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Summary of Research 1997, Department of Oceanography

Faculty of the Department of Oceanography, Naval Postgraduate School

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SUMMARY OF RESEARCH 1997

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Monterey, California

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13. ABSTRACT (Maximum 200 words.)

This report contains summaries of research projects in the Department of Oceanography. A list of recent publications is also included which consists of conference presentations and publications, books, contributions to books, published journal papers, technical reports, and thesis abstracts.

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THE NAVAL POSTGRADUATE SCHOOL MISSION

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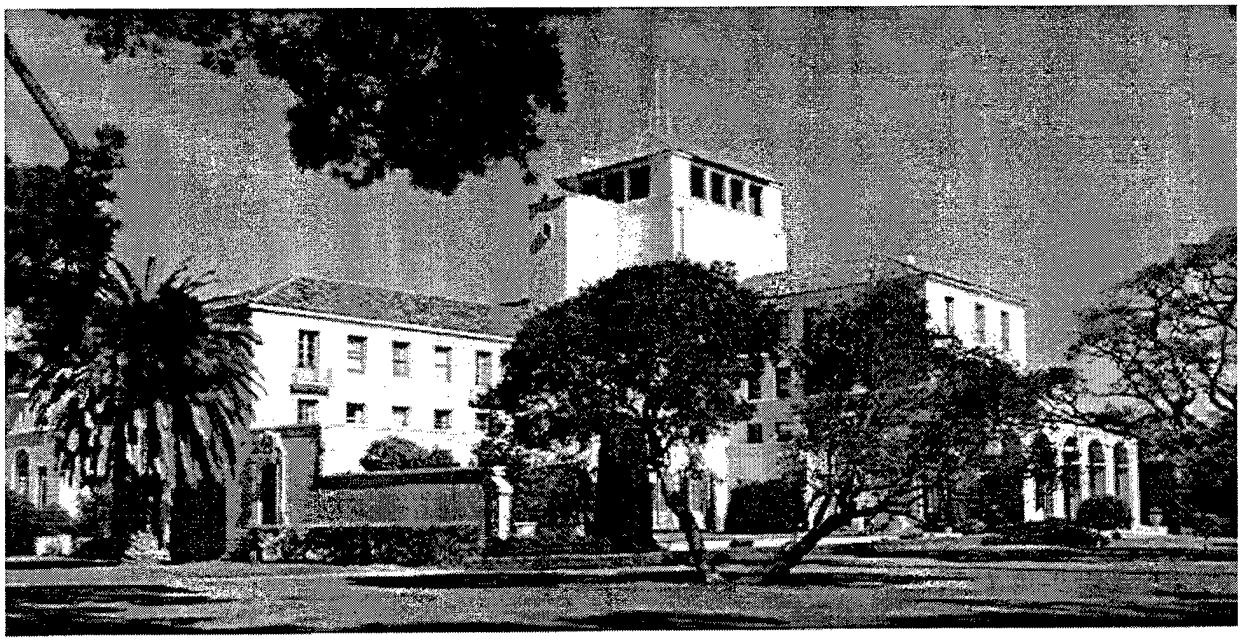

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PREFACE

Research at the Naval Postgraduate School is carried out by faculty in the School's eleven academic departments, four interdisciplinary groups, and the School of Aviation Safety. This volume contains research summaries for the projects undertaken by faculty in the Department of Oceanography during 1997. Also included is an overview of the department, faculty listing, a compilation of publications/presentations, and abstracts from theses directed by the department faculty.

Questions about particular projects may be directed to the faculty Principal Investigator listed, the Department Chair, or the Department Associate Chair for Research. Questions may also be directed to the Office of the Associate Provost and Dean of Research. General questions about the NPS Research Program should be directed to the Office of the Associate Provost and Dean of Research at (831) 656-2098 (voice) or research@nps.navy.mil (e-mail). Additional information is also available at the RESEARCH AT NPS website, http://web.nps.navy.mil~code09/.

INTRODUCTION

The research program at the Naval Postgraduate School exits to support the graduate education of our students. It does so by providing militarily relevant thesis topics that address issues from the current needs of the Fleet and Joint Forces to the science and technology that is required to sustain the long-term superiority of the Navy/DoD. It keeps our faculty current on Navy/DoD issues, permitting them to maintain the content of the upper division courses at the cutting edge of their disciplines. At the same time, the students and faculty together provide a very unique capability within the DoD for addressing warfighting problems. This capability is especially important at the present time when technology in general, and information operations in particular, are changing rapidly. Our officers must be able to think innovatively and have the knowledge and skills that will let them apply technologies that are being rapidly developed in both the commercial and military sectors. Their unique knowledge of the operational Navy, when combined with a challenging thesis project that requires them to apply their focussed graduate education, is one of the most effective methods for both solving Fleet problems and instilling the life-long capability for applying basic principles to the creative solution of complex problems.

The research program at NPS consists of both reimbursable (sponsored) and institutionally funded research. The research varies from very fundamental to very applied, from unclassified to all levels of classification.

- Reimbursable (Sponsored) Program: This program includes those projects externally funded on the basis of proposals submitted to outside sponsors by the School's faculty. These funds allow the faculty to interact closely with RDT&E program managers and high-level policymakers throughout the Navy, DoD, and other government agencies as well as with the private sector in defense-related technologies. The sponsored program utilizes Cooperative Research and Development Agreements (CRADAs) with private industry, participates in consortia with other government laboratories and universities, provides off-campus courses either on-site at the recipient command or by VTC, and provides short courses for technology updates.

- NPS Institutionally Funded Research Program (NIFR): The institutionally funded research program has several purposes: (1) to provide the initial support required for new faculty to establish a Navy/DoD relevant research area, (2) to provide support for major new initiatives that address near-term Fleet and OPNAV needs, (3) to enhance productive research that is reimbursable sponsored, (4) to contribute to the recapitalization of major scientific equipment, and (5) to cost-share the support of a strong post-doctoral program.

- Institute for Joint Warfare Analysis (IJWA) Program: The IJWA Program provides funding to stimulate innovative research ideas with a strong emphasis on joint, interdisciplinary areas. This funding ensures that joint relevance is a consideration of research faculty.

In 1997, the overall level of research effort at NPS was 151 faculty workyears and exceeded $32 million. The Department of Oceanography's effort was 16.82 faculty workyears and exceeded $3 million. The sponsored research program has grown steadily to provide the faculty and staff support that is required to sustain a strong and viable graduate school in times of reduced budgets. In FY97, over 87% percent of the NPS research program was externally supported. In the Department of Oceanography 94% was externally supported.

The department's research sponsorship in FY97 is provided in Figure 1.

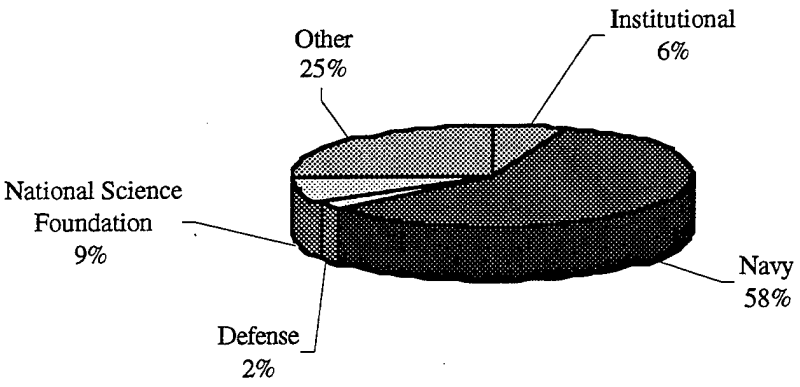

Figure 1. FY97 Sponsor Profile of the Department of Oceanography

These are both challenging and exciting times at NPS and the research program exists to help ensure that we remain unique in our ability to provide graduate education for the warfighter.

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January 1999

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DEPARTMENT SUMMARY

The Oceanography Department has developed a broad research program focused on physical oceanography to meet the anticipated future needs of the Navy. The priority basic research themes are the development of scientific capabilities to measure, analyze, and forecast fields of littoral ocean variables which occur in association with synoptic/mesoscale processes over limited regional and temporal domains. The areas of emphasis include coastal and nearshore ocean dynamics, air-sea interaction phenomena, and boundary currents. Regions of interest include the marginal sea ice zone, coastal ocean regions, and strategic straits of the world.

The priority applied research themes are the application of analyses and forecasts of upper ocean synoptic/mesoscale variability to Naval operations. Areas of emphasis include the impact of littoral processes, eddies, and boundary currents on ocean surveillance systems, the effect of coastal ocean response storms on acoustic propagation's and ambient noise and the impact that the wave climate exert on nearshore processes and beach character as pertains to mine/mine countermeasure, amphibious warfare, and special forces operations.

These research themes require the development of numerical ocean prediction and synoptic oceanography capabilities. They are achieved through employment of modern dynamical and mathematical principles, numerical and statistical methods, computational and graphical facilities, and in-situ and remote sensing observation.

The diverse talents of the faculty of the department are blended by the use of these various techniques to solve problems of common interest. The students are actively involved in these research programs and participate in research cruises, conference presentations, and as co-authors of research reports and papers. Much of the research results, both theoretical and applied, are incorporated into the curricula we support. A summarization of particular research areas follows below.

COASTAL AND NEARSHORE OCEANOGRAPHY

Under sponsorship of the Office of Naval Research (ONR), Associate Professor M.L. Batteen is using an eddy-resolving, primitive equation coastal model to study the generation, stability, and maintenance of currents and eddies in the California and Iberian Current Systems.

Professor C.A. Collins, working with Professors N. Garfield, R. Paquette and E. Carter, continued investigations of the California Inshore Current (CIC). The seasonal cycle of currents off Pt. Sur, California, was resolved: flow was poleward year round, with maximum flow in spring. The structure of the flow at the entrance to the Gulf of California was also resolved and it appears that CIC waters may be ventilated within the Gulf. Lagrangian studies of the structure of the CIC resulted in the discovery of a "new" mechanism for salt dispersion: submesoscale coherent vortices which have been termed "cuddies." These Lagrangian studies also showed that the alongshore flow can be coherent over distances of 400 Km.

Associate Professor P.C. Chu and Professor R.H. Bourke, under the sponsorship of the Office of Naval Research, have determined the coherent time and length scales of the temperature and salinity field in the Beaufort Sea using the complete historical hydrographic database for the Beaufort Sea. This research is in support of the field program and modeling effort associated with the Surface Heat Budget of the Arctic Ocean (SHEBA) Experiment.

Associate Professor P.C. Chu, under the sponsorship of the Naval Oceanographic Office, has developed a parametric model for regional sea T, S data analysis, quantitatively determined temporal and spatial thermohaline variability, and established a diagnostic model for the regional seas, e.g., the South China Sea, the Japan Sea, and the Yellow Sea. He has developed an optimization method to determine the open boundary conditions of coastal models.

Associate Professor P.C. Chu, under the sponsorship of the Office of Naval Research, has developed several high-order difference schemes which will increase the accuracy of ocean models, especially the sigma coordinate ocean models with abrupt topography. Under separate funding, he developed a statistical model to identify the South China Sea warm-core and cool-core eddies, a new technique (S-transform) for obtaining localized spectra has been developed and validated, a parametric model for obtaining physical characteristics (SST, mixed layer depth, thermocline depth and thermocline strength) from vertical profiles.

Associate Professor P.C. Chu, Professors R.H. Bourke, and C.A. Collins, under the sponsorship of NPS, have tested the sensitivity of the Navy's Research, Evaluation, and Systems Analysis (RESA) wargame to the environment. At the same time, they are incorporating realistic environments into high-resolution, high fidelity wargames of mine warfare.

Under the sponsorship of the Navy Engineering Logistics Office, Professors N. Garfield and R. Olsen, Department of Physics, are conducting an investigation of nearshore bathymetric estimates derived from hyperspectral visible and infrared data.

Associate Professor T.H.C. Herbers, is investigating the dynamics of ocean surface waves in shallow coastal waters using theory and field observations. Current research projects (funded by the Office of Naval Research) focus on nonlinear wave-wave interactions, shoaling of waves on beaches, the generation of surf beat, and the propagation of waves over a continental shelf.

Research Associate Professor L. Ly in cooperation with Dr. P. Luong (NAVOCEANO), under multi-year sponsorship of the Office of Naval Research Navy Ocean Modeling and Prediction Program (NOMP), developed a Coastal Ocean System (COS) with curvilinear nearly-orthogonal, multi-block grids, which better handle complicated coastlines, bathymetry and open boundary conditions. The generated numerical grids were coupled to the coastal ocean models with data assimilation schemes. Under the sponsorship of ONR NOMP, Professors L. Ly, J. Paduan and Dr. P. Luong (NAVOCEANO) use the Monterey Bay COS to study the response of MOB to diurnal wind and tidal forcing.

Associate Professor J.D. Paduan, with funding from the Office of Naval Research (ONR) and the National Science Foundation (NSF) is undertaking studies of coastal circulation problems in Monterey Bay, CA and off Chesapeake Bay, VA, using high frequency (HF) radar-derived currents. Of particular interest are the coastal phenomena of sea-breeze driven currents related to sea-land temperature differences and internal tidal currents generated when sea level fluctuations interact with the sloping ocean bottom. A primitive-equation modeling study is also underway using the Princeton Ocean Model to simulate the three-dimensional generation and propagation of internal tides around the Monterey Submarine Canyon.

Assistant Professor P.-M. Poulain has started to make direct measurements of the surface currents in the Strait of Sicily and the Ionian Sea using satellite-tracked drifters in order to describe the variability of the surface circulation mesoscale structures and gain knowledge on their dynamics. This project, in close collaboration with NATO/SACLANTCEN and Italian research institutes, is sponsored by NPS.

Under the sponsorship of NAVO, Professors C.A. Collins and P.-M. Poulain have developed digital layers of information about currents in the Adriatic Sea that will be tactically useful for mine warfare operations.

Research Associate Professor L. Rosenfeld is studying internal waves, particularly at tidal frequencies, in the littoral zone. She is working with Professor Paduan on model studies funded by ONR, and is making field measurements, funded by NSF with colleagues from the University of Washington.

Professors E.B. Thornton and T.P. Stanton are developing models to predict the wave-induced three-dimensional velocity field and induced sediment transport over arbitrary bathymetry in the nearshore zone, and comparing the models to comprehensive field data. They participated in the two-month extensive nearshore field experiment SandyDuck. This work is sponsored by ONR. Under a separate ONR contract, they are evaluating their wave and current surf zone models that have been transitioned to the fleet Tactical Environment Support System.

ACOUSTICAL OCEANOGRAPHY

Professors R.H. Bourke and J.H. Wilson are analyzing bottom backscattering data from shallow water areas with a goal of developing a bottom reverberation algorithm for the AN/SQS-53C sonar when operating in shallow coastal waters. They have recently expanded this research to include the new helicopter sonar (ALFS) and the low frequency active (LFA) sonar. Investigations in the past year have centered on quantifying the energy spreading loss phenomenon. The Sponsors are Naval Undersea Warfare Center (NUWC), Space and Naval Warfare Systems Command (SPAWAR), and Naval Air Systems Command (NAVAIR).

Professors R.H. Bourke and J.H. Wilson are developing a predictive ambient noise model for submarines operating in the Arctic Ocean which will forecast periods of extremely loud (>95th percentile level) and quiet (<5th percentile) noise levels. The ice prediction model, PIPS, is being modified to produce output fields of energy disruption as an indicator of pressure ridge formation. They are also studying RADARSAT imagery to verify the response of the ice deformation field to windforcing. The sponsor is ONR.

Professor C.-S. Chiu is conducting an integrated oceanographic-acoustic field study in the Mid-Atlantic Bight in collaboration with Woods Hole Oceanographic Institute and Harvard University. The research is designed to study the influence of shelf-slope ocean mesoscale processes on the propagation of sound from the continental slope onto the continental shelf. In a separate program, the vertical structure, generation, propagation, spectral characteristics, and acoustic effects of the nonlinear internal solitons on the New Jersey shelf are being studied. Data for the study were measured in the 1995 Shallow Water Acoustic Random Medium Experiment (SWARM 95). The work is funded by ONR.

Professor C.-S. Chiu and the staff of the Coastal Ocean Acoustic Center are continuing the development of the Pt. Sur Ocean Acoustic Observatory. The objectives are to preserve the functionality of the Pt. Sur SOSUS horizontal hydrophone

array and to convert the facility into a dual-use Ocean Acoustic Observatory for the purpose of undersea research. The development is sponsored by University of Washington Applied Physics Laboratory, Center of Monitoring Research, Monterey Bay Aquarium Research Institute, Naval Postgraduate School, and Cornell University.

Professor C.-S. Chiu organized the International Conference on Shallow-Water Acoustics with the Institute of Acoustics of the Chinese Academy of Sciences and Georgia Tech. This conference was held in Beijing, China, in April 1997 and represents a follow-on to the first joint USA-China Conference in Shallow-Water Acoustics convened and chaired by Professor Chiu in 1995. An important goal of these international meetings is to plan an international shallow-water acoustics experiment in the South China or Yellow Sea for 1999. The work is funded by ONR.

Assistant Professor K.B. Smith and Professor C.-S. Chiu are investigating time-domain acoustic signal processing and propagation modeling techniques for the localization of sources of acoustic transient signals. The research is funded by NUWC.

AIR-SEA INTERACTION AND OCEAN TURBULENCE

Professor L. Ly developed an air-wave-sea interaction model of semi-empirical turbulence and similarity theories. The model was used in the modeling of vertical distributions of turbulent dissipation in the Upper Oceanic Turbulent Layer under surface breaking wave conditions. This work was under multi-year sponsorship of ONR.

Professor R.W. Garwood is sponsored by ONR to simulate the response of Lagrangian drifters, buoys, mines and AUVs to oceanic flows and turbulence in the Labrador Sea. This project is part of a five-year accelerated research initiative (ARI) of the Office of Naval Research to observe and model deep convection in the Labrador Sea.

Ms. Arlene Guest and Professor Garwood have a four-year grant from the National Oceanic and Atmospheric Administration (NOAA) and National Science Foundation (NSF) for the project,"Equatorial Mixed Layer System." This project is part of the TOGA Coupled Ocean Atmosphere Response Experiment (COARE), to explain large-scale feedback between the ocean and atmosphere in the Western Pacific.

Professor R.W. Garwood is also funded by the National Science Foundation with a new four-year grant to study Polar Sea convective instabilities and deep-water formation.

Research Associate Professor T.P. Stanton, participated in the first open ocean iron enrichment experiment under ONR sponsorship by designing a Lagrangian reference frame for the experiment and defining mixed layer processes which contribute to the dispersion of surface injected tracers. Under National Science Foundation sponsorship, he participated in the Antarctic ANZFLUX program by deploying three instrument systems which measured anomalously high winter heat fluxes across the ocean mixed layer in the Weddell Sea. He also participated in the ONR/NOAA sponsored COPE experiment by defining the upper ocean mixing contributed by highly non-linear solitons on the continental shelf. He is currently participating in the NSF-sponsored Surface Heat Budget Program, SHEBA, in the Arctic Ocean.

Professors T.P. Stanton and E.B. Thornton are measuring dissipation of shoaling surface gravity waves over the continental shelf in the new five-year ONR sponsored "Shoaling Waves."

NUMERICAL PREDICTION AND DATA ASSIMILATION

Under sponsorship of NSF, Associate Professor Batteen is carrying out eddy-resolving, modeling studies of the Leuuwin Current in the coastal region off Western and Southern Australia. Process-oriented studies are being used to explore the roles of thermal and wind forcing, coastline irregularities, and topography in the generation, stability, and maintenance of the currents and eddies in this anomalous eastern boundary current region.

Professor A.J. Semtner, Jr., under National Science Foundation sponsorship, has developed a global eddy-resolving ocean model with 1/4 degree grid size. Comparisons with in-situ and satellite observations show the simulation to be very realistic, hence the model provides a means of improving physical understanding of the ocean and enabling climate change prediction. In another project funded by the Department of Energy, developmental studies are underway to incorporate all the relevant physical processes (including sea ice and a surface mixed layer) important to climate predictability and change in his global eddy-resolving ocean models. A third project funded by NASA seeks to identify climate changes in the ocean using satellite data and model output.

With funding from the National Science Foundation, two global 1/4-degree simulations were made by Professor Semtner and Dr. Tokmakian using an improved form of an earlier model and with the best available atmospheric forcing. In addi-

tion, satellite altimeter data were used to force the second run, so as to reconstruct the detailed turbulent global circulation of 1992-1996.

Professors J.L. McClean and A.J. Semtner, Jr., sponsored by NSF as part of the analysis and modeling phase of the World Ocean Circulation Experiment (WOCE), have performed extensive analyses of the 1/6-degree Parallel Ocean Program (POP) model both globally and in specific basins. Particular emphasis was placed on the comparison of results from WOCE and POP.

Professors W. Maslowski, Y. Zhang and Semtner, in an on-going study have developed a coupled ice-ocean model of the Arctic at resolution of 18 km and 30 levels. The model will use increasingly high resolution in three dimensions and employ high-quality parameterizations of surface exchanges, ice dynamics, near-surface mixing, deep convection, and topographic interactions. An eddy-resolving simulation of 200 years has been completed, and it will continue including implementation of a 9-km and 40 level grid. The significance of this research lies in better understanding of the Arctic Ocean as a physical system, enabling applications to biological, geochemical, and climate problems, and in the practical predictive capability of clearly exceeding what is presently available. The sponsor is NSF.

Professors Maslowski and Semtner received a grant from Cray Research, Inc., to conduct Arctic Ocean research on massively parallel computers. A successful 200-year simulation was conducted on a T3D machine in Alaska.

MARINE OPERATIONS

Mr. P. Jessen and Professor R.H. Bourke managed shipboard support for NPS at-sea instruction and research projects off the central California coast. Twenty-four days of operations were carried out on the Research Vessel (R/V) *Pt. Sur*. Students and faculty participated in these shipboard projects from both the Departments of Oceanography and Meteorology. The sponsor for this project is the Commander, Naval Oceanography Command. NPS acquired the Point Sur SOSUS array and it is being used in a variety of sponsored research projects.

Professor J. R. Clynch conducted several studies in the application of the Global Positioning System (GPS) to DoD applications. For NISE-West he designed and validated a differential GPS system that can be used on an aircraft of opportunity to calibrate the operations of Precision Approach Landing Radars (PARs). In addition, he supported NISE-West in the planning for installation of a DGPS landing system in Antarctica. For the Defense Mapping Agency, he studied methods of improving solutions from military GPS receivers to geodetic quality.

PROCESS MODELING STUDIES OF THE CALIFORNIA CURRENT SYSTEM

Mary L. Batteen, Associate Professor
Department of Oceanography
Sponsor: National Science Foundation and Naval Postgraduate School

OBJECTIVE: The overall objectives of this research are to investigate the generation, stability, and maintenance of currents and eddies in the California Current System (CCS), and to better describe their contributing forcing mechanisms and their relative importance.

SUMMARY: Process-oriented modeling studies have been used to explore the roles of wind and thermal forcing, and coastal irregularities in the generation of currents and eddies in the CCS.

PUBLICATIONS:

Batteen, M.L., Buch, E.J., and Huang, M.-J., "On the Effects of Coastline Irregularities in Eastern Boundary Currents," *Proceedings of the 44th Eastern Pacific Ocean Conference*, Fallen Leaf Lake, CA, 17 September 1997.

Batteen, M.L., "Wind-Forced Modeling Studies of Currents, Meanders, and Eddies in the California Current System," *Journal of Geophysical Research*, Vol. 102, No. 102, pp. 985-1010, 15 January 1997.

Batteen, M.L. and Huang, M.-J., "The Effect of Salinity on Density in the Leeuwin Current System," *Research Activities in Atmospheric and Oceanic Modeling, CAS/JSC Working Group on Numerical Experimentation*, Vol. 25, 8.6, January 1997.

Buch, E.J. and Batteen, M.L., "Wind-Forced Modeling Studies of Currents, Meanders, Eddies, and Filaments of the Canary Current System," Naval Postgraduate School Technical Report, NPS-OC-97-004, June 1997.

Monroe, J.T. and Batteen, M.L., "A Large-Scale Modeling Study of the California Current System," Naval Postgraduate School Technical Report, NPS-OC-97-007, December 1997.

Vance, P.W. and Batteen, M.L, "Modeling Studies of Wind and Thermohaline Forcing on the California Current System," Naval Postgraduate School Technical Report, NPS-OC-97-005, June 1997.

CONFERENCE PRESENTATION:

Batteen, M.L., Buch, E.J., and Huang, M.-J., "On the Effects of Coastline Irregularities in Eastern Boundary Currents," 44th Eastern Pacific Ocean Conference, Fallen Leaf Lake, CA, 17 September 1997.

THESES DIRECTED:

Buch, E.J., "Wind-Forced Modeling Studies of Currents, Meanders, Eddies, and Filaments of the Canary Current System," Master's Thesis, Naval Postgraduate School, June 1997.

Monroe, J.T., "A Large-Scale Modeling Study of the California Current System," Master's Thesis, Naval Postgraduate School, December 1997.

Vance, P.W., "Modeling Studies of Wind and Thermohaline Forcing on the California Current System," Master's Thesis, Naval Postgraduate School, June 1997.

DoD KEY TECHNOLOGY AREA: Battleship Environments

KEYWORDS: California Current System

ASSESSMENT OF THE IMPACT OF TRANSMITTED WAVEFORMS ON ENERGY SPREADING LOSS (ESL) ON THE AN/SQS-53C TACTICAL SONAR IN VARIOUS SHALLOW WATER ENVIRONMENTS

Robert H. Bourke, Professor
James H. Wilson, Professor
Department of Oceanography
Sponsor: Naval Undersea Warfare Center

OBJECTIVE: This is a continuation of a multi-year project to investigate the influence of bottom reverberation and energy spreading loss on the performance of the hull-mounted, mid-frequency sonar (AN/SQS-53C) in shallow water. The project has been extended to examine the expected performance of the 53C using various wave forms and to assess performance in two specific shallow water areas.

SUMMARY: The earlier efforts used the Generic Sonar Model (GSM) to develop estimates of the transmission loss (TL) and bottom reverberation level (RL) based upon geophysical input data from AREA F off the U.S. eastern continental shelf. This was followed by an investigation (Tanaka, 1996) into the cause and quantification of the time stretching of the echo level in shallow water, termed energy spreading loss (ESL). The time spreading of a 200 Hz-wide Blackman pulse at 3.5 kHz was modeled as a function of geoacoustic bottom type, water depth, sound speed profile, and source/receiver depth.

Currently, NPS student, LT Peter Smith, is studying the effect of various pulse shapes (Blackman, CW and HFM) on ESL for the shallow waters of Onslow Bay and Long Bay off the Carolina coast. These areas have served as test beds for the Navy's critical sea test studies and will continue to do so. They represent a stark contrast in that the former has only a thin sediment cover leading to highly reflective bottom interactions. The latter has a thick sediment cover. Tanaka (1996) has shown that a 5-8 dB difference can exist between these two extreme environments. Preliminary studies indicate that the wave form shape exerts little influence on ESL with pulse duration being a prime factor. Additionally, the effect of bottom slope (up and down) and water depth on ESL will be examined.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Shallow Water Acoustics, Onslow Bay, Long Bay, Energy Spreading Loss

DEVELOPMENT OF AN ARCTIC LOW FREQUENCY AMBIENT NOISE MODEL

Robert H. Bourke, Professor
James H. Wilson, Professor
Department of Oceanography
Sponsors: Office of Naval Research and Naval Postgraduate School

OBJECTIVE: The goal of this multi-year project is to develop a low frequency Arctic ambient noise model to predict extremely high and low noise conditions. Arctic ambient noise levels can vary over 20 dB in short time (hours) intervals and currently U.S. submarines operating in the Arctic Ocean have no reliable way to anticipate the occurrence of extremely low or high noise periods. Obviously, the two extremes in noise levels result in significantly different tactical employment of submarine sonar systems.

SUMMARY: An empirically-based model has been developed based on wind forcing to establish the source level spectral density related to ice fracture during pressure ridging activity. The PIPS model is in the process of being modified to produce output fields of energy dissipation rate as a direct measure of ridging activity. High resolution SAR data is being examined to understand and quantify the changes in the ice cover (leads/ridges) due to the passage of storms. Colleagues from University of Washington Applied Physics Laboratory, Jet Propulsion, and the Navy Ice Center are assisting in this latter effort which is the thesis topic of LT Marcus Speckhann.

CONFERENCE PRESENTATION:

Bourke, R.H., Wilson, J.H., Collins, D.A., and Ehret, L., "Arctic Storm Ambient Noise Model," Ocean Atmosphere Ice Interaction Workshop, Virginia Beach, VA, 8-10 May 1997.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Arctic, Ambient Noise, Storms, Sea Ice, ANDES

CHAIR IN ARCTIC MARINE SCIENCE

Robert H. Bourke, Professor and Chair
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The Chief of Naval Research has established a Chair in Arctic Marine Science at the Naval Postgraduate School. The objectives of the Chair are to foster oceanographic research in the Arctic, acquaint naval officer students with Arctic problems, reduce results of pure research to operational usage, and publicize Navy interest in the Arctic.

SUMMARY: Professor Bourke served as administrator of the Chair handling such details as selecting Chair candidates, writing IPAs and proposals and setting up visits and seminars for the Chair incumbent.

CAPT Lawson Brigham USCG (Ret.) was the Chairholder during FY97. During CY97 CAPT Brigham provided several seminars, worked with Professor Bourke on sea-ice studies and continued with his research on remote sensing of sea ice and the inferred circulation in the Laptev Sea. He also attended several conferences dealing with the future use of the Northern Sea Route and wrote articles on this and navigation in ice-covered waters.

A search was conducted for the follow-on Chairholder. Professor William D. Hibler, III from Dartmouth College has been selected. He will be in residence from January 1998 to September 1998 and will conduct sea-ice modeling research in conjunction with Professors Bourke and Semtner.

PUBLICATIONS:

Brigham, L.W., "The Northern Sea Route, 1996," *Polar Record*, 33(187), 333-336, 1997.

Brigham, L.W., "Commentary: An International Polar Navigation Code for the Twenty-First Century," *Polar Record*, 33(187), 283-284, 1997.

CONFERENCE PRESENTATIONS:

Brigham, L.W., "Satellite Remote Sensing of Sea Ice in the Laptev Sea," 12th International Symposium of Okhost Sea and Sea Ice, Mombetsu, Hokkaido, Japan, 2-5 February 1997.

Keys, H.J.R., Jacobs, S.S., Brigham L.W., "The Ross Ice Shelf Continues its Record Northward Expansion," Symposium on Antarctica and Global Change: Interactions and Impacts, Hobart, Tasmania, Australia, 13-18 July 1997.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Arctic Ocean, Sea Ice

ASSESSMENT OF ENVIRONMENTAL IMPACT OF ENERGY SPREADING LOSS IN SHALLOW WATER ON THE LOW FREQUENCY ACTIVE (LFA) SONAR SYSTEM

Robert H. Bourke, Professor
James H. Wilson, Professor
Department of Oceanography
Sponsor: Space and Naval Warfare Systems Command

OBJECTIVE: To determine the performance degradation due to energy spreading loss (ESL) at LFA frequencies in shallow water environments. Initially geoacoustic and water column data was used from an area where LFA measurements have been made, namely Tanner Bank off the southern California coast.

SUMMARY: Model runs were conducted in intermediate and shallow water depths and along an up-slope path to determine the role of ESL on sonar performance. Various pulse form shapes (Blackman and CW) and a pulse duration of 4 sec were used. At these long pulse durations, little time stretching of the signal was noted. ESL is an important parameter primarily for pulse durations associated with mid-frequency tactical sonars (~3 kHz). However, LFA detection ranges are so short in shallow water that reverberation will blank target detections over considerable distances if long pulse durations are used.

THESIS DIRECTED:

Adams, B.S., "An Analysis of the Effects of Energy Spreading Loss and Transmission Loss on Low Frequency Active Sonar Operations in Shallow Water," Master's Thesis, Naval Postgraduate School, September 1997.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Low Frequency Active Sonar, Energy Spreading Loss, Shallow Water Acoustics

RESEARCH OPPORTUNITIES FOR PROGRAM OFFICERS (ROPO) FOR DR. STEVEN R. RAMP "PROCESSES IN EASTERN BOUNDARY CURRENTS"

Robert H. Bourke, Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: To permit Dr. Steven R. Ramp to continue processing and analyzing data from several Navy-sponsored field programs in the California Current System (CCS) and to publish the results in the refereed literature.

SUMMARY: Dr. Ramp returned to NPS for several one-week stays during the year to work on two primary tasks, namely: (1) analysis and synthesis of data from the ONR-sponsored Eastern Boundary Current Accelerated Research Initiative and (2) commence a literature study of the circulation and dynamics of the South China Sea.

PUBLICATIONS:

Chumbinho, R., Haney, R.L., and Ramp, S.R., "Kinematics and Dynamics of a Cyclonic Eddy off Point Arena, CA," *Journal of Physical Oceanography*, in press.

Noble, M. and Ramp, S.R, "Subtidal Currents over the Central California Continental Slope: Evidence for Spatial and Temporal Variations in the Poleward Undercurrent," *Continental Shelf Research*, submitted.

Ramp, S.R., McClean, J.L., Collins, C.A., Semtner, A.J., Hays, and K.A.S., "Observations, Equations, and Modeling of the 1991-92 El Niño off Central California," *Journal of Geophysical Research*, 102, 5553-5582, 1997.

Ramp, S.R., Rosenfeld, L.K., Tisch, T.D., and Hicks, M.R., "Moored Observation of the Current and Temperature Structure over the Continental Slope off Central California. Part I: A Basic Description of the Variability," *Journal of Geophysical Research,* in press.

Ramp, S.R. and Abbott, C.L., "The Vertical Structure of Currents Over the Continental Shelf Off Point Sur, CA, during Spring 1990," *Continental Shelf Research,* accepted.

Tisch, T.D. and Ramp, S.R., "Moored Observations of the Current and Temperature Structure over the Continental Slope off Central California. Part II: The Energetics of the Flow off Point Sur," *Journal of Geophysical Research,* in press.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: California Current System, Eastern Boundary Currents, Fronts and Eddies Coastal Oceanography, Ocean Modeling

INTERNATIONAL CONFERENCE IN SHALLOW-WATER ACOUSTICS

Ching-Sang Chiu, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVES: The long-term goal is to formulate and conduct a collaborative international experiment in the seas of China. Such an experiment will focus on studying the physics and variability of sound propagation and scattering that are unique to the coastal waters of the Asian Pacific region. The FY97 objective was to promote scientific exchange and establish a dialog between Asian and U.S. scientists who are active in shallow-water acoustics research.

SUMMARY: The approach was to hold an international conference in Beijing, China as an outgrowth from the Office of Naval Research (ONR) USA-China Conference in Shallow-Water Acoustics held at the Naval Postgraduate School in December 1995. An international conference in China could attract many of the top-notch Asian scientists to attend. It could help to establish a dialog between the Asian and U.S. underwater acoustics communities, and provide a forum to exchange and discuss the latest scientific ideas, approaches and results in shallow-water acoustics which might form the basis for future collaborative research efforts between the U.S. and Asian communities.

The principal investigator worked closely with the Chinese co-organizers to coordinate the conference logistics and plan the conference agenda and co-chaired the technical committee to assist in identifying topics for special sessions, selecting invited speakers, and session chairs, and assigning contributed papers to the appropriate sessions. He also served on an ONR delegation to visit several oceanographic and acoustic laboratories in China following the conference. The post-conference tour was designed to begin the development of an international steering group to formulate and execute a collaborative field study.

A major accomplishment is that the conference and the post-conference tour have led to a strong dialog with the Chinese, Japanese, Korean, Singaporean, Russian and Indian scientists. An international steering group workshop to investigate the scientific, engineering, and logistic rationales that might form the basis for a collaborative international experiment in the seas of China is now in the planning.

PUBLICATION

Chiu, C.-S. and Lynch, J. F., "Acoustic Tomography in Shallow Water: Issues, Methods and Experimental Results," *Proceedings of the International Conference on Shallow-Water Acoustics, 1997*, in press.

CONFERENCE PRESENTATION:

Chiu, C.-S. and Lynch, J.F, "Acoustic Tomography in Shallow Water: Issues, Method and Experimental Results," International Conference on Shallow-Water Acoustics," Beijing, China, 21-25 April 1997.

DoD KEY TECHNOLOGY AREAS: Sensors, Environmental Quality

KEYWORDS: Shallow-Water Acoustics

MIDDLE ATLANTIC BIGHT (SHELFBREAK PRIMER) FIELD STUDY

Ching-Sang Chiu, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The objectives of this multi-year, multi-institutional field study in the Middle Atlantic Bight are to improve our understanding of the physical variability of the shelf break front south of New England, and to apply this improved knowledge to problems in acoustical propagation. To do this, detailed measurements of physical and acoustical properties during the contrasting summer and winter seasons have been made. These measurements are being related to physical and acoustical modeling studies. Results from these modeling efforts, tested against the observations, should be broadly applicable to shelf-break regions on a more global basis.

SUMMARY: The field program surveying the frontal region has just been concluded. The field work included two intensive three-week experiments, one in July 1996 (summer) and the other one in February 1997 (winter). Specifically, each of the two experiments successfully employed a suite of observational techniques including an acoustic tomography array consisting of multiple transceivers/sources and two vertical hydrophone arrays (VLAs) straddling the shelf-break front, several high-resolution, three-dimensional surveys of the frontal region with a SeaSoar, a shelf-to-slope hydrographic section, and moored arrays of ADCPs, current meters and thermistors. The resultant data set is both comprehensive and of high quality, and will allow for gaining fundamental insights into the oceanographic processes which influence acoustic propagation in a slope-shelf region. The measurements are being supplemented by model studies, both oceanographic and acoustic. The detailed analysis of the data and the modeling has begun in earnest, with an initial emphasis being upon understanding the oceanographic field through which the acoustic signals have propagated NPS played a lead role in all phases of the study including experimental planning, data collection, data processing, acoustic modeling, and data analysis. Specifically, NPS has initiated modal processing, modeling and time-series analysis of the acoustic data in an effort to quantify the dominant space and time scales of the variability in the sound field and to relate the observed acoustic variability to ocean processes.

PUBLICATIONS:

Chiu, C.-S., Miller, C.W., and Lynch, J.F., "Optimal Modal Beamforming of Bandpass Signals Using an Undersized, Sparse Vertical Hydrophone Array: Theory and a Shallow-Water Experimentation," *IEEE Journal of Oceanic Engineering,* 22(3), 522-533, 1997.

Lynch, J.F., Gawarkiewicz, G.G., Chiu, C.-S., Pickart, R., Miller, J.H., Smith, K.B., Robinson, A., Brink, K., Beardsley, R., Sperry, B., and Potty, G., "Shelfbreak PRIMER - An Integrated Acoustic and Oceanographic Field Study in the Mid-Atlantic Bight," *Proceedings of the International Conference on Shallow-Water Acoustics*, Beijing, China, 1997, in press.

CONFERENCE PRESENTATIONS:

Beardsley, R.C., Brink, K.H., Caruso, M.J., Chiu, C.-S., Gawarkiewicz, G.G., Lynch, J.F., Miller, J.H., Pickart, R., Robinson, A.R., and Smith, K.B., "Shelfbreak PRIMER - An Integrated Acoustic and Oceanographic Field Study in the Middle Atlantic Bight," International Conference on Shallow-Water Acoustics, Beijing, China, 21-25 April 1997.

Chiu, C.-S. and Lynch, J.F., "Acoustic Tomography in Shallow Water," International Workshop on Ocean Acoustic Tomography, Yokosuka, Japan, 13-14 March 1997.

Chiu, C.-S., Miller, C.W., and Lynch, J.F., "Optimal Modal Beamforming of Bandpass Signals Using an Undersized, Sparse Vertical Hydrophone Array: Theory and a Shallow-Water Experimentation," 3rd International Conference on Theoretical and Computational Acoustics, Newark, NJ, 14-18 July 1997.

Chiu, C.-S., Lynch, J.F. Gawarkiewicz, G.G., Pickart, R.S., Sperry, B., Miller, J.H., Smith, K.B., and Robinson, A.R., "Measurement and Analysis of the Propagation of Sound from the Continental Slope to the Continental Shelf," 134th Meeting of the Acoustical Society of America, San Diego, CA, 1-5 December 1997.

Gawarkiewicz, G., Pickart, R., Lynch, J.F., Chiu, C.-S., Smith, K.B., and Miller, J.H., "The Shelfbreak Front PRIMER Experiment," 133rd Meeting of the Acoustical Society of America, State College, PA, 15-20 June 1997.

DoD KEY TECHNOLOGY AREAS: Sensors, Environmental Quality

KEYWORDS: Littoral, Acoustics, Nowcast, Shelfbreak fronts

MONITORING WHALES USING THE PT. SUR ACOUSTIC ARRAY - A FEASIBILITY STUDY

Ching-Sang Chiu, Associate Professor
Curtis A. Collins, Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The objectives include: (1) To investigate the feasibility of locating and tracking distant California blue whales using a former SOSUS array and matched signal algorithms. (2) To explore the possibility of providing supplementary information on counts and transit paths of California blue whales. (3) To enhance the understanding of low-frequency sound propagation physics in a littoral environment.

SUMMARY: Detecting, classifying, localizing, and tracking vocalizing whales using receiver arrays at long ranges is a complex problem. It is a combined signal processing-acoustics-oceanography problem. First, knowledge of the loudness and frequency-time distribution of the different whale sounds is required for classification purposes. Equally important is the understanding of the basic structure and variability of the ocean sound channel. The ocean scrambles the vocalized signal by its multipaths as the signal propagates to a distant receiver. The ability to predict the mean and variance of the propagation is thus required to unscramble the received signal and to constrain the uncertainty.

In the summer of 1997, two three-day experiments were conducted to test the feasibility of acoustically detecting, classifying, localizing, and tracking blue whales at long ranges using a former SOSUS listening array located at the Naval Postgraduate School Ocean Acoustic Observatory (OAO) at Pt. Sur, California. During each experiment, full-array data were archived continuously at the OAO. In concert with the shore-based acoustic monitoring, an aircraft was assigned to locate blue whales in the Monterey Bay National Marine Sanctuary and to direct a research vessel to a whale site. The research vessel was manned with observers and instrumented with a towed hydrophone array to ground-truth the locations of the blue whales and classify the vocalized near-field signals. These shipboard measurements were required to provide a means to separate the source signal characteristics from the multipath signatures for the calibration and validation of broadband, model-based localization methods. Initial experimental as well as modeling results show great promise, which included assessments of the predictability, i.e., variability, of the vocalized sound and the uniqueness of the location-dependent multipath structure. Both are fundamental to the applicability of model-based algorithms.

CONFERENCE PRESENTATION:

Chiu, C.-S., Collins, C.A., Hager, C.A., Miller, C.W., Moore, T.C., Rocheleau, M.R., Lashkari, K., and Hayes, S., "A Feasibility Field Study of Monitoring Blue Whales Using the Pt. Sur Ocean Acoustic Observatory," 134th Meeting of the Acoustical Society of America, San Diego, CA, 1-5 December, 1997.

THESIS DIRECTED:

Hager, C.A., "Modeling the Performance of the Pt Sur Hydrophone Array in Localizing Blue Whales," Master's Thesis, Naval Postgraduate School, September 1997.

DoD KEY TECHNOLOGY AREAS: Sensors, Environmental Quality

KEYWORDS: Coastal, Acoustics, Whale Monitoring, Alternate Uses

DATA ANALYSIS FOR THE SWARM EXPERIMENT

Ching-Sang Chiu, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research and Naval Postgraduate School

OBJECTIVE: The objective of this research is to characterize the internal waves and their impact on the spatial and temporal variability and coherence of acoustic transmissions in a shelf environment.

SUMMARY: During the summer of 1995, a multi-institutional field study called Shallow Water Acoustics in a Random Medium (SWARM) was conducted in the Mid-Atlantic Bight continental shelf region off the coast of New Jersey. Environmental and acoustic sensors were deployed as part of SWARM to measure and characterize the non-linear internal waves and their impact on the spatial and temporal coherence of the acoustic transmissions. As part of the environmental monitoring network, two bottom-moored, upward-looking Acoustic Doppler Current Profilers (ADCPs) were deployed. An oceanographic, modal, time-series analysis of the ADCP data reveals that: large-amplitude, nonlinear, internal wavepackets were generated at multiple sites near the shelfbreak; the generation mechanism was consistent with the lee-wave hypothesis of generation; the propagation characteristics were in good agreement with nonlinear soliton theory; and the power spectral density was spatially varying and changed markedly during the passage of these nonlinear waves. Based on these observations, a model of the induced sound-speed perturbations was developed. Using a coupled normal-mode propagation model, the temporal and vertical structure of the sound field were subsequently calculated for comparison to data obtained by a vertical line array.

PUBLICATIONS:

Apel, J., Badiey, M., Chiu, C.-S., Finnette, S., Headrick, R., Kemp, J., Lynch, J., Newhall, A., Orr, M., Pasewark, B., Tielbuerger, D., Turgut, A., von der Heyt, K., and Wolf, S., "An Overview of the 1995 SWARM Shallow Water Internal Wave Acoustic Scattering Experiment," *IEEE Journal of Oceanic Engineering*, 22(3), 465-500, 1997.

Chiu, C.-S., Ng, S.-L., and Denner, W.W., "Estimating the Properties of the Sound Field in a Shelf Region Near the Shelfbreak," *Proceedings of the 6th Western Pacific Regional Acoustics Conference, Volume 1*, 329-334, 1997.

CONFERENCE PRESENTATIONS:

Apel, J., Badiey, M., Chiu, C.-S., Finnette, S., Headrick, R., Kemp, J., Lynch, J., Newhall, A., Orr, M., Pasewark, B., Tielbuerger, D., Turgut, A., von der Heyt, K., and Wolf, S., "The New Jersey Shelf Shallow-Water Acoustic Random Media Propagation Experiment (SWARM)," International Conference on Shallow-Water Acoustics, Beijing, China, 21-25 April 1997.

Apel, J., Chiu, C.-S., Headrick, R., Lynch, J., Orr, M., Pasewark, B., and Wolf, S., "Acoustic Travel Time and Intensity Fluctuations Measured in the 1995 SWARM Experiment," 133rd Meeting of the Acoustical Society of America, State College, PA, 15-20 June 1997.

Chiu, C.-S., NG, S.-L., and Denner, W.W., "Estimating the Properties of the Sound Field in a Shelf Region Near the Shelfbreak," 6th Western Pacific Regional Acoustics Conference, Hong Kong, 19-21 November 1997.

THESIS DIRECTED:

Ng, S.-L., "A Simulation Study of Acoustic Variability Due to Internal Solitary Waves on the Mid-Atlantic Continental Shelf," Master's Thesis, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREAS: Sensors, Environmental Quality

KEYWORDS: Littoral, Acoustics, Internal Tides, Internal Waves

DEVELOPMENT OF THE PT. SUR OCEAN ACOUSTIC OBSERVATORY

Ching-Sang Chiu, Associate Professor
Department of Oceanography
Sponsors: SAIC, Cornell University, and Office of Naval Research

OBJECTIVE: The objectives are: (1) to preserve the functionality of the Pt. Sur SOSUS horizontal hydrophone array and (2) to convert the facility into a dual-use Ocean Acoustic Observatory for the purpose of undersea research.

SUMMARY: In 1995, the Pt. Sur Ocean Acoustic Observatory in the Monterey Bay National Marine Sanctuary was established, for the purpose of undersea research. Several sponsoring organizations have contributed greatly to this commendable community effort. Their contributions were in terms of hardware, reimbursable funding for electric and electronic maintenance, labor, and the conduct of high-quality research using the data.

In 1997, the development of the Pt. Sur Ocean Acoustic Observatory (OAO) was continued using reimbursable funding provided by SAIC, Cornell University and the Office of Naval Research. The 1997 OAO research projects include nuclear test ban treaty monitoring, coastal ocean circulation studies, and marine mammal studies. The latest accomplishment is the development of a full-array classified data archival capability. This enhanced capability will enable the conduct of both classified and unclassified research that require spatial beamforming using the horizontal array.

THESES DIRECTED:

Morvillez, T., "Monitoring Temperature Variability Along the California Coast Using Acoustic Tomography," Master's Thesis, Naval Postgraduate School, September 1997.

Smith, Amy, "Analysis of Modal Travel Time Variability due to Ocean Mesoscale Structure," Doctor of Philosophy Dissertation, Naval Postgraduate School, June 1997.

DoD KEY TECHNOLOGY AREAS: Sensors, Environmental Quality

KEYWORDS: SOSUS, Alternate Uses, Acoustic Observatory

SHALLOW WATER ANALYSIS AND FORECAST SYSTEM FOR THE SOUTH CHINA SEA

Peter C. Chu, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research and Naval Postgraduate School

OBJECTIVE: This is a two-year proposal for extending the currently existing NOMP research project to improve our South China Sea Shallow Water Analysis and Forecast System (SCS-SWAFS) with establishment of an open boundary

diagnosis and to transition SWAFS-SCS from basic research and exploratory development to an operational system at NAVOCEANO. This is an important component of the recently developed Integrated Education/Research Program at NPS on Naval Ocean Analysis and Prediction. The goals are: (1) to investigate the underlying causes of the recently detected central South China Sea warm-core and cold-core eddies and their transient features and effects on the monsoon onset (scientific goal) and (2) to transfer SCS-SWAFS to Dr. Ruth Preller's Group at NRL-Stennis Space Center and in turn to Mr. Andy Johnson's Group at the Naval Oceanographic Office for operational use (operational goal).

SUMMARY: During the current year, the following tasks were completed: (1) a statistical model was developed to identify the South China Sea warm-core and cool-core eddies, and the thermal variability of the South China Sea and Yellow Sea; (2) a new technique, S-transform, for obtaining localized spectrum was developed and validated. (3) a parametric model was developed for obtaining physical characteristics (SST, mixed layer depth, thermocline depth, thermocline strength,...) from vertical profiles; (4) an optimization method was developed for determining the open boundary conditions of coastal models; (5) a new diagnostic model (P-vector Model) was validated; and (6) synoptic forcing functions were included into the SCS-SWAFS Model.

PUBLICATIONS:

Cai, W.J. and Chu, P.C., "Effects of Convective Instability Due to Incompatibility Between Ocean Dynamics and Surface Forcing," *Annals Geophysicae*, 15, 1,067-1,075, 1997.

Cai, W.J. and Chu, P.C., "Ocean Climate Drift and Interdecadal Oscillation due to a Change in Thermal Damping," *Journal of Climate*, 11, 2821-2833, 1996.

Cai, W.J., and Chu, P.C., "1997: A Thermal Oscillation Under a Restorative Forcing," *Quarterly Journal of the Royal Meteorological Society*, in press.

Chu, P.C., "The S-Transform for Obtaining Localized Spectra," *Journal of Marine Technological Society*, 29 (4), 28-38, 1996.

Chu, P.C., Wells, S.K., Haeger, S.D., Szczechowski, C., and Carron, M., "Temporal and Spatial Scales of the Yellow Sea Thermal Variability," *Journal of Geophysical Research*, 102, 5655-5668, 1997.

Chu, P.C., Fralick, C.R., Haeger, S.D., and Carron, M.J., "A Parametric Model for Yellow Sea Thermal Variability," *Journal of Geophysical Research*, 102, 10499-10508, 1997.

Chu, P.C., Fan, C.W., and Ehret, L.L., "Determination of Open Boundary Conditions from Interior Observational Data," *Journal of Meteorological and Oceanic Technology*, 14, 723-734, 1997.

Chu, P.C. and C.P. Chang, "South China Sea Warm Pool," *Advances in Atmospheric Sciences*, 14, 195-206, 1997.

Chu, P.C., Tseng, H.C., Chang, C.P., and Chen, J.M., "South China Sea Warm Pool Detected from the Navy's Master Oceanographic Observational Data Set (MOODS)," *Journal of Geophysical Research*, 102, 15761-15771, 1997.

Chu, P.C. and Fan, C.W., "Sixth-Order Difference Scheme for Sigma Coordinate Ocean Models," *Journal of Physical Oceanography*, 27, 2064-2071, 1997.

Chu, P.C., Lu, S.H., and Chen, Y., "Temporal and Spatial Variabilities of the South China Sea Surface Temperature Anomaly," *Journal of Geophysical Research*, 102, 20937-20955, 1997.

Chu, P.C., Fan, C.W., and Cai, W.J., "1997: Evaluation of P Vector Method Using Modular Ocean Model (MOM)," *Journal of Oceanography*, in press.

Chu, P.C., Chen, Y.C., and Lu, S.H., "1997: On Haney-Type Surface Thermal Boundary Conditions for Ocean Circulation Models," *Journal of Physical Oceanography*, in press.

Steger, J., Collins, C.A., and Chu, P.C., "Circulation in the Archipelago de Colon (Galapagos Islands), November 1993," *Deep Sea Research*, 1996, in press.

CONFERENCE PRESENTATIONS:

Chu, P.C., "Effect of Drake Passage on the Brazilian Coastal Currents," Inter-American Institute for Global Change Workshop, Sao Paulo, Brazil, 11-14 April 1997.

Chu, P.C., "South China Sea Oceanography and Sampling Strategy," International South China Sea Monsoon Experiment (SCSMEX) Planning Meeting, Hong Kong, 15-18 September 1997.

Chu, P.C. and Lu, S.H., "Response of Radiative Fluxes to Tiny Random Sea Surface Temperature Disturbances," American Meteorological Society Ninth Conference on Atmospheric Radiation, Long Beach, CA, 2-7 February 1997.

Chu, P.C. and Lu, S.H., "Response of Hydrological Cycle to Tiny Random Sea Surface Temperature Disturbances," The American Meteorological Society 13th Conference on Hydrology, Long Beach, CA, 2-7 February 1997.

Chu, P.C., Chen, Y.C., and Lu, S.H., "On Haney-Type Ocean Surface Thermal Boundary Conditions," Oceanographic Society Meeting, Seattle, WA, 31 March-3 April 1997.

Chu, P.C., Chen, Y.C., and Lu, S.H., "Ice-Albedo Effect on the Global Climate Variability," 22nd General Assembly of the European Geophysical Society, Vienna, Austria, 21-25 April 1997.

Chu, P.C., Lu, S.H., and Chen, Y.C., "Effects of Drake Passage on the Global Climate Variability," 22nd General Assembly of the European Geophysical Society, Vienna, Austria, 21-25 April 1997.

Chu, P.C., Ehret, L.L., and Scott, J., "Multifractal Analysis of Ocean Mixed Layer Near the Norwegian Coast," 22nd General Assembly of the European Geophysical Society, Vienna, Austria, 21-25 April 1997.

Chu, P.C., Lu, S.H., and Chen, Y.C., "Simulation of Winter and Summer Monsoons over East Asia with a Nested Global-Regional Climate Model," 22nd General Assembly of the European Geophysical Society, Vienna, Austria, 21-25 April 1997.

Chu, P.C., Lu, S.H., and Chen, Y.C., "Simulation of Spring-to-Summer Monsoons over East Asia with an NCAR Regional Climate Model," 22nd General Assembly of the European Geophysical Society, Vienna, Austria, 21-25 April 1997.

Chu, P.C., Lu S.H., and Chen, Y.C., "Predictability of Climate Models - Sensitivity to Tiny Sea Surface Temperature Disturbances," 22nd General Assembly of the European Geophysical Society, Vienna, Austria, 21-25 April 1997.

THESIS DIRECTED:

Jimenez, G., "Diurnal Variation over the Tropical Monsoon Regions during Northern Summer," Master's Thesis, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Environmental Quality

KEYWORDS: P-Vector, Geostrophic Velocity, Beta-Spiral, Inverse Method, Primitive Equation Model, Turbulence Closure

ENVIRONMENTAL EFFECTS ON NAVAL WARFARE SIMULATIONS

Peter C. Chu, Associate Professor
Department of Oceanography
Sponsor: Naval Oceanographic Office

OBJECTIVE: This is a three-year interdisciplinary and multi-institutional project pursued collaboratively among the NPS Naval Ocean Analysis and Prediction (NOAP) Lab, the NPS Wargame Lab, NAVOCEANO Ocean Modeling Division, and the Army's Coastal Engineering Research Center (CERC). The purposes of the project are: (1) to investigate environmental effects on the joint warfare simulations at various scales (e.g., theater level, technical level) and to incorporate the Navy's Meteorological and Oceanographic (METOC) data and models effectively into the joint warfare simulation models, such as RESA and mine warfare models obtained from COMMINWARCOM; (2) to estimate the value added of knowing the METOC data; and (3) to quantitatively analyze the value added of knowing the environment and to identify the measure of effectiveness of METOC knowledge.

SUMMARY: (1) Mine Counter Measure Simulation System (MCM96) was obtained from COMMINWARCOM and installed in the NPS Secure Computing and Simulation Laboratory. The principal investigator visited the Coastal System Station at Panama City, Florida and built up a collaborative relationship between NPS and the Coastal System Station. (2) MCM96 was tested under different METOC conditions. The sensitivity of save currents in the Mine Sweeping on the METOC data (Electric Depth versus Actual Depth, wave height) was obtained. (3) The sensitivity study of the Navy's Research, Evaluation, and Systems Analysis (RESA) wargame was finished (theater level simulation) to the METOC environment. A quantitative analysis scheme (entropy) was established to estimate the value added of knowing the METOC data and to identify the measure of effectiveness of METOC knowledge. These results will be included in the thesis study by LCDR Eric. (4) RESA was implemented for the Korea Peninsula region for several different weather scenarios representing various METOC conditions: wave height, wave direction, wind speed, wind direction, cloud cover, visibility, etc. The NPS Wargaming Lab used the weather scenario for the instruction purpose. (5) The Army's Post-Engagement Ground Effects Model (PEGEM) was installed and tested into the NOAP Lab. (6) A joint research effort was established on METOC information in mine warfare with SACLANT Undersea Research Center at La Spezia, Italy.

The primary results of this project have transferred to NAVO and NPS Wargaming Lab as a training tool to increase the sensitivity of modeling and simulation to environmental effects. Military personnel serving as NPS graduate students already studied these results through class work and thesis research. Furthermore, the results of the project were also used by NAVO to initiate a new mine warfare program.

CONFERENCE PRESENTATIONS:

Chu, P.C., Gottshall, E., and Halwachs, T., "Environmental Effects on Mine Counter Measures," 65th Military Operations Research Society Symposium, Quantico, VA, 10-12 June 1997.

Chu, P.C., "Importance of METOC Information in Military Operations," 65th Military Operations Research Society Symposium, Marine Corps Combat Development Command, Quantico, VA, 10-12 June 1997.

THESIS DIRECTED:

Jimenez, G., "Diurnal Variation over the Tropical Monsoon Regions During Northern Summer," Master's Thesis, Naval Postgraduate School, March 1997.

DoD TECHNOLOGY AREAS: Battlespace Environments, Environmental Quality

KEYWORDS: P-Vector, Geostrophic Velocity, Beta-Spiral, Inverse Method, Primitive Equation Model, Turbulence Closure

LITTORAL ZONE NAVAL OCEAN PREDICTION SYSTEMS

Peter C. Chu, Associate Professor
Department of Oceanography
Sponsor: Naval Oceanographic Office

OBJECTIVE: The main objectives of this project are to develop a parametric model for regional sea T, S data analysis, to quantitatively determine temporal and spatial thermohaline variability, and to establish a diagnostic model for the regional seas, e.g., the South China Sea, the Japan Sea, and the Yellow Sea.

SUMMARY: During the current year the following studies were completed: (1) The South China Sea thermohaline variability has been identified from the Navy's Master Oceanographic Observational Data Set (MOODS) by analyzing more than 230,000 T, S profiles., a new phenomenon of the South China Sea warm pool. (2) The numerical simulation greatly enhances the understanding of the J Sea thermohaline variability and circulation. The model established in this project can be used widely for the other regional seas. (3) The P-vector method was validated. (4) The S-Transform was validated. (5) New difference schemes have been developed for littoral prediction systems.

PUBLICATIONS:

Cai, W.J. and Chu, P.C., "Effects of Convective Instability Due to Incompatibility Between Ocean Dynamics and Surface Forcing," *Annals Geophysicae,* 15, 1,067-1,075, 1997.

Chu, P.C., Wells, S.K., Haeger, S.D., Szczechowski, C., and Carron, M., "Temporal and Spatial Scales of the Yellow Sea Thermal Variability," *Journal of Geophysical Research,* 102, 5655-5668, 1997.

Chu, P.C., Fralick, C.R., Haeger, S.D., and Carron, M.J., "A Parametric Model for Yellow Sea Thermal Variability," *Journal of Geophysical Research,* 102, 10499-10508, 1997.

Chu, P.C., Fan, C.W., and Ehret, L.L., "Determination of Open Boundary Conditions from Interior Observational Data," *Journal of Meteorological and Oceanic Technology,* 14, 723-734, 1997.

Chu, P.C. and Chang, C.P., "South China Sea Warm Pool," *Advances in Atmospheric Sciences,* 14, 195-206, 1997.

Chu, P.C., Tseng, H.C., Chang, C.P., and Chen, J.M., "South China Sea Warm Pool Detected from the Navy's Master Oceanographic Observational Data Set (MOODS)," *Journal of Geophysical Research,* 102, 15761-15771, 1997.

Chu, P.C. and Fan, C.W., "Sixth-Order Difference Scheme for Sigma Coordinate Ocean Models," *Journal of Physical Oceanography,* 27, 2064-2071, 1997.

Chu, P.C., Lu, S.H., and Chen, Y., "Temporal and Spatial Variabilities of the South China Sea Surface Temperature Anomaly," *Journal of Geophysical Research,* 1997, 102, 20937-20955.

Chu, P.C., Chen, Y.C., and Lu, S.H., "On Haney-Type Surface Thermal Boundary Conditions for Ocean Circulation Models," *Journal of Physical Oceanography,* 1997, in press.

Chu, P.C., Fan, C.W., and Cai, W.J., "Evaluation of P Vector Method Using Modular Ocean Model (MOM)," *Journal of Oceanography,* 1997, in press.

CONFERENCE PRESENTATIONS:

Chu, P.C., Gottshall, E., and Halwachs, T., "Environmental Effects on Mine Counter Measure," 65th Military Operations Research Society Symposium, Quantico, VA, 10-12 June 1997.

Chu, P.C. and Fan, C.W., "High-Order Coastal Ocean Modeling," Fifth International Conference on Estuarine and Coastal Modeling, Alexandria, VA, 22-24 October 1997.

Chu, P.C., "A Quick Assessment System for Coastal Environments," U.S.-U.K. Naval IEP B-6 Ocean Modeling Workshop, DERA Hasler, Gosport, U.K., 28-29 October 1997.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Ocean Prediction, Littoral Zone, Thermohaline Variability, Parametric Model, Statistical Model

GLOBAL POSITIONING SYSTEM (GPS) ANTARCTIC LANDING SYSTEM: LANDING SYSTEMS COMMITTEE STUDIES

James R. Clynch, Research Professor
Department of Oceanography
Sponsor: NISE-East

OBJECTIVE: The aircraft landing system at the U.S. bases in Antarctica must be replaced in the next few years. GPS is the primary candidate system for use in this remote site. There are several special features about the local environment in polar latitudes that must be studied and validated before flight safety can be assured.

SUMMARY: The technical capability of a differential GPS system to meet the landing requirements in Antarctic has been demonstrated in an ongoing effort over five years. During 1997 the effort focused on following the FAA specification development process for the Local Area Augmentation System (LAAS) and assisting in the transition from Navy to Air Force air operations in Antarctica. The desire to have a landing capability beyond Category I has shifted focus from a Special Category I (SCAT I) system to LAAS. During the year Dr. Clynch attended two RTCA committee meeting on GPS landing system, met with the Air Force office in Boston, and participated in three meeting at Charleston SC. He also attended two GPS technical meetings to stay abreast of the civilian technology. He made site visits to two vendors.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Electronics, Sensors

KEYWORDS: GPS Aircraft Landing Systems

FUNDAMENTALS OF MAPPING, CHARTING, AND GEODESY (MC+G) REPORT

James R. Clynch, Research Professor
Department of Oceanography
Sponsor: National Imagery and Mapping Agency

OBJECTIVE: The objective is to update the NIMA (formally DMA) document "Geodesy for the Layman." This document was last revised in 1983. The advances in satellite geodesy and other fields need to be included.

SUMMARY: The document, "Geodesy for the Layman," DMA TR 80-003 has been used as an introduction to geodesy for many military and civilian workers at NIMA. First produced in 1957, this document needs to be updated to better serve its projected audience. It has also been widely used by civilians, especially by DoD contractors.

During 1997, the update of this document began with a user survey. This involved discussions with members of all three services, the Coast Guard, and DoD agencies. Persons at levels from Lieutenant to Captain (USN) who had or were currently having an interaction with this subject were contacted. People in the both the operations and education/training areas were included.

Based on these inputs, it was decided to produce a fairly extensive rework of this document. It needs to have both a lower level set of discussions for some and a more detailed mathematical summary for others. It was decided to add a more extensive introduction for the first and a set of appendixes for the latter.

In addition to the changes in the substance of this document, it was desired to publish the update on the world wide web. Investigations into how to publish a document with substantial mathematical content were undertaken. It was decided that a PDF version was necessary.

Significant work on the update itself took place during 1997, especially in the area of the appendices. It is anticipated that this project will be completed in early 1998.

DoD KEY TECHNOLOGY AREAS: Manpower, Personnel and Training, Battlespace Environments

KEYWORDS: Geodesy, Mapping

GLOBAL POSITIONING SYSTEM (GPS) SHIP REFERENCE SYSTEM

James R. Clynch, Research Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The objective of this project is to design and validate a GPS system to be used as a Differential GPS (DGPS) reference station on a ship at sea.

SUMMARY: This project is to establish the techniques necessary to achieve a 2 m or better absolute position on a ship using precise positioning system GPS receivers and other sensors. It is anticipated that the receivers will have to be run from atomic clocks and that an inertial system may be required. Once the system has been initialized, the position should be held to sub-meter accuracy. That is, the 2-meter level initialization errors will be biases in the operational position.

During 1997 the data from a 1996 at-sea experiment were analyzed. A second at-sea experiment was performed with all the elements of the proposed system. The results of the 1996 sea test were reported at the ION GPS-97 conference.

The PT SUR-96 experiment utilized simple 4 channel, single frequency military receivers (PLGRs). From this test, it was established that: (1) multipath errors will be significantly reduced for ships underway due to the ships motion moving the antenna through different multipath orientations and (2) the broadcast ephemeris error will be the principal error to be averaged down.

The PT SUR-97 experiment included three dual frequency PPS receivers, two single frequency PPS receiver, three civilian dual frequency receivers, and three attitude systems. The results of this test are under study.

PUBLICATION:

Clynch, J.R., "One Meter Positioning on a Ship with PLGR," *Proceedings of the ION GPS-97*, p. 973, Kansas City, MO, 16-17 September 1997.

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: Global Positioning System, GPS, Differential GPS

QUASI-LAGRANGIAN MEASUREMENTS OF THE CALIFORNIA UNDERCURRENT

Curtis A. Collins, Professor
Newell Garfield, Research Assistant Professor
Department of Oceanography
Sponsor: Office of Naval Research and Naval Postgraduate School

OBJECTIVE: To analyze and report the results from 26 neutrally buoyant RAFOS Lagragian drifters which were launched in the eastern Pacific to investigate the flow of the California Undercurrent. Nine of these floats were entrained in the undercurrent, three exhibited flow reversal along the continental margin and the rest were entrained in subsurface anti-

cyclonic eddies. The second year will be used to analyze current meter data from the Eastern Boundary Current Accelerated Research Initiative offshore site.

DoD KEY TECHNOLOGY AREAS: Sensors, Other (Environmental Effects)

KEYWORDS: California Current System, Subsurface Ocean Circulation, Lagragian Statistics, Eastern Boundary Currents, Mesoscale Ocean Variability

DEVELOPMENT OF LITTORAL CURRENT DATA BASE IN THE ADRIATIC SEA

Curtis A. Collins, Professor
Pierre-Marie Poulain, Assistant Professor
Department of Oceanography
Sponsor: Naval Oceanographic Office

OBJECTIVE: The main objective of this project is to develop digital layers of information about currents in the Adriatic Sea that will be tactically useful for Mine Warfare (MIW) planning and operations.

SUMMARY: Various data sets on currents in the Adriatic Sea were acquired, assessed, deconflicted, analyzed, and interpreted in view of their inclusion into a common data base. These data sets comprise moored current meter data, shipboard and moored acoustic Doppler current profiler (ADCP) data, surface drifter and sub-surface float measurements. Useful statistics and summaries obtained from the acquired data and from ancillary information extracted from the literature were presented in the form of digital layers. The layers contain either provinced, point, or gridded information. The information presented in the layers include the forcing mechanisms, the current speed histograms, the peak tidal currents, the long-term drifts, the local current conditions, and related text and references.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Ocean Currents, Adriatic Sea, Database

UPPER OCEAN CIRCULATION IN THE ADRIATIC SEA

Curtis A. Collins, Professor
Pierre-Marie Poulain, Assistant Professor
Department of Oceanography
Sponsor: Naval Oceanographic Office

OBJECTIVE: The main objective of this project is to analyze current observations in the Adriatic Sea collected by the Naval Oceanographic Office (NAVO) in 1993 and by the SACLANT Undersea Research Centre in 1994-1995. The goal is to describe the spatial structure and the temporal variability of the near-surface and intermediate-depth (300 m) currents and gain insights on the Adriatic basin dynamics.

SUMMARY: Current measurements using a ship-board Acoustic Doppler Current Profiler (ADCP) operated during various hydrographic surveys mostly conducted in the southern Adriatic and the Straits of Otranto areas were made available for the following time periods: January, February, November and December 1993, and December 1994, May and August 1995.

The raw ADCP data were processed using the CODAS3 software and a variety of graphical representations of the calibrated and edited current data were produced. The results reveal a significant intensification of the currents in the coastal and continental margin areas.

Tidal current analysis was conducted using a least-squares regression technique. The results indicate limited tidal currents with a maximum magnitude reaching 5 cm/s in the southwestern Adriatic for the M2 component. The ADCP observa-

tions were compared to other ocean current observations (i.e., from moored ADCP's and from surface drifters) and to contemporaneous satellite sea surface temperature images. There is a good qualitative agreement between all the observations.

THESIS DIRECTED:

Brauns, B.A., "Adriatic Sea Current Observations Using Acoustic Doppler Current Profiler (ADCP) Measurements," Master's Thesis, Naval Postgraduate School, September 1997.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Ocean Currents, Adriatic Sea, Straits of Otranto

LONG-TERM MONITORING OF CIRCULATION AND SEDIMENT-TRANSPORT PATTERNS NEAR THE SAN FRANCISCO DEEP-OCEAN DISPOSAL SITE

Curtis A. Collins, Professor
Department of Oceanography
Sponsor: Environmental Protection Agency

OBJECTIVE: The Environmental Protection Agency (EPA) has designated a deep-water site on the continental slope off San Francisco as a disposal site for dredge material from the greater San Francisco Bay. This was the first deep-ocean disposal site in the nation and involves a program of long-term monitoring of the site. Moorings to measure the movement of water and resuspended material near the disposal site will be made during the period November 1997 to November 1998.

SUMMARY: Moorings were deployed at three locations at and near the deep ocean disposal site on 11-12 November 1997 from the R/V *Point Sur*. Moorings included upward looking acoustic Doppler current meters at 100 m depth and standard current meters at 225, 400, 800, 2000 m, and 50 m above the bottom. Sediment traps were included at mid-depth (200 and 395 m) and near bottom. A near-bottom package consisting of vector-averaging current meters, temperature gradient measurements, and a transmissometer was included. The moorings are scheduled for recovery in November 1998. This is a joint project with the Dr. Marlene Noble, U.S. Geological Survey.

DoD Key Technology Area: Environmental Quality

KEYWORDS: Ocean Currents, Sediment Transport, Deep-Ocean Disposal

MESOSCALE VARIABILITY OF THE CALIFORNIA CURRENT

Curtis A. Collins, Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: This project was part of the Eastern Boundary Current (EBC) Accelerated Research Initiative (ARI). It extended the two-year time series of upper ocean current measurements at 37°-06.7'N, 127°-32.1'W from August 1994 to August 1996. The specific objective of these measurements was to resolve seasonal and mesoscale variability of ocean currents at this location. Since the location coincides with a TOPEX/Poseidon cross over, the temporal variability of observed velocity can be compared to that obtained from observations of the variability of the slope of the ocean's surface.

SUMMARY: Current meters were recovered on 27 August 1996. They were subsequently re-calibrated and the data processed. Data was provided to other EBC investigators and incorporated into analyses and comparisons of nearshore, slope, and offshore currents.

Current measurements at 50 m extended only to February 1995, when the rotor became fouled by biological growth. At the other three depths, there was a high degree of coherence between the observations. Although the flow was less energetic than that measured during the previous two years, the strongest flow (~ 1 knot) appeared as a pulse of southward flow in January 1995, and resembled eddies observed at this site in April-May and November 1993. The spectrum of the 4-year record has a distinct peak at 100-days, a somewhat longer period than the 60-day motion which dominated the inshore locations.

RAFOS float measurements at intermediate depths (150-600 m) over the continental margin revealed a region of varying width of subsurface, poleward flow adjacent to the continental margin. The trajectories exhibited three patterns: poleward flow in the undercurrent, reversing, but predominately alongshore, flow adjacent to the continental margin, and farther offshore, anticyclonic motion accompanied by slow westward drift. Flow continuity of the undercurrent exists between Pt. Reyes and at least Cape Mendocino with an average speed dependent upon the float depth. Speeds were variable but common features were acceleration occurring to the south of Pt. Arena and deceleration to the north of Cape Mendocino. An important mechanism for floats, and water, to leave the undercurrent and enter the ocean interior is through the formation of submesoscale coherent vortices. Single particle statistics provide zonal and meridional eddy diffusivity estimates of 1970 and 1830 m^2/s.

PUBLICATIONS:

Ramp, S.R., McClean, J.L., Collins, C.A., Semtner, A.J., and Hays, K.A.S., "Observations and Modeling of the 1991-1992 El Niño Signal off Central California," *Journal of Geophysical Research,* 102: pp. 5553-5582, 1997.

THESIS DIRECTED:

Steger, J. M., "Use of Ship-Mounted Acoustic Doppler Current Profiler Data to Study Mesoscale Oceanic Circulation Patterns in the Archipelago de Colon and the Gulf of the Farallones," Doctor of Philosophy Dissertation, Naval Postgraduate School, June 1997.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Ocean Currents, Tides, Mesoscale Eddies

POLAR SEA CONVECTIVE INSTABILITIES

Roland W. Garwood, Jr., Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: The major scientific objective of this new four-year study is to understand the coupled ocean mixed layer-ice system response to the passage of atmospheric storms. The most intense surface cooling and wind stresses in the Arctic are associated with these storms, and their long-term accumulative effects on the heat and water budgets for the Arctic Ocean cannot be predicted without including: (1) realistic mixed layer physics; (2) ice thermodynamics; and (3) three-dimensional wind-driven ocean circulation. This proposed work builds on the previous project, "Enhancements to Deep Oceanic Convection in the Arctic System," in which the possibility of two kinds of oceanic conditional instabilities were demonstrated. These convection processes, termed "parcel" and "layer" instabilities may lead to significant deep oceanic convection and possible formation of bottom water. The initial energy source to trigger these instabilities may be provided by transient atmospheric forcing. Strong local cooling and wind stress may lead to parcel-type instabilities, and large-scale wind forcing is hypothesized to lead potentially to layer-type instabilities by a combination of mixed-layer upwelling, enhanced vertical turbulent mixing, and downwelling that will occur in response to the passage of atmospheric cyclones and anticyclones.

The principal method for the proposed research includes development and application of a hierarchy of numerical models, with a major milestone being the three-dimensional simulation of the upper ocean (temperature, salinity, circulation, and ice) response to passage of atmospheric storms. This numerical model will consist of an existing ocean primitive

equation model with embedded turbulence-closure mixed layer and an ice model with realistic thermodynamics and mechanical properties. The embedded mixed layer will include the previously-neglected physics to predict the onset of conditional instabilities and possible formation of deep water.

SUMMARY: The realistic prediction of deep convection is necessary to understand the start of the global conveyor belt and the role of the oceans in climate change. A major deficiency in earlier ocean models has been the lack of adequate convection physics to realistically predict the correct temperature and salinity properties for the convectively-produced deeper water masses. During the first year of this modeling program, the inclusion of realistic storm forcing in the simulation of ocean convection will directly tie atmospheric forcing and ice thermodynamics to mixed layer dynamics and the start of the global conveyor belt in the Greenland-Iceland Seas. The results are leading to more realistic parameterization of subgrid convection of heat, mass, momentum, nutrients, and tracers in basin and global oceanic models.

CONFERENCE PRESENTATIONS:

Garwood, R.W., Jr., "Simulating the Response of Drifters to Polar Sea Convection," University of Washington Applied Physics Laboratory, Seattle, WA, 9 September 1997.

Garwood, R.W., Jr., Jiang, L., and Harcourt, R., "Simulation of Motion of Drifting Buoys, Organisms, and Tracers in the Polar Sea Mixed Layer," Arctic System Science OAII Workshop, Norfolk, VA, May 1997.

THESES DIRECTED:
Stone, R.E., "Deep Mixed Layer Entrainment," Master's Thesis, Naval Postgraduate School, March 1997.

Tramm, E.P., "A Study of the Surface Heat Budget of the Weddell Sea Using a Radiative Transfer Model During the Austral Winter 1994," Master's Thesis, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Environmental Quality, Modeling and Simulation

KEYWORDS: Ocean Turbulence, Air-Sea Interaction, Ocean Mixed Layer

SIMULATION OF LAGRANGIAN DRIFTERS IN THE LABRADOR SEA

Roland W. Garwood, Jr., Professor
Department of Oceanography
Sponsor: Office of Naval Research and Naval Postgraduate School

OBJECTIVE: The purpose of this study is to understand the motion and sensor response of drifting packages of scientific instruments in the Office of Naval Research's Accelerated Research Initiative (ONR-ARI) on Deep Oceanic Convection in the Labrador Sea. A key scientific objective is to understand the turbulent kinetic energy budget for free and forced deep oceanic convection. A primary method in developing an understanding of deep oceanic convection is by large-eddy simulation (LES), using a nonhydrostatic numerical model for geophysical turbulent flows.

SUMMARY: LES has been used to show that isobaric (Rossby-type) drifters will sense mean fields for temperature and velocity that will be biased by the tendency for the fixed-depth drifters to seek out and maintain position in zones of horizontal convergence. This result is very important for: (1) suggesting strategies for drifter deployment and (2) understanding the results from the ONR-ARI on deep convection that is presently occurring (winter 1997). An important corollary result is that the isobaric float-observed fluxes may be corrected by a predictable structure function, calculated by large-eddy simulation. These results have direct implications for the conduct of mine warfare and mine warfare countermeasures.

PUBLICATIONS:

Garwood, R.W., Jr. and Harcourt, R.R., "The Oceanic Planetary Boundary Layer in the Polar Seas," *Workshop on Polar Processes in Global Climate, American Meteorological Society*, 4.2, 4 pp., Cancun, Mexico, 13-15 November 1996, 1997.

Jiang, L. and Garwood, R.W., Jr., "Effects of Topographic Steering and Ambient Stratification on Overflows on Continental Slopes: A Model Study," *Journal of Geophysical Research,* 18 pp., in press, December 1997.

CONFERENCE PRESENTATIONS:

Garwood, R.W., Jr., "Large-Eddy Simulation of the Response of Drifter/Sensor Bodies to Ocean Turbulence," U.S.-U.K. Ocean Modeling Workshop, DERA Haslar, Gosport, UK, 28-29 October 1997.

Garwood, R.W., Jr., "Simulating the Response of Drifters to Polar Sea Convection," University of Washington Applied Physics Laboratory, Seattle, WA, 9 September 1997.

Garwood, R., W. Jr., "Organized Structure of the Ocean Surface Turbulent Boundary Layer and the Implications for Air-Sea Interactions," Naval Research Lab Workshop on Ocean-Atmosphere Coupling, Monterey, CA, July 1997.
technical report:

Harcourt, R., Jiang, L., and Garwood, R.W., Jr., "Numerical Simulation of Drifter Response to Labrador Sea Convection," prepared for the Office of Naval Research, Code 322OM, 70 pp., June 1997.

THESIS DIRECTED:

Bramson, L.S., "Air-Sea Interactions and Deep Convection in the Labrador Sea," Master's Thesis, Naval Postgraduate School, December 1997.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Environmental Quality, Sensors, Surface/Under Surface Vehicles – Ships and Watercraft, Modeling and Simulation

KEYWORDS: Ocean Turbulence, Air-Sea Interaction, Ocean Mixed Layer

TROPICAL OCEAN MIXED LAYER SYSTEM

Roland W. Garwood, Jr., Professor
Arlene A. Guest, Oceanographer
Department of Oceanography
Sponsors: National Oceanic and Atmospheric Administration and National Science Foundation

OBJECTIVE: The scientific objective of this three-year study is to understand the response of the tropical and equatorial ocean turbulent boundary layer system to unsteady atmospheric forcing on time scales from diurnal to annual. Numerical models are developed for and/or applied to tropical turbulent boundary layer and air-sea interaction problems. A principal goal is the verification and improvement of a generalized mixed layer/entrainment zone parameterization in Ocean Global Circulation Models (OGCM) that is physically consistent and globally valid. For this study, the surface layer mixing parameterization is used to explain the transition from the eastern and central Pacific mixed layer system to that of the western region, realistically responding to differences in local (wind and buoyancy flux) and advective (upwelling and zonal pressure gradient) forcing regimes.

SUMMARY: As part of the international Tropical Oceans Global Atmosphere Coupled Ocean Atmosphere Response Experiment (TOGA COARE), a hierarchy of numerical models was used to simulate and better understand the tropical ocean

mixed layer system. In the third year of this multi-year study, progress has been made in understanding the importance of time and space resolution in representing mixed layer physics (Hone, 1997). Also, the importance of transient forcing for mixed-layer entrainment has been demonstrated with regards to biological productivity (Dusek, 1997). In the final phase of the project, two related studies are underway: (1) large-eddy simulation (LES) of temperature and salinity microstructure in the western Pacific warm pool and (2) use of the coupled ocean general circulation model with embedded mixed layer (OGCM/ML) to understand the interaction between large-scale 3-D circulation and mixed layer dynamics. The LES model has been used to simulate the equatorial turbulent boundary region and contrast the turbulence statistics with those derived from mid-latitude simulations. Langmuir-like wind-driven circulation has been shown to develop for mid-latitude cases. The LES model also predicts the fine-scale structure or microstructure associated with both time-varying surface forcing associated with wind bursts and heavy precipitation events. Extensive development of OGCM/ML, the embedded ocean general circulation-mixed layer model has been done. The improvement in the horizontal friction formulation from Laplacian to biharmonic has allowed much more realistic representation of mesoscale waves and eddies which modulate the entrainment zone activity, with the entrainment zone mixing depending on the shear enhancement or reduction attributable to the mesoscale motion. The simulations with new entrainment zone parameterization improve the representation of sea surface temperature and the vertical distribution of heat. It was also found that large-basin (20S - 20N, 140E - 110W), 25 km grid resolution simulations are necessary for both realistic mesoscale circulation and undercurrent evolution, especially when using real surface forcing data, and that the diurnal cycle in heat flux needs to be included for realistic vertical transport of heat and momentum.

CONFERENCE PRESENTATION:

Garwood, R.W., Jr., "Organized Structure of the Ocean Surface Turbulent Boundary Layer and the Implications for Air-Sea Interactions," Naval Research Lab Workshop on Ocean-Atmosphere Coupling, Monterey, CA, July 1997.

THESES DIRECTED:

Hone, D.M., "Time and Space Resolution and Mixed Layer Accuracy," Master's Thesis, Naval Postgraduate School, March 1997.

Dusek, D.P., "Ocean Mixed Layer Biological Response to Transient Ocean Events," Master's Thesis, Naval Postgraduate School, September 1997.

OTHER: The "NPS Mixed Layer Model" code has been requested and distributed to a variety of international researchers (FORTRAN package of subroutines).

DoD KEY TECHNOLOGY AREAS: Computing and Software, Environmental Quality, Modeling and Simulation

KEYWORDS: Ocean Turbulence, Air-Sea Interaction, Ocean Mixed Layer

INNER SHELF AND NEARSHORE WAVE TRANSFORMATION

Thomas H.C. Herbers, Associate Professor
Department of Oceanography
Sponsors: Office of Naval Research and Naval Postgraduate School

OBJECTIVE: The main objective of this project is to predict accurately the evolution of surface waves from deep water across the continental shelf to the beach.

SUMMARY: This continuing project is focussed on the effects of nonlinear wave-wave interactions and wave breaking on the evolution of wind-wave spectra across the inner continental shelf. A new theoretical model is under development that incorporates the effects of a gently sloping bottom and nonlinear interactions. A directional buoy and an array of nine

bottom pressure recorders were deployed on the inner shelf offshore of Duck, NC, during the SandyDuck experiment, to test predictions of nonlinear interactions and estimate energy dissipation rates.

PUBLICATIONS:

Feddersen, F., Guza, R.T., Elgar, S., and Herbers, T.H.C., "Longshore Momentum Balances in the Nearshore," *Journal of Geophysical Research,* accepted with minor revisions.

Herbers, T.H.C., Elgar, S., and Guza, R.T., "Directional Spreading of Waves in the Nearshore," submitted to *Journal of Geophysical Research.*

Lentz, S.J., Herbers, T.H.C., Guza, R.T., Feddersen, F., and Elgar, S., "Momentum Balances on the North Carolina Inner Shelf," to be submitted to *Journal of Geophysical Research.*

DoD KEY TECHNOLOGY AREA: Other (Environmental Effect)

KEYWORDS: Ocean Surface Waves, Nonlinear Interactions, Continental Shelf

WAVE EVOLUTION ON THE CONTINENTAL SHELF

Thomas H.C. Herbers, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The main objective of this project is to evaluate the energy balance of wind-generated waves in shallow water.

SUMMARY: In this new project the spectral energy balance of wind waves on the continental shelf will be evaluated with a field experiment scheduled to take place off Duck, NC, in the fall of 1999. Preparations are underway for the deployment of a coherent array of 5 internal recording bottom pressure sensors and 5 directional wave buoys in depths ranging from 20-40 m. The measurements will be used to verify theoretical predictions of nonlinear spectral energy transfers and estimate wave energy losses resulting from bottom friction and whitecaps.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effect)

KEYWORDS: Ocean Surface Waves, Nonlinear Interactions, Wave Breaking, Bottom Friction, Continental Shelf

PROPAGATION OF SURFACE WAVES ACROSS THE CONTINENTAL SHELF

Thomas H.C. Herbers, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The overall objective of this project is to evaluate and improve model predictions of the evolution of swell propagating across a continental shelf.

SUMMARY: The propagation of surface gravity waves over a wide, shallow continental shelf was investigated with data collected in the DUCK94 Nearshore Field Experiment. Four-month-long seafloor pressure records were obtained with a cross-shore array of 20 bottom-mounted and moored pressure sensors extending from the shoreline to the shelf break (87 m depth, 100 km from shore). The measurements span a wide range of conditions including several nor'easters, very energetic swells from Hurricane Gordon (maximum significant wave height 8 m), and periods of extremely low wave energy (minimum significant wave height 0.2 m). When swell energy levels were low or moderate, the swell energy varied weakly

across the shelf, consistent with predictions of a linear propagation model. During high-energy conditions, strong attenuation of swell energy levels across the shelf was observed that is likely caused by bottom friction.

OTHER:

Herbers, T.H.C., Hendrickson, E.J., and O'Reilly, W.C., "Propagation of Swell Across a Wide Continental Shelf," manuscript in preparation.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effect)

KEYWORDS: Ocean Surface Waves, Continental Shelf, Swell

NEARSHORE WAVE PROCESSES

Thomas H.C. Herbers, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The main objective of this project is to develop a better understanding of the nonlinear transformation of waves shoaling on beaches.

SUMMARY: As ocean surface waves propagate from deep to shallow water, nonlinear wave-wave interactions transfer energy to phase-coupled harmonics, causing the characteristic steep, pitched-forward wave crests on beaches. A stochastic shoaling model for directionally spread wind waves propagating over a gently sloping beach with straight and parallel depth contours was developed based on weakly dispersive Boussinesq theory. A one-dimensional version of this model was validated with field data. Extensive measurements of the evolution of directional wave spectra across a natural beach were collected in the fall of 1997 during the SandyDuck Experiment.

PUBLICATIONS:

Herbers, T.H.C. and Burton, M.C., "Nonlinear Shoaling of Directionally Spread Waves on a Beach," *Journal of Geophysical Research,* 102, 21101-21114, 1997.

Lippmann, T.C., Herbers, T.H.C., and Thornton, E.B., "Gravity and Shear Wave Contributions to Nearshore Infragravity Motions," *Journal of Physical Oceanography*, accepted with minor revisions.

Norheim, C.A., Herbers, T.H.C., and Elgar, S., "Nonlinear Evolution of Surface Wave Spectra on a Beach," *Journal of Physical Oceanography,* in press.

CONFERENCE PRESENTATION:

Herbers, T.H.C., Norheim, C.A., Burton, M.C., Elgar, S., and Guza, R.T., "A Stochastic Model for Shoaling Waves," Waves in Shallow Water Environments Meeting, San Francisco, CA April 1997.

THESIS DIRECTED:

Norheim, C.A., "A Stochastic Model for Shoaling Waves," Master's Thesis, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Ocean Surface Waves, Nearshore Processes, Surf Zone

NONLINEAR INTERACTIONS IN OCEAN SURFACE WAVES

Thomas H.C. Herbers, Associate Professor
Department of Oceanography
Sponsor: Washington State University

OBJECTIVE: The main objective of this continuing project is to evaluate the importance of nonlinear interactions in naturally occurring ocean surface waves.

SUMMARY: Although sophisticated nonlinear theories for ocean surface waves were developed more than 30 years ago, a detailed verification with field observations has not been reported. In this continuing project extensive ocean wave data sets are compared to nonlinear theory predictions. At about three times the frequency of the dominant wind waves, tertiary waves forced by nonlinear interactions between three wind-wave components are important. Trispectral analysis of data collected during a severe nor'easter (the significant wave height was about 5 m) indicates significant tertiary wave contributions to the bottom pressure field.

PUBLICATION:

Elgar, S., Guza, R.T., Raubenheimer, B., Herbers, T.H.C., and Gallagher, E., "Spectral Evolution of Shoaling and Breaking Waves on a Barred Beach," *Journal of Geophysical Research*, 102, 15797-15805, 1997.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Ocean Surface Waves, Nonlinear Interactions, Sea Floor Pressure

MODELING THE RESPONSE OF MONTEREY BAY TO DIURNAL WIND AND TIDAL FORCING

Le Ngoc Ly, Research Associate Professor
Jeffrey D. Paduan, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: Research includes validation of the Monterey Bay (MOB) coastal ocean model developed by Professor Ly and Princeton ocean model (POM) against observed diurnal current variations in Monterey Bay. The more recent developed MOB model includes data processing routines, a grid generation routine, a grid-model coupling package, and visualization routines. Its curvilinear, coastline-following (coastline fitted) orthogonal and nearly-orthogonal, multi-block grid options represent a new advance in coastal ocean modeling. The MOB and POM models will be forced with diurnal winds and tidal sea level oscillations observed in MOB and compared against surface current observations from a network of high frequency (HF) radar sites along the coast.

SUMMARY: The MOB curvilinear nearly-orthogonal grid model (multi-block grid code version with 131X131X25 grid points) for a single-block grid has been newly initialized. The summer diurnal MOB observed and mesoscale model (NCAR MM5) winds has been analyzed. A new 3-D MOB temperature and salinity fields of all available observational data has been generated and used in the model. A map of seasonal CODAR surface current location has been generated for studying CODAR data applications to the MOB model. Several numerical experiments were carried out, with and without, CODAR surface current data to study horizontal and vertical propagation of the information contained in the data. The propagation of information of two surface current components from the various data sets with various temporal and spatial resolutions, the effect of data insertion intervals, and conversion of the dynamic evolution to the true ocean are being studied.

Extensive work have been done on the HF radar (CODAR) data for Monterey Bay to produce maps of surface current variability at diurnal and semidiurnal periods. The dataset is most completed for the period of August through December, 1994. A rotated Monterey Bay POM domain has been produced so that simulations of sea breeze and tidal forcing can be accomplished using the offshore and alongshore open boundary conditions.

PUBLICATIONS:

Benilov, A. Y. and Ly, L.N., "Dynamic Structure of the Upper Ocean Under Effects of the Surface Waves and their Breaking," *Physics of Fluids,* 1997, in review.

Ly, L.N. and Luong P., "A Mathematical Coastal Ocean Circulation System with Breaking Waves and Numerical Grid Generation," *Applied Mathematical Modeling,* 10, 633-641, 1997.

Ly, L.N. and Luong P. "A Coastal Ocean Circulation System and Its Application to the South China Sea," *VACETS Technical Journal,* Vol. 2, 6-16, 1997.

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Ly, L.N., "A Numerical Study of Aerodynamic Roughness Lengths as Seen from Above and Below in Air-Sea Coupling," *Fluid Dynamics Research,* 1997, in press.

Ly, L.N and Luong P., "Numerical Multi-Block Grids in Coastal Ocean Modeling," *Computational Physics,* 1997, in review.

Ly, L. N. and Jiang, L., Horizontal Pressure Gradient Errors of the Monterey Bay Sigma Coordinated Ocean Model with Various Grids," *Journal of Geophysical. Research* 1997, in review.

Ly, L.N., "Modeling Wave-Enhanced Turbulence in the Upper Oceanic Layer," *Physics of Fluid,* 1997, submitted.

Ly, L.N., "Numerical Modeling of Turbulent Dissipation Rate Under Surface Breaking Waves," *The Royal Society Proceedings: Mathematical and Physical Sciences,* 1997, in review.

CONFERENCE PRESENTATIONS:

Benilov, A. Yu., and Ly, L.N., "The Ocean Upper Layer with the Presence of the Surface Waves and Their Breaking," American Geophysical Union Spring Meeting, Transactions OS52A-10, Baltimore, MD, May 1997.

Ly, L.N., "Aerodynamic Roughness from Above and Below in Air-Sea Coupling," American Geophysical Union Fall Meeting, Transactions OS31A-9, San Francisco, CA, December 1997.

Ly, L.N. and Luong P., "On Numerical Grids Used in an Ocean Circulation Model with Breaking Wave Effects," Second Pan-American Workshop in Applied and Computational Mathematics, Brazil, September 1997.

Ly, L.N. and Luong P., "On Numerical Multi-Block Grids in Coastal Ocean Circulation Modeling," Fourth SIAM Conference on Mathematical and Computational Issues in the Geosciences, Albuquerque, NM, June 1997.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Other (Environmental Effects, Data and Software, New Technique)

KEYWORDS: Monterey Bay Response, Wind and Tide Forcing, Nowcast/Forecast Systems, Data-Model Combination, Coastal Ocean Modeling, Numerical Grid Generation, Data Assimilation, HF Radar Ocean Currents

INFLUENCES OF OCEAN SURFACE WAVES ON AIR-SEA SYSTEM

Le Ngoc Ly, Research Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The goal of this multi-year project which is expanded from the Office of Naval Research (ONR) sponsored project under the Marine Boundary Layer Program, "Effects of Ocean Surface Waves on Fluxes and Turbulence and Resulting Impacts on Coupling Modeling." The problem to be solved in this project is one aspect of air-wave-sea interaction modeling, which includes air-wave-sea model development of semi-empirical turbulence theory. The goal of this project is also to apply the developed models, theory to larger scale ocean and atmospheric models.

SUMMARY: In FY97 the focus was on improving recently developed Ly's (1995) air-wave-sea interaction model of semi-empirical turbulence theory by using new formulations of roughness lengths from above and below, and of surface wave parameterization through turbulent kinetic energy fluxes at the air-sea interface. The work in FY97 is also focused on validation of numerical model results by comparison to available datasets. Results of the study are published in a new series of publications.

PUBLICATIONS:

Benilov, A.Y. and Ly, L.N., "Dynamic Structure of the Upper Ocean under Effects of the Surface Waves and Their Breaking," *Physics of Fluids,* 1997, in review.

Ly, L.N. and Luong P., "A Mathematical Coastal Ocean Circulation System with Breaking Waves and Numerical Grid Generation," *Applied Mathematical Modeling,* 10, 633-641, 1997.

Ly, L.N. and Luong P. "A Coastal Ocean Circulation System and Its Application to the South China Sea," *VACETS Technical Journal,* Vol. 2, 6-16, 1997.

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Ly, L.N. and Jiang, L., "Horizontal Pressure Gradient Errors of the Monterey Bay Sigma Coordinated Ocean Model with Various Grids," *Journal of Geophysical Research,* 1997, in review.

Ly, L.N., "Modeling Wave-Enhanced Turbulence in the Upper Oceanic Layer," *Physics of Fluid,* 1997, submitted.

Ly, L.N., "Numerical Modeling of Turbulent Dissipation Rate Under Surface Breaking Waves," *The Royal Society Proceedings: Mathematical and Physical Sciences,* 1997, in review.

CONFERENCE PRESENTATIONS:

Benilov, A. Yu, and Ly, L.N., "The Ocean Upper Layer with the Presence of the Surface Waves and Their Breaking," American Geophysical Union Spring Meeting, Transactions OS52A-10, Baltimore, MD, May 1997.

Ly, L.N., "Aerodynamic Roughness from Above and Below in Air-Sea Coupling," American Geophysical Union Fall Meeting, Transactions OS31A-9, San Francisco, CA, December 1997.

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Ly, L.N. and Luong P., "On Numerical Multi-Block Grids in Coastal Ocean Circulation Modeling," Fourth SIAM Conference on Mathematical and Computational Issues in the Geosciences, Albuquerque, NM, June 1997.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects, Environmental Physics and Software, New Technique)

KEYWORDS: Ocean Wave Effect, Wave-Fluxes Relation Air-Wave-Sea Interaction Theory, Air-Wave-Sea Modeling, Wave-Turbulence Relation, Air-Sea Boundary Layers

MODELING THE LONG-TERM TURBULENT CIRCULATION OF THE ARCTIC OCEAN AND THE SEA ICE

Wieslaw Maslowski, Research Assistant Professor
Yuxia Zhang, Research Associate
Albert J. Semtner, Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: The main goal of this project is: (1) to develop an eddy resolving coupled Arctic ocean-ice model with proper connections to surrounding subpolar ocean environments and (2) to integrate the model for long enough time to determine the quasi-equilibrium turbulent circulation of the ice-covered Arctic Ocean as driven by multi-year observed atmospheric forcing using advanced parallel computers.

SUMMARY: This project started in October 1996 and it is a continuation of the earlier work supported by other sponsors. In this ongoing study a coupled ice-ocean model of the Arctic at resolution of 18 km and 30 levels was developed. The model will use increasingly high resolution in three dimensions and employ high-quality parameterizations of surface exchanges, ice dynamics, near-surface mixing, deep convection, and topographic interactions. Daily surface forcing has utilized re-analyzed datasets from forecast centers, and lateral exchanges with the subpolar North Atlantic and at Bering Strait will derive from comparably forced model of the remaining global ocean. An eddy-resolving simulation of 200 years has been completed and it will continue including implementation of a 9-km and 40 level grid. The equilibrium circulation with decadal variability is being analyzed to understand the physics of the Arctic Ocean and its sea-ice cover. Model results will continue to be analyzed and compared with the existing observations to evaluate the model and extend interpretation of the data. Significance of this research lies in better understanding of the Arctic Ocean as a physical system, enabling applications to biological, geochemical, and climate problems - and in practical predictive ability, clearly exceeding what is presently available.

PUBLICATIONS:

Dickson, R.R., Osborn, T.J., Hurrell, J.W., Meincke, J., Blindheim, J., Adlansvki, B., Vigne, T., Alekseev, G., Maslowski, W., and Cattle, H., "The Arctic Ocean Response to the North Atlantic Oscillation," *Proceedings of the Rosario Symposium on Polar Processes and Global Climate*, pp. 46-47, World Climate Research Program Office, Oslo, Norway,1997.

Hunke, E.C. and Zhang, Y., "A Comparison of Sea Ice Dynamics Models at High Resolution." *Monthly Weather Review*, 1997, submitted.

Hunke, E.C. and Zhang, Y., "Comparison of Elastic-Viscous-Plastic and Viscous-Plastic Dynamics Models Using a High Resolution Arctic Sea Ice Model," *Proceedings of the Rosario Symposium on Polar Processes and Global Climate,* pp. 97-99, World Climate Research Program Office, Oslo, Norway, 1997.

Newton, R., Maslowski, W., and Schlosser, P., "Freshwater Distribution in the Arctic: Comparing a High Resolution Model with Observations," *Proceedings of the Rosario Symposium on Polar Processes and Global Climate.* p. 175,World Climate Research Program Office, Oslo, Norway, 1997.

Maslowski, W., Parsons, A.R., Zhang, Y., and Semtner, A. J., "High Resolution Arctic Ocean and Sea Ice Simulations: Ocean Model Design and Early Results," *Journal of Geophysical Research,* submitted.

Maslowski, W., "Advanced Modeling of the Arctic Ocean and Sea Ice in Support of Global Climate Studies," *Proceedings of the Global Change Workshop on Polar Processes,* ed: D. Martinson, pp. 93-96, American Meteorology Society, Boston, MA, 1997.

Maslowski, W., Zhang, Y., and Semtner, A., "Modeling Freshwater Sources, Their Distribution, and Sinks in the Arctic Ocean," *Proceedings of Rosario Symposium on Polar Processes and Global Climate,* pp. 159-161, World Climate Research Program Office, Oslo, Norway, 1997.

Maslowski, W., Zhang, Y., and Semtner, A.J., "Coupled Modeling to Improve Understanding of the Arctic Ocean and its Sea Ice," *Arctic System Science Ocean-Atmosphere-Ice Interactions All Hands Meeting and Planning Workshop,* p.48, eds: Codispoti, L.A., Grