in the review process at the JPO. It has resulted in a request from Klaus Hasselmann for SCR data to help verify his third generation wave model, and an invitation from Gerbrand Komen to address the May 1987 meeting of the International Wave Modelling Group, which resulted in more requests for data. A paper on sea ice observations with the SCR (Fedor et al., 1987) during the NOAA Arctic Cyclone Experiment (ACE) appeared in the May 1987 issue of IEEE Trans. on Geoscience and Remote Sensing. The initial analysis (Beal et al., 1986) of ocean wave data from the Shuttle Imaging Radar (SIR-B) experiment appeared in Science in June 1986. A second paper for the refereed literature is in process. Work is in process on a paper with Fuk Li on the Frontal Air/Sea Interaction Experiment (FASINEX) data set. The SCR participated in the Labrador Extreme Waves Experiment (LEWEX) in March 1987 and obtained excellent data sets on all flights. The analysis of the SIR-B, FASINEX, LEWEX, ACE and other data sets will continue. A paper will be written dealing with the SCR measurements of the shape of the spreading function and the nondirectional spectrum. The SCR historical data sets will be reanalyzed in an orderly fashion over the next several years using the recent improvements in processing to increase our knowledge of the generation and dissipation of waves and the mechanisms which control the shape of the directional wave spectrum. The design work for upgrading the SCR will continue. The improved system would have greatly improved data quality and reliability, collect data with little operator assistance, and be easily installed on other aircraft.

SIMULATION ANALYSIS OF NON-STATIONARY CZCS TIME SERIES FROM CONTINENTAL SHELVES

John J. Walsh
Department of Marine Science
University of South Florida
St. Petersburg, Florida 33701
(813) 893-9164

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

Objective: To contrast 1979-84 CZCS time series of the spring blooms of shelf and slope waters of the Mid-Atlantic Bight with those of the northern Gulf of Mexico, in order to accurately specify the seasonal and interannual carbon and nitrogen fluxes from estuaries to oceanic waters.

Approach: CZCS images from the Gulf of Mexico and the Mid-Atlantic Bight are too infrequent for the necessary daily sampling interval to resolve algal (0.5 day^{-1}) and wind event (0.2 day^{-1}) contributions to changes in phytoplankton biomass detected by successive overflights of the NIMBUS-7. Simulation analysis of seasonal phytoplankton response to daily changes in wind forcing, nutrient resupply, grazing and sinking losses are being used to interpolate the CZCS time series. Drs. Otis Brown and Bob Evans of RSMAS, University of Miami, are processing the 1979-1984 images, while J. J. Walsh, W. W. Gregg and D. A. Dieterle of USF are performing the simulation analyses.

Status: A March-June 1979 time series of CZCS images has been compared to shipboard under-way chlorophyll maps and fluorescence/temperature/depth profiles taken during cruises in the same time period. A manuscript, "Satellite detection of phytoplankton export from the mid-Atlantic Bight during the 1979 spring bloom," has been accepted by Deep-Sea Research. A barotropic circulation sub-model has been developed at USF to simulate the flow response to winter-spring wind events. Using this sub-model, the simulated algal populations over 3 depth layers within the Mid-Atlantic Bight were compared to the 1979 CZCS data set. A manuscript, "A simulation analysis of the fate of phytoplankton within the Mid-Atlantic Bight," has been accepted by Continental Shelf Research. Compilation of all of the 1979-84 CZCS time series is now under way at RSMAS, and interannual simulation analyses have begun at USF.

SCATTEROMETER MEASUREMENT ANALYSIS TO DETERMINE
WIND, WAVE AND ENVIRONMENTAL DEPENDENCE

Principal Investigator: Dr. David E. Weissman
Department of Engineering
Hofstra University
Hempstead, New York 11550
Phone: (516) 560-5546

Long Term Interests: To understand and model the combined effects of ocean surface winds, waves and air-sea temperature on radar cross section measurements made from aircraft and satellites. A important need is to evaluate the accuracy of existing RCS model functions. The goal is to develop new algorithms for the aircraft scatterometer (AMSCAT) that will permit more accurate estimates of ocean surface winds, and possibly wave conditions.

Specific Objectives: To assimilate new aircraft RCS data obtained during FASINEX that was acquired simultaneously with surface truth and wave directional spectra. The focus is on determining the magnitude of variation of the mean and azimuthal dependence of the RCS that is caused by variations in the wave spectra and the atmospheric stability, along the flight track of the aircraft. This analysis will point to needed improvements in the geophysical model function for AMSCAT and NSCAT.

Approach: The AMSCAT data for the FASINEX experiment is being analyzed, in conjunction with the wave spectrum measurements (by the Surface Contour Radar) and meteorological data. One of the valuable aspects of this RCS data is the rapid azimuthal scanning of the antenna to permit observations of the upwind, crosswind and downwind backscatter. The asymetries within each scan and the spatial variations from one scan to the next provide critical insight into non-wind forces on the surface reflectivity and the radar cross section

Current Status: The AMSCAT data acquired during FASINEX is being divided into individual circular azimuthal scans of the RCS, and a set of Fourier coefficients has been calculated for each rotation. These Fourier coefficients are useful to represent many of the key aspects of the scattering signature, and its variation across the temperature front and with respect to the wave field. Studies are continuing to model these coefficients as functions of the radar, sea surface and environmental parameters.

SSMI DATA PROCESSING AND EVALUATION

Frank J. Wentz
Remote Sensing Systems
475 Gate Five Road
Sausalito, CA 94965
(415) 332-8911

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

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

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

Status: Due to the delay in the launch of SSMI, Phase I was extended. The Nimbus-7 SMMR data set was analyzed in order to better understand the systematic errors that can affect satellite microwave radiometers. Six-years (1979-1984) of antenna temperatures were processed by a variety of error-detecting routines, which will later be used on the SSMI data. A number of systematic errors in the antenna temperatures were detected and removed. Currently, the SSMI data processing system is nearing completion. We are anticipating that SSMI will be launched in the summer of 1987, at which time the sensor evaluation will begin. We expect to begin delivering ocean products at the end of 1987.

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

Dr. Carl Wunsch
M.I.T.
Cambridge, MA 02139
(617) 253-5937

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

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

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

Status: Two regions have been the focus of present concern: the North Atlantic and a much smaller region north of Hawaii where a reciprocal tomography experiment is taking place. Reference mean altimetric surfaces have been computed for both regions using SEASAT altimetry and optimal estimation theory. In the smaller Pacific region, the mean surface has been subtracted from the GEM-10 gravity model, and the difference corrected using inverse methods and the Levitus mean hydrography to produce a high precision regional geoid. The next step in both regions is to produce maps of the deviation from the mean at regular intervals. The GEOSAT data has been arriving recently and the correction channels are being examined for use prior to employing the data for the production of maps of the deviation from the mean surfaces (recursive improvement techniques are being developed). Inverse model making, for ultimate combination of hydrography and steady/transient tracers is continuing.

*Partially supported also by the National Science Foundation.

SATELLITE TRANSMISSION OF SEA LEVEL DATA

Klaus Wyrtki
Department of Oceanography
University of Hawaii MSB 307
1000 Pope Road
Honolulu, Hawaii 96822
(808) 948-7037

Long term interests: The topography of the sea surface is one of the most important geophysical features on the globe. By measuring and studying it I expect to learn more about ocean dynamics, about the variability of ocean circulation, about climatic influences, and about El Nino.

Objectives: The development of a network of island-based sea level stations, first in the Pacific and now also in the Indian Ocean will allow us to understand and monitor ocean circulation, provide ground truth and calibration for satellite based altimeters and provide monitoring of ocean circulation for both TOGA and WOCE.

Approach: Satellite transmission of sea level data is being used to relay data from remote island stations via geostationary satellites to the data center for near-real time analysis. This is most important for the operation of the Pacific Tsunami Warning System, and also for the monitoring of ocean currents and of the heat content of the ocean. The satellite transmitted data are being used for the preparation of monthly synoptic maps of sea level in the Pacific which have a wide distribution to the scientific community.

Status: Since the start of the project in 1983 we have converted 25 sea level stations on islands in the Pacific and along the coast of South America to satellite transmission of their data. The data are routinely processed and used for the analysis and monitoring of ocean processes.

PHOTOECOLOGY, OPTICAL PROPERTIES AND REMOTE SENSING OF WARM CORE RINGS AND MAJOR OCEAN FRONTS

Charles S. Yentsch
Bigelow Laboratory for Ocean Sciences
McKown Point, W. Boothbay Harbor, ME 04575
207/633-2173

Long-Term Interests: The interest and excitement of this biological oceanographer is driven by the time/space problems associated with estimates of primary productivity. To close on this problem we ask: how much information on characteristics and kinetics of photosynthetic autotrophs can be obtained from remotely sensed signals of color and/or fluorence. From such measurements can the biochemical cycles of oceanic productivity be understood. These are the long-term interests.

Objectives: By measuring light absorption and fluorescent emission in natural populations we are developing methods whereby characteristics specific to taxonomic groups and their growth kinetics can be obtained. These methods are applicable to passive and active remote sensors flourese in aircraft and satellites.

Approach: Sea observations have concentrated on oceanic features where marked changes occurs in phytoplankton species and diversity. We establish empirical relationships between light absorption, scattering, fluoresence and physical/chemical parameters of water masses.

Status: The combination of fluorescence with light absorption measurements has produced predictive tools for characterizing populations in oceanic water masses. We observe distinctive patterns in these optical signals associated with oceanic fronts in general and meanders, streamers, and eddies specifically. The site specific relationships suggest that the mechanisms responsible are a combination of the interaction of nutrients and light. The interaction is complexed by the fluid dynamics of the systems. Without a substantive theory which unifies optical properties with the physical/chemical dynamics of water masses we are continuing to study in detail, optical signals compatiable with time/space scales of the fluid flows.
The characterization by fluorescence and absorption provides a means for assessing the errors and concepts associated with existing remote sensing techniques. For example the major error in the watercolor algorithm is due to variations in the accessory pigmentation in populations and not the result of detritus or packaging.

This research was supported by NASA, ONR and NSF.

STUDIES OF SEA SURFACE TOPOGRAPHY AND TEMPERATURE

Dr. Victor Zlotnicki
Jet Propulsion Laboratory, 169-236
Pasadena, CA 91109
(818) 354-5519

Long-Term Interests: To understand and model those properties of the general circulation of the oceans and its variability that can be measured using a combination of radar altimetry and infrared radiometry.

Specific Objectives: 1) estimate circulation of the North Atlantic based on Seasat and Geos-3 altimetry, combined with ship gravimetry, and compare to hydrography and ship-drift data; 2) correlate Geosat altimetry and NOAA-AVHRR for the California current system, and compare to hydrography (with M. Abbott).

Approach: 1) avoid a geoid computation altogether, by converting mean sea surfaces to gravity accelerations and computing the 'gravity equivalent' of the general circulation signal; 2) estimate statistical covariance between altimetric and temperature measurements, and use to estimate surface velocities.

Status: 1) results for the North Atlantic are in manuscript form (with J. Marsh), showing retrieval of general circulation signals using nine cruises with ship gravity (far fewer than a geoid computation would require) and matching ship drift measurements closer than geostrophic estimates from hydrography; 2) recently available Geosat data are being explored for errors, consistency, etc. M. Abbott is contributing temperature data from the West Coast Time Series project, in the same time frame as Geosat.

GEOSAT ICE ALTIMETRY DATA PROCESSING

H. Jay Zwally
Robert A. Bindschadler
Oceans and Ice Branch, Code 671
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
(301) 286-8239

LONG-TERM INTEREST: Investigation of the dynamics and variability of the Antarctic and Greenland ice sheets and floating ice shelves. Determination of the mass balance and changes in ice volume.

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

APPROACH: Data processing techniques that account for differences in the operation of ocean radar altimeters over sea ice and the continental ice sheets have been developed. Arrangements have been made to obtain all the Geosat waveform data records (WDR's) and the geophysical data records (GDR's) over sea ice and the Greenland and Antarctic ice sheets from the U. S. Navy. Several levels of data sets including ice elevations with corrections in orbital format, a geo-referenced data base, and gridded elevations and contours will be produced, evaluated, and archived.

STATUS: Algorithms for retracking the waveform data and automatically evaluating and editing the range corrections have been developed and tested. A data tape and Users Guide for Greenland Seasat elevation data was prepared and sent to data centers (comparable Antarctic data is in preparation). GEOSAT WDR tapes are being received from NRL, condensed, and copies distributed to NRL and the DMA achieve. GDR tapes (with the precision orbits over ice unclassified) are being obtained for the 18 months of the geodetic mission of GEOSAT. Preliminary analysis of retracked data shows excellent GEOSAT coverage over the ice sheets with more continuous profiles due to improved altimeter tracking compared to Seasat and with range precision comparable to Seasat.

ICE MARGIN MAPPING BY SATELLITE ALTIMETRY

H. Jay Zwally
Oceans and Ice Branch Code 671
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
(301) 286-8239

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 applied 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 are analyzed for evidence of ice rises and the positions of grounding lines.

STATUS: The Seasat radar altimeter data along the entire Antarctic coastline north·of 72°S has been analyzed using interactive software on an HP9845C. The procedure includes display of the waveforms in the vicinity of each ice margin crossing, examination and correction of the track points, display of apparent elevations, and calculation and mapping of the ice margin position. The derived coastline positions have been critically evaluated and compared with existing maps and Landsat imagery in several regions. Results include information on changes in the position of the Amery ice shelf front and the locations of ice rises and grounding lines (Zwally et al., 1987).

SEA ICE DYNAMICS

H. Jay Zwally
Oceans and Ice Branch, Code 671
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
(301) 286-8239

LONG-TERM INTERESTS: Dynamics and variability of Arctic and Antarctic sea ice and evaluation of methods for extracting and using geophysical parameters from satellite data.

SPECIFIC OBJECTIVES: 1) To investigate the large-scale dynamics and variability of the Arctic and Antarctic sea ice and associated oceanic and atmospheric processes, 2) to evaluate sea ice parameters derived from multifrequency passive-microwave imagery (ESMR, SMMR, & SSMI), and 3) to develop new methods for using satellite-derived parameters along with numerical sea ice models for studies of ice dynamics and processes.

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

STATUS: Results have shown that the multiyear ice distributions derived from SMMR, in particular changes in multiyear concentrations during winter in the central Arctic ocean, can be used to study drift of the multiyear ice pack and convergence/divergence within the pack. The boundary of the multiyear ice pack is well-defined in the microwave data and the large-scale drift of the ice pack is indicated by the displacement of the boundary. The total area of multiyear ice is approximately conserved during winter and local changes in the multyiyear concentration are indicative of convergence or divergence. Specific ice-divergent events and ice drift patterns deduced from SMMR data have been correlated with atmospheric cyclones and changes in surface winds by comparison with modeled ice velocity fields (collaboration with John E. Walsh). Particular attention is being given to the time series of global sea ice extent and the drift and mass balance of the perennial ice in the Arctic Ocean.

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.

Abbott, M. R., and P. M. Zion, 1985: Satellite observations of phytoplankton variability during an upwelling event. *Cont. Shelf Res.*, **4**, 661-680.

Abbott, M. R., and P. M. Zion, 1987: Spatial and temporal variability of phytoplankton pigment off Northern California during CODE-1. *J. Geophys. Res.*, **92**, 1745-1756.

Alfultis, M. A. Oceanographic Implications of SMMR Sea Ice Observations of the Sea of Okhotsk. Masters Thesis, School of Oceanography, University of Washington, Seattle, WA 98195, 1987.

Atakturk, S. S., and K. B. Katsaros, 1987: Intrinsic frequency spectra of short gravity-capillary waves obtained from temporal measurements of wave height on a lake. *J. Geophys. Res.*, (in press).

Atlas, D., R. C. Beal, R. A. Brown, P. Demey, R. K. Moore, C. G. Rapley and C. T. Swift, 1986: Problems and future direction in remote sensing of the oceans and troposphere: A workshop report. *J. Geophys. Res.*, **91**(C2), 2525-2548.

Atlas, R., 1986: The role of oceanic fluxes and initial data in the numerical prediction of intense coastal storm. *Dynam. Atmos. Oceans.*, **10**, 359-388.

Atlas, R., E. Kalnay and M. Halem, 1985: The impact of satellite temperature sounding and wind data on numerical weather prediction. *Optical Engineering*, **24**, 341-346.

Atlas, R., 1986: Simulation studies of the effect of low level wind data on Southern Hemisphere analysis and numerical forecasts. *Research Activities in Atmospheric and Oceanic Modeling.*

Atlas, R., A. J. Busalacchi, M. Ghil, S. Bloom and E. Kalnay, 1986: Global surface wind and flux fields from model assimilaiton of Seasat data. *J. Geophys. Res.*, **92**, (in press).

Atlas, R., A. J. Busalacchi, E. Kalnay, S. Bloom, and M. Ghil, 1986: Global surface wind and flux fields from model assimilation of Seasat data. "Second Conference on Satellite Meteorology/Remote Sensing and Applications," American Meteorology Society, Boston, MA, 146-154.

Banse, K., and C. R. McClain, 1986: Satellite-observed winter blooms of phytoplankton in the Arabian Sea. *Mar. Ecol. Progr. Ser.*, **34**, 201-211.

Barale, V., C. R. McClain and P. Malanotte-Rizzoli, 1986: Space and time variability of the surface color field in the northern Adriatic Sea. *J. Geophys. Res.*, **91**(C11), 12957-12974.

Beal, R. C., ed., 1987: Proceedings of the Symposium Measuring Ocean Waves from Space. *Johns Hopkins APL Tech. Digest*, **8**(1), 147 pp.

Beal, R. C., T. W. Gerling, D. E. Irvine, F. M. Monaldo and D. G. Tilley, 1986: Spatial variations of ocean wave directional spectra from the Seasat synthetic aperture radar. *J. Geophys. Res.*, **91**(C2), 2433-2449.

Beal, R. C., F. M. Monaldo, D. G. Tilley, D. E. Irvine, E. J. Walsh, F. C. Jackson, D. W. Hancock III, D. E. Hines, R. N. Swift, F. I. Gonzales, D. R. Lyzenga and L. F. Zambresky, 1986: A comparison of SIR-B directional ocean wave spectra with aircraft scanning radar spectra and global spectral ocean wave model predictions. *Science*, **232**, 1531-1535.

Bernstein, R. L., and D. B. Chelton, 1985: Large-scale sea surface temperature variability from satellite and shipboard measurements. *J. Geophys. Res.*, **90**, 11619-11630.

Born, G. H., R. H. Stewart and C. A. Yamarone, 1985: Topex - A spaceborne ocean observing system. In: *Monitoring Earth's Ocean, Land, and Atmosphere from Space- Sensors, Systems and Applications,* A. Schnapf, ed., American Institute of Aeuronautics and Astronautics, New York, 464-479.

Born, G. H., B. D. Tapley, J. C. Ries and R. H. Stewart, 1986: Accurate measurement of mean sea level changes by altimetric satellites. *J. Geophys. Res.*, **91**(C10), 11775-11782.

Born, G. H., J. L. Mitchell and G. A. Heyler, 1987: Geosat ERM-Mission Design, *Journ. Astronaut. Scienc.*, (in press).

Briscoe, M. G., 1986: A primer on the U.S. contribution to the World Ocean Circulation Experiment, U.S. WOCE Planning Report Number 4, College Station, Texas 77843, June, 35 pp.

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

Brown, R. A., 1986: On satellite scatterometer capabilities in air-sea interaction. *J. Geophys. Res.*, **91**(C2), 2221-2232.

Brown, R. A., and G. Levy, Ocean surface fields from satellite-sensed winds. *Mon. Wea. Rev.*, **114,** 2197-2206.

Burns, B. A., D. J. Cavalieri, M. R. Keller, W. J. Campbell, T. C. Grenfell, G. A. Maykut and P. Gloersen, 1987: Multisensor comparison of ice concentration estimates in the MIZ. *J. Geophys. Res.*, (accepted for special MIZEX issue).

Busalacchi, A. J., and M. A. Cane, 1985: Hindcasts of sea level variations during the 1982-83 El Nino. *J. Phys. Oceanogr.*, **15**, 213-221.

Busalacchi, A. J., and J. Picaut, 1986: The wind-driven sea-level response of the tropical Atlantic Ocean, 1964-1979. *Geophys. J. R. Astr. Soc.*, **87**, 117.

Busalacchi, A. J., 1987: Atlantic seasonality: II. Theory. In: *Further Progress in Equatorial Oceanography,* E. J. Katz and J. M. Witte, (eds.), Nova University Press, Miami, 235-254.

Campbell, J. W., and W. E. Esaias, 1985: Spatial patterns in temperature and chlorophyll on Nantucket Shoals from airborne remote sensing data, May 7-9, 1981. *J. Mar. Res.*, **43**, 139-161.

Campbell, J. W., C. S. Yentsch and W. E. Esaias, 1986: Dynamics of phytoplankton patches on Nantucket Shoals: An experiment involving aircraft, ships and buoys. In: *Tidal Mixing and Plankton Dynamics,* M. J. Bowman, C. M. Yentsch and W. T. Peterson, (eds.), Springer-Verlag, New York, 140-163.

Campell, J. W., and J. E. O'Reilly, 1987: Role of satellites in estimating primary productivity on the northwest Atlantic continental shelf. *Continental Shelf. Res.*, (in press).

Campbell, W. J., P. Gloersen, E. G. Josberger, O. M. Johannessen, P. S. Guest, N. M. Mognard, R. Shuchman, B. A. Burns, N. Lannelongue and K. L. Davidson, 1987: Variations of mesoscale and large-scale sea ice morphology in MIZEX-84 as observed by microwave remote sensing, *J. Geophys. Res.*, (accepted for special MIZEX issue).

Cane, M. A., and S. E. Zebiak, 1985: A theory for El Nino and the Southern Oscillation. *Science*, **228**, 1085-1087.

Cane, M. A., 1986: El Nino. *Annual Review of Earth and Planetary Sci.*, **14**, 43-70.

Cane, M. A., S. E. Zebiak and S. C. Dolan, 1986: Experimental forecasts of El Nino. *Nature* , **321**, 827-832.

Cane, M. A., and A. J. Busalacchi, 1987: Atlantic seasonality: III. Conclusions. In: *Further Progress in Equatorial Oceanography.* E. J. Katz and J. M. Witte, (eds.), Nova University Press, Miami, 255-258.

Carder, K. L., and R. G. Steward, 1985: A remote-sensing reflectance model of the red tide dinoflagellate off west Florida. *Limnol. Oceanogr.*, **30**(2), 286-298.

Carder, K. L., R. G. Steward and P. R. Payne, 1985: Solid-state spectral transmissometer and radiometer. *Optical Engineering*, **24**(5), 863-868.

Carder, K. L., D. Costello and R. G. Steward, 1986: State-of-the-art instrumentation for measuring ocean aggregates. In: *Aggregate Dynamics in the Sea*, A. Alldredge and E. Hartwig, (eds.). Office of Naval Research, Asilomar, CA., p. 131-180.

Carder, K. L., R. G. Steward, J. H. Paul and G. A. Vargo, 1986: Relationships betweeen cholorphyll and ocean color constituents as they affect remote-sensing reflectance models. *Limnol. Oceanogr.*, **31**(2), 403-413.

Carder, K. L, R. G. Steward, P. R. Betzer, D. L. Johnson and J. M. Prospero, 1986: Dynamics and composition of particles from an aeolian input event to the Sargasso Sea. *J. Geophys. Res.*, **91**(D1), 1055-1066.

Carder, K. L., D. J. Collins, M. J. Perry, H. L. Clark, J. M. Mesias, J. S. Cleveland and J. Greenier, 1986: The interaction of light with phytoplankton in the marine environment. In: *Ocean Optics VIII Symposium*, SPIE Proceedings, Orlando, FL, 31 March - 2 April, 1986, 42-55.

Carder, K. L., J. M. Melack and M. R. Abbott: High-resolution spaceborne imaging spectrometry: Science opportunities for the 1990's--Oceans and inland waters. In Chapters 2.B2, 2.C2, 2.E3, 4B: *Imaging Spectrometry Science Advisory Group's Science Plan.* NASA-JPL, (in press).

Carder, K. L., W. Gregg, D. Costello, K. Haddad and J. Prospero: Measures of Saharan dust, sunglint, marine aerosols and chlorophyll from CZCS imagery. *J. Geophys. Res.*, (in revision).

Carsey, F. D., B. Holt, S. Martin, S. L. McNutt, D. A. Rothrock, V. A. Squire and W. F. Weeks, 1986: Weddell-Scotia Sea marginal ice zone observations from space, October 1984. *J. Geophys. Res.*, **91**, 3920-3924.

Carsey, F. D., K. C. Jezek, J. Miller, W. Weeks and G. Weller, 1987: The Alaska synthetic aperture radar (SAR) facility project. *EOS*, **68**(25), 593-596.

Cavalieri, D. J., and S. Martin, 1985: A passive microwave study of polynyas along the Antarctic Wilkes Land Coast. In: *Oceanology of the Antarctic Continental Shelf*, Antarctic Research Series, Vol. 43, American Geophsyical Union, Washington, D.C., 227-252.

Cavalieri, D. J., and H. J. Zwally, 1985: Satellite observations of sea ice. IN: *XXVth COSPAR, Advances in Space Research*, Vol. 5, No. 6, 247-255.

Cavalieri, D. J., P. Gloersen and T. T. Wilheit, 1986: Aircraft and satellite passive microwave observations of the Bering Sea ice cover during MIZEX-West, *IEEE Trans. Geosci. Remote Sensing.*, **GE-24**(3), 368-377.

Cavalieri, D. J., and C. L. Parkinson, 1987: On the relationship between atmospheric circulation and the fluctuations in the sea ice extents of the Bering and Okhotsk seas, *J. Geophys. Res.*, (in press).

Chelton, D. B., 1985: Comments on: Seasonal variation in wind speed and sea state from global satellite measurements. *J. Geophys. Res.*, **90**, 5001-5008.

Chelton, D. B., and P. J. McCabe, 1985: A review of satellite altimeter measurement of sea surface wind speed; with a proposed new algorithm. *J. Geophys. Res.*, **90**, 4707-4720.

Chelton, D. B., and F. J. Wentz, 1986: Further development of an improved altimeter wind speed algorithm. *J. Geophys. Res.*, **91**(C12), 14250-14260.

Chereskin, T. K., J. N. Moum, P. J. Stabeno, D. R. Caldwell, C. A. Paulson, L. A. Regier and D. Halpern, 1986: Fine-scale variability at 140°W in the equatorial Pacific. *J. Geophys. Res.*, **91**, 12887-12898.

Chereskin, T. K., D. Halpern and L. A. Regier, 1987: Comparison of shipboard acoustic Doppler current profiler and moored current measurements in the equatorial Pacific. *J. Atmos. Oceanic Tech.*, (in press).

Christodoulidis, D. C., D. E. Smith, R. G. Williamson and S. M. Klosko, 1987: Observed tidal breaking in the Earth/Moon/Sun system. *J. Geophys. Res.*, (submitted).

Collins, D. J., D. A. Kiefer, J. Beeler SooHoo and I. S. McDermid, 1986: The role of reabsorption in the spectral distribution of phytoplankton fluorescence emission. *Deep-Sea Res.*, **32**(8), 983-1003.

Collins, D. J., D. A. Kiefer, J. Beeler SooHoo, C. Stallings and W.-L. Yang, 1986: A model for the use of satellite remote sensing for the measurement of primary production in the ocean. *Ocean Optics VIII* Proceedings of SPIE, -- *The International Society for Optical Engineering*, Vol. 637, 335-348.

Comiso, J. C., 1986: Characteristics of winter sea ice from satellite multispectral microwave observations. *J. Geophys. Rev.*, **91**(C1), 975-994.

Comiso, J. C., and C. W. Sullivan, 1986: Satellite microwave and in-situ observations of the Weddell Sea ice cover and its marginal ice zone. *J. Geophys. Res.*, **91**(C8), 9663-9681.

Comiso, J. C., and A. L. Gordon, 1987: Recurring polynyas over the Cosmonaut Sea and the Maud Rise. *J. Geophys. Res.*, **92**(C3), 2819-2834.

Donelan, M. A., and W. J. Pierson, 1987: Radar scattering and equilibrium ranges in wind-generated waves with application to scatterometry. *J. Geophys. Res.*, **92**(C5), 4971-5029.

Duffy, D., and R. Atlas, 1986: The impact of Seasat-A scatterometer data on the numerical prediction of the QEII storm. *J. Geophys. Res.*, **91**, 2241-2248.

Dunlap, E. A., 1985: Abundance and distribution of cetaceans in the California Current System as observed from ship and satellite data, M. A. Thesis, University of California, Santa Barbara.

Eppley, R. W., E. Stewart, M. R. Abbott and U. Heyman, 1985: Estimating ocean primary production from satellite chlorophyll; Introduction to regional differences and statistics for the Southern California Bight. *J. Plankton Res.*, **7**, 57-70.

Eppley, R. W., E. Stewart, M. R. Abbott and R. W. Owen, 1987: Estimating ocean production from satellite-derived chlorophyll: Insights from the EASTROPAC data set. *Ocean Acta*, (in press).

Esaias, W. E., G. C. Feldman, C. R. McClain and J. A. Elrod, 1986: Monthly satellite-derived phytoplankton pigment distribution for the North Atlantic ocean basin. *EOS*, **67**(44), 835-837.

Evans, R. E., K. S. Baker, R. C. Smith and O. B. Brown, 1985: Chronology of Warm Core Ring 82B. *J. Geophys. Res.*, **90**, 8803-8811.

Fedor, L. S., E. J. Walsh and D. J. Cavalieri, 1987: Observations of sea ice using the 36 GHz surface contour radar, *IEEE Trans. Geosci. Remote Sens.*, **25**(3), 394-403.

Feldman, G. C., 1986: Variability of the productive habitat in the Eastern Equatorial Pacific. *EOS, Transactions*, **67**(9), 106-108.

Fily, M., and D. A. Rothrock, 1986: Extracting sea ice data from satellite SAR imagery. *IEEE Trans. Geosci. Remote Sens.*, **GE-24**(6), 849-854.

Fily, M., and D. A. Rothrock, 1987: Sea ice tracking by nested correlations. *IEEE Trans. Geosci. Remote Sens.*, (in press).

Freilich, M. H., and D. B. Chelton, 1986: Wavenumber spectra of Pacific winds measured by the Seasat scatterometer. *J. Phys. Oceanogr.*, **16**, 741-757.

Freilich, M. H., and S. S. Pawka, 1987: Statistics of S_{xy} estimates. *J. Phys. Oceanogr.*, (accepted for publication).

Fu, L.-L., and D. B. Chelton, 1985: Observing large-scale temporal variability of ocean currents by satellite altimetry; with application to the Antarctic Circumpolar Current. *J. Geophys. Res.*, **90**, 4721-4739.

Fu, L.-L., 1986: Mass, heat, and freshwater fluxes in the South Indian Ocean, *J. Phys. Oceanogr.*, **16**, 1683-1693.

Fu, L.-L., J. Vazquez and M. E. Parke, 1987: Seasonal variability of the Gulf Stream from satellite altimetry. *J. Geophys. Res.*, **92**(C1), 749-754.

Glazman, R. E., 1985: Mathematical modeling of breaking wave statistics. In: *The Ocean Surface: Wave Breaking, Turbulent Mixing and Radio Probing*, Y. Toba and H. Mitsuyasu, (eds.), D. Reidel Publishing Co., Boston, 145-150.

Glazman, R. E., 1986: Statistical characterization of sea surface geometry for a wave slope field discontinuous in the mean square. *J. Geophys. Res.*, **91**(C5), 6629-6641.

Glazman, R. E., 1987: Effects of organics-coated microbubbles on acoustical properties of the near-surface layer of the ocean. *J. Geophys. Res.*, (in press).

Glazman, R. E., 1987: Fractal nature of surface geometry in a developed sea. Presented at The Workshop on Scaling, Fractals, and Non-Linear Variability in Geophysics, 25-29 August 1986, McGill University, Montreal. (in press by D. Reidel Publ. Co., S. Lovejoy and D. Schertzer, (eds.).

Glazman, R. E., 1987: Wind-fetch dependence of Seasat scatterometer measurements. *Int. J. Remote Sensing*, (submitted for publication).

Glazman, R. E., G. G. Pihos and J. Ip, 1987: SASS wind speed bias induced by the large-scale component of the wave field. *J. Geophys. Res.*, (submitted for publication).

Gloersen, P., and D. J. Cavalieri, 1986: Reduction of weather effects in the calculation of sea ice concentration from microwave radiances. *J. Geophys. Res.*, **91**(C3), 3913-3919.

Grenfell, T., and J. C. Comiso, 1986: Multifrequency passive microwave observations of first-year sea ice grown in a tank. *IEEE Trans. Geosci. Remo. Sens.*, **GE-24**, 826-831.

Guan, F., J. Pelaez and R. H. Stewart, 1985: The atmospheric correction and measurement of chlorophyll concentration using the coastal zone color scanner. *Limnol. Oceanogr.*, **30**(2), 273-285.

Halpern, D., 1987: Comparison of moored wind measurements from a spar and toroidal buoy in the eastern equatorial Pacific during February-March 1981. *J. Geophys. Res.*, (in press).

Halpern, D., 1987: Comparison of upper ocean VACM and VMCM observations in the equatorial Pacific. *J. Atmos. and Oceanic Tech.*, **4**, 84-93.

Halpern, D., 1987: Observations of annual and El Nino thermal and flow variations along the equator at 0º, 110ºW and 0º, 95ºW during 1980-1985. *J. Geophys. Res.*, (in press).

Halpern, D., and H. P. Freitag, 1987: Vertical motion in the upper ocean of the equatorial eastern Pacific. *Oceanologica Acta*, (in press).

Haury, L. R., J. J. Simpson, J. Pelaez, C. J. Koblinsky and D. Weisenhahn, 1986: Biological consequences of a recurrent eddy off Point Conception, California. *J. Geophys. Res.*, **91**, 12937-12956.

Hill, S. H., M. R. Abbott and K. L. Denman, 1985: A computer-controlled turbidostat for the culture of planktonic algae. *Can. J. Fish. Aquat. Sci.*, **42**, 744-753.

Hilland, J. E., D. B. Chelton and E. Njoku, 1985: Production of global sea surface temperature fields for the Jet Propulsion Laboratory Workshop comparisons. *J. Geophys. Res.*, **90**, 11642-11665.

Hoge, F. E., and R. N. Swift, 1985: Airborne mapping of laser-induced fluorescence of chlorophyll a and phycoerythrin in a Gulf Stream warm core ring. In: *Mapping Strategies in Chemical Oceanography*, A. Zirino, (ed.), Advances in Chemistry Series No. 209, American Chemical Society, Washington, D.C., 335-372.

Hoge, F. E., and R. N. Swift, 1986: Active-passive correlation spectroscopy: A new technique for identifying ocean color algorithm spectral regions. *Applied Optics*, **25**, 2571-2583.

Hoge, F. E., and R. N. Swift, 1986: Chlorophyll pigment concentration using spectral curvature algorithms: An evaluation of present and proposed satellite ocean color sensor bands. *Applied Optics*, **25**, 3677-3682.

Hoge, F. E., R. E. Berry and R. N. Swift, 1986: Active-passive airborne ocean color measurement: 1. Instrumentation. *Applied Optics*, **25**, 39-47.

Hoge, F. E., R. N. Swift and J. K. Yungel, 1986: Active-passive airborne ocean color measurement: 2. Applications. *Applied Optics*, **25**, 48-57.

Hoge, F. E., and R. N. Swift, 1987: Ocean color spectral variability studies using solar-induced chlorophyll fluorescence. *Applied Optics*, **26**, 18-21.

Hoge, F. E., C. W. Wright and R. N. Swift, 1987: Radiance-ratio algorithm wave-lengths for remote oceanic chlorophyll determination. *Applied Optics*, (in press).

Huang, N. E., L. F. Bliven, S. R. Long and P. S. DeLeonibus, 1986: A study of the relationship among wind speed, sea state, and the drag coefficient for a developing wave field. *J. Geophys. Res.*, **91**, 7733-7742.

Huang, N. E., L. F. Bliven, S. R. Long and C. C. Tung, 1986: An analytic model for oceanic whitecap coverage. *J. Phys. Oceanogr.*, **16**, 1597-1604.

Huang, N. E., 1987: Wind wave phenomenon. In: *Ed. N. Cheremisinoff Encyclopedia of Fluid Mechanics.* Gulf Stream Publishing Co., (in press).

Huhnerfuss, H. W. D. Garrett and F. E. Hoge, 1986: The discrimination between crude oil spills and monomolecular sea slicks by an airborne lidar. *Int. J. Rem. Sens.*, **7**, 137-150.

Jackson, F. C., W. T. Walton, B. A. Walter and C. Y. Peng, 1987: Sea surface mean square slope from Ku-band backscatter data, *J. Geophys. Res.*, (accepted for publication).

Joyce, T. M., C. Wunsch and S. D. Pierce, 1986: Synoptic Gulf Stream velocity profiles through simultaneous inversion of hydrographic and acoustic doppler data. *J. Geophys. Res.*, **91**, 7573-7585.

Kalnay, E., and R. Atlas, 1986: Global analysis of ocean surface wind and wind stress using the GLAS GCM and Seasat scatterometer winds. *J. Geophys. Res.*, **91**, 2233-2240.

Keller, W. C., W. J. Plant and D. E. Weissman, 1985: The dependence of X-band microwave sea return on atmospheric stability and sea state. *J. Geophys. Res.*, **90**(C1), 1019-1029.

Kiefer, D. A., 1986: Biological sources of optical variability in the sea. Ocean Optics VIII Proceedings of SPIE -- The International Society for Optical Engineering, Vol. 637, 25-34.

Lee, H. S., and C. L. Parkinson, 1986: Mesoscale ocean eddy measurements by multibeam altimetry, *J. Geophys. Res.*, **91**(C8), 9693-9699.

Levy, G., and R. A. Brown, 1986: A simple, objective analysis scheme for scatterometer data. *J. Geophys. Res.*, **91**, 5153-5158.

Ling, C. H., and C. L. Parkinson, 1986: Arctic sea ice extent and drift, modeled as a viscous fluid. *Ocean Science Engr.*, **11**, 71-98.

Livingstone, C. E., R. G. Onstott, L. D. Arsenault and A. L. Gray, 1987: Microwave sea-ice signatures near the onset of melt. *IEEE Trans. Geosci. Rem. Sens.*, **GE-25**, no. 2, 174-187.

Liu, W. T., 1986: Statistical relation between monthly mean precipitable water and surface level humidity over global oceans. *Mon. Wea. Rev.*, **114**, 1591-1602.

Liu, W. T., 1987: Comment on the effect of inaccuracies in weather-ship data on bulk-derived estimates of flux, stability, and sea surface roughness. *J. Atmos. Oceanic Tech.*, (in press).

Liu, W. T., 1987: 1982-83 El Niño Atlas Nimbus-7 Microwave Radiometer Data. JPL Pub. 87-5, National Aeronautics and Space Administration, 68 pp.

Lyzenga, D. R., R. A. Shuchman and J. D. Lyden, 1985: SAR imaging of waves in water and ice: Evidence for velocity bunching. *J. Geophys. Res.*, **90**, 1031-1036.

Lyzenga, D. R., 1986: Numerical simulation of synthetic aperture radar image spectra for ocean waves. *IEEE Trans. Geosci. Rem. Sens.*, **GE-24**, 863-872.

Mackas, D. L., K. L. Denman and M. R. Abbott, 1985: Plankton patchiness: Biology in the physical vernacular. *Bull. Mar. Sci.*, **37**, 652-674.

Marsh, J. G., F. J. Lerch, R. G. Williamson, 1985: Precision geodesy and geodynamics using Starlette laser ranging. *J. Geophys. Res.*, **90**(B11), 9335-9345.

Marsh, J. G., A. C. Brenner, B. D. Beckley and T. V. Martin, 1986: Global mean sea surface based upon Seasat altimeter data. *J. Geophys. Res.*, **91**(C3), 3501-3506.

Marsh, J. G., F. J. Lerch, D. E. Smith, S. M. Klosko, E. Pavlis and R. G. Williamson, 1986: Gravity model development for precise orbit computations for satellite altimetry. In: *Advances in Space Research.* Pergammon Press, (in press).

Marsh, J. G., and et. al., 1986: An improved model of the Earth's gravitational field - GEM-T1. NASA/GSFC document, (in press).

Marsh, J. G., and et. al., 1987: An improved model of the Earth's gravitational field - GEM-T1. *J. Geophys. Res.*, (submitted for publication).

Martin, S., B. Holt, D. J. Cavalieri and V. Squire, 1987: Shuttle Imaging Radar-B (SIR-B) Weddell Sea ice observations: derived ice band properties and a comparison of SIR-B and SMMR ice concentrations. *J. Geophys. Res.*, (in press).

McClain, C. R., S.-Y. Chao, L. P. Atkinson, J. O. Blanton and F. de Castillejo, 1986: Wind-driven upwelling in the vicinity of Cape Finisterre, Spain. *J. Geophys. Res.*, **91**(C7), 8470-8486.

Monaldo, F. M., and D. R. Lyzenga, 1986: On the estimation of wave slope and height variance spectra from SAR imagery. *IEEE Trans. Geosci. Rem. Sens.*, **GE-24**, 543-551.

Monaldo, F. M., J. Goldhirsh and E. J. Walsh, 1986: Altimeter height measurement error introduced by the presence of variable cloud and rain attenuation. *J. Geophys. Res.*, **91**(C2), 2345-2350.

Moore, B. III, 1986: The oceans, carbon dioxide, and global climate change. *Oceanus*, **29**, 9-15.

Muench, R. D., S. Martin and J. E. Overland, 1987: MIZEX Special Issue. *J. Geophys. Res.*, **92**(C7), 6715-7225.

Niiler, P. P., and C. J. Koblinsky, 1985: A local time-dependent Sverdrup balance in the eastern North Pacific Ocean. *Science*, **229**, 754-756.

Nystuen, J. A., 1986: Rainfall measurements using underwater ambient noise. *J. Acoust. Soc. Am.*, **79**(4), 972-982.

Onstott, R. G., T. C. Grenfell, C. Matzler, C. A. Luther and E. A. Svendsen, 1987: Evolution of microwave sea ice signatures during early and mid summer in the marginal ice zone. *J. Geophys. Res.*, (accepted for publication in the MIZEX special issue).

Palmisano, A. C., J. Beeler SooHoo, R. L. Moe and C. W. Sullivan, 1987: Sea ice microbial communities. VII. Changes in under-ice spectral irradiance during the development of Antarctic sea ice microalgal communities. *Mar. Ecol.*, **35**, 165-173.

Parke, M. E., 1987: The applicability of satellite data to tidal models. *ASCE* report, (in press).

Parke, M. E., R. H. Stewart, D. Farless and D. E. Cartwright, 1987: On the choice of orbits for an altimetric satellite to study ocean circulation and tides. *J. Geophys. Res.*, (in press).

Parkinson, C. L., J. C. Comiso, H. J. Zwally, D. J. Cavalieri, P. Gloersen and W. J. Campbell, 1987: Arctic Sea Ice, 1973-1976: Satellite Passive-Microwave Observations. NASA SP-489, National Aeronautics and Space Administration, 296 pp.

Parkinson, C. L., J. C. Comiso, H. J. Zwally, D. J. Cavalieri, P. Gloersen and W. J. Campbell, 1987: Seasonal and regional variations of northern hemisphere sea ice as illustrated with satellite passive-microwave data for 1974. *Annals of Glaciology*, (in press).

Pullen, P. E., R. L. Bernstein and D. Halpern, 1987: Equatorial long wave characteristics determined from satellite sea surface temperature and subsurface in situ data. *J. Geophys. Res.*, **92**, 742-748.

Raghavan, R. S., R. E. McIntosh and C. T. Swift, 1985: Increasing the azimuthal resolution of ocean surface currents for dual-frequency radars. *IEEE Trans. Geosci. Rem. Sens.*, **GE-23**, 906-909.

Roesler, C. S., and D. B. Chelton, 1987: Seasonal and non-seasonal zooplankton variability in the California Current 1951-1981. *California Cooperative Oceanic Fisheries Investigations Reports*, **28**, (in press).

Schmitz, W. J., Jr., P. P. Niiler and C. J. Koblinsky, 1987: Two-year moored instrument results along 152E. *J. Geophys. Res.*, (in press).

Schroeder, L. C., W. L. Grantham, E. M. Bracalente, C. L. Britt, K. S. Shanmugam, F. J. Wentz, D. P. Wylie and B. B. Hinton, 1985: Removal of ambiguous wind directions from a Ku-band wind scatterometer using three different azimuth angles. *IEEE Trans. Geosci. Rem. Sens.*, **GE-23**(2), 91-100.

Schroter, J., and C. Wunsch, 1986: Solution of non-linear finite difference ocean models by optimization methods with sensitivity and observational strategy analysis. *J. Phys. Oceanogr.*, **16**, 1855-1874.

Schroter, J., and C. Wunsch, 1987: Reply to P. C. McIntosh. *J. Phys. Oceanogr.*, (in press).

Servain, J., J. Picaut and A. J. Busalacchi, 1985: Interannual and seasonal variability of the tropical Atlantic Ocean depicted by sixteen years of sea-surface temperature and wind stress. In: Chapter 16. *Coupled Ocean-Atmosphere Models*, J. C. J. Nihoul, (ed.), Elsevier.

Shuchman, R. A., D. R. Lyzenga and G. A. Meadows, 1985: Synthetic aperture radar imaging of ocean bottom topography via tidal current interactions: Theory and observations. *Int'l J. Remote Sens.*, **6**, 1179-1200.

Simpson, J. J., C. J. Koblinsky, J. Pelaez, L. R. Haury and D. Wiesenhahn, 1986: Temperature-plant pigment-optical relations in a recurrent offshore mesoscale eddy near Point Conception, California. *J. Geophys. Res.*, **91**, 12919-12936.

Smith, R. C., and K. S. Baker, 1985: Spatial and temporal patterns in pigment biomass in Gulf Stream Warm Core Ring 82B and its environs. *J. Geophys. Res.*, **90**, 8859-8870.

Smith, R. C., and K. S. Baker, 1986: The analysis of ocean optical data. II. Proceedings of the SPIE Ocean Optics VIII, Soc. of Photo-Optical Instrumentation Engineers, Vol. 637, 95-107.

Smith, R. C., P. Dustan, D. Au, K. S. Baker and E. A. Dunlap, 1986: Distribution of cetaceans and sea-surface chlorophyll concentrations in the California Current. *J. Marine Biology*, **91**, 385-402.

Smith, R. C., R. R. Bidigare, B. B. Prezelin, K. S. Baker and J. M. Brooks, 1987: Optical characterization of primary productivity across a coastal front. *J. Marine Biology*, (accepted for publication).

Smith, R. C., O. B. Brown, F. E. Hoge, K. S. Baker, R. H. Evans, R. N. Swift and W. E. Esaias, 1987: Multiplatoform sampling (ship, aircraft, and satellite) of a Gulf Stream warm core ring. *Applied Optics*, (accepted for publication).

SooHoo, J. Beeler, D. A. Kiefer, D. J. Collins and I. S. McDermid, 19886: In vivo fluorescence excitation and absorption spectra of marine phytoplankton. I. Taxonomic characterstics and responses to photoadaptation. *J. Plankton Res.*, **8**, 197-214.

SooHoo, J. Beeler, A. C. Palmisano, M. P. Lizotte, S. T. Kottmeier, S. L. SooHoo and C. W. Sullivan, 1987: Spectral light absorption and quantum yield of photosynthesis in sea ice microalgae and a bloom of Phaeocystis from McMurdo Sound, Antarctica. *Mar. Ecol.* -- Prog. Series, (in press).

Stewart, R. H., 1985: Application of remote sensing to physical oceanography. *Bull. Airborne and Satellite Phys. and Fish.*, **7**, 93-96. (Japanese and English).

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

Stewart, R. H., 1986: Information from satellites. In: *The Oceans and the Economy of San Diego*, E. D. Goldberg, (ed.), San Diego Oceans Foundation.

Stewart, R. H., 1986: Review of "Geodetic Refraction," edited by F. K. Brunner. *Bull. Am. Meteorological Soc.*, **67**, 199-200.

Stewart, R. H., L.-L. Fu and M. Lefebvre, 1986: Science Opportunities from the Topex/Poseidon Mission. JPL Publication 86-18, Jet Propulsion Lab., Pasadena, CA, 58 pp.

Stow, D. A., 1985: Numerical derivation of a hydrodynamic surface flow-field from time sequential remotely sensed data. Ph.D. Thesis. University of California, Santa Barbara.

Swift, C. T., and D. J. Cavalieri, 1985: Passive microwave remote sensing for sea ice research. *EOS, Trans.*, **66**(49), 1210-1212.

Swift, C. T., W. J. Campbell, D. J. Cavalieri, L. S. Fedor, P. Gloersen, N. M. Mognard, S. Peteherych and H. J. Zwally, 1985: Cryospheric observations from satellites. In: Chapter 9 of *Advances in Geophysics*, B. Saltzman, (ed.), 335-392.

Swift, C. T., D. C. DeHority, A. B. Tanner and R. E. McIntosh, 1986: Passive microwave spectral emission from saline ice at C-band during the growth phase. *IEEE Trans. Geosci. Rem. Sens.*, **GE-24**, 840-848.

Tai, C.-K., and L.-L. Fu, 1986: On crossover adjustment in satellite altimetry and its oceanographic implications. *J. Geophys. Res.*, **91**, 2549-2554.

Tchen, C. M., and W. J. Pierson: A group kinetic theory with a closure by memory loss for modeling turbulence in the atmosphere and the oceans. (To be published in Meteorology and Atmospheric Physics. Springer-Verlog-Wien, 1988).

Tung, C. C., and N. E. Huang, 1987: Spectrum of deep water breaking on the wave energy spectrum. *J. Eng. Mech. Proc. ASCE*, **113**, 293-302.

Tung, C. C., and N. E. Huang, 1987: The effect of wave breaking on the wave energy spectrum. *J. Phys. Oceanogr.*, (accepted for publication).

Tung, C. C., and N. E. Huang, 1987: Breaking wave spectrum. *J. Geophys. Res.*, (accepted for publication).

U.S. Science Steering Committee for WOCE, 1986: WOCE Discussions of Physical Processes: Reports of subject meetings on interbasin exchanges, gyre interactions, deep circulation and its relation to topography, and oceanic heat flux. U.S. WOCE Planning Report Number 5, College Station, Texas 77843, November, 143 pp.

Vargo, G. A., K. L. Carder, W. Gregg, E. Shanley, C. Heil, K. A. Steidinger and K. D. Haddad: The potential contribution of primary production by red-tides to the West Florida Shelf ecosystem. *Limnol. Oceanogr.*, (in press).

Vesecky, J. F., R. H. Stewart, R. A. Shuchman, H. M. Assal, E. S. Kasischke and J. D. Lyden, 1986: On the ability of synthetic aperture radar to measure ocean waves. In: *Wave Dynamics and Radio Probing of the Ocean Surface*, O. M. Phillips and K. Hasselmann, (eds.), Plenum Publishing Corp., NY, 403-421.

Volk, T., 1987: Limitations on relating ocean surface chlorophyll to productivity. In: *Advances in Space Research*, (in press).

Volk, T., 1987: Limiting controls on large-scale surface ocean carbon dioxide sources and sinks: temperature, surface nutrients. In: *Global Biogeochemical Cycles*, (in press).

Walsh, E. J., D. W. Hancock III, D. E. Hines, R. N. Swift and J. F. Scott, 1985: Directional wave spectra measured with the surface contour radar. *J. Phys. Oceanogr.*, **15**(5), 566-592.

Walsh, E. J., D. W. Hancock III, D. E. Hines, R. N. Swift and J. F. Scott, 1985: Elimination of directional wave spectrum contamination from noise in elevation measurements. *J. Oceanic Enginr.*, **OE-10**(4), 376-381.

Walsh, J. J., 1987: On the Nature of Continental Shelves. Academic Press, (in press).

Walsh, J. J., and D. A. Dieterle, 1987: Use of satellite ocean color observations to refine understanding of global geochemical cycles. *Spatial and Temporal Variability in Biospheric and Geospheric Processes*, T. Rosswall, R. G. Woodmansee, and P. G. Risser, (eds.), J. Wiley, (in press).

Walsh, J. J., D. A. Dieterle and W. E. Esaias, 1987: Satellite detection of phytoplankton export from the mid-Atlantic Bight during the 1979 spring bloom. *Deep-Sea Res.*, (in press).

Walsh, J. J., D. A. Dieterle and M. B. Meyers, 1987: A simulation analysis of the fate of phytoplankton within the mid-Atlantic Bight. *Cont. Shelf Res.*, (in press).

Walters, J. M., C. Ruf and C. T. Swift, 1987: A microwave radiometer weather-correcting sea ice algorithm. *J. Geophys. Res.*, (in press).

Washington, W. M., and C. L. Parkinson, 1986: An Introduction to Three-Dimensional Climate Modeling. University Science Books, 422 pp.

Weisberg, R. H., D. Halpern, T. Y. Tang and S. M. Hwang, 1987: M2 tidal currents in the eastern equatorial Pacific Ocean. *J. Geophys. Res.*, (in press).

Weissman, D. E., and J. W. Johnson, 1986: Measurements of ocean wave spectra and modulation transfer function with the airborne two-frequency scatterometer. *J. Geophys. Res.*, **91**(C2), 2450-2460.

Weissman, D. E., 1987: Modeling the interactions between the ocean and the environment for microwave radar sensing. *Radio Sci.*, **22**(1), 87-99.

Wentz, F. J., L. A. Mattox and S. Peteherych, 1986: New algorithms for microwave measurements of ocean winds: Applications to Seasat and the Special Sensor Microwave Imager. *J. Geophys. Res.*, **91**(C2), 2289-2307.

White, W. B., and G. McNally, 1987: Evanescent pressure gradient response in the upper ocean to sub-inertial wind stress forcing of finite wavelength. *J. Phys. Oceanogr.*, (in press).

Williamson, R. G., and J. G. Marsh, 1985: Starlette geodynamics: The Earth's tidal response. J. Geophys. Res., 90(B11), 9346-9352.

Wunsch, C., 1986: Calibrating an altimeter: How many tide gauges is enough? *J. Atm. and Oceanic Tech.*, **3**, 746-754.

Wunsch, C., 1986: Dynamics of the North Sea pole tide revisited. *Geophys. J. Roy. Astron. Soc.*, **87**, 869-884.

Yoder, J. A., C. R. McClain, J. O. Blanton and L.-Y. Oey, 1987: Spatial scales in CZCS-chlorophyll imagery of the Southeastern U.S. continental shelf. *Limn. Oceanogr.*, (in press).

Zebiak, S. E., 1986: Atmospheric convergence feedback in a simple model for El Nino. *Mon. Wea. Rev.*, **114**, 1263-1271.

Zebiak, S. E., and M. A. Cane, 1987: A model for ENSO. *Mon. Wea. Rev.*, (in press).

Zwally, H. J., and J. E. Walsh, 1987: Comparison of observed and modeled ice motion in the Arctic Ocean. *Annals of Glaciology*, **9**, 136-144.

Zwally, H. J., S. N. Stephenson, R. H. Thomas and R. A. Bindschadler, 1987: Antarctic ice shelf boundaries and elevations from satellite radar altimetry. *Annals of Glaciology*, **9**.

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No. NASA TM-4025	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle NASA Oceanic Processes Program Biennial Report - Fiscal Years 1986 and 1987		5. Report Date February 1988
		6. Performing Organization Code EEC
7. Author(s)		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Oceanic Processes Branch, Earth Science and Applications Division, NASA Office of Space Science and Applications, Washington, D.C. 20546-0001		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington, D.C. 20546-0001		14. Sponsoring Agency Code

15. Supplementary Notes

W. Stanley Wilson: Chief, Oceanic Processes Branch
NASA Code: EEC
Washington, D.C. 20546-0001

16. Abstract

This, the Report for NASA's Oceanic Processes Program, provides an overview of our recent accomplishments, present activities, and future plans. The report was prepared for Fiscal Years 1986 and 1987 (October 1, 1985 to September 30, 1987). Sections following the Introduction provide summaries of current flight projects and definition studies, brief descriptions of individual research activities, and a bibliography of referred Journal Articles appearing within the past three years.

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

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	192	A09

NASA FORM 1626 OCT 86

☆ U.S. GOVERNMENT PRINTING OFFICE: 1988— 526-064/61815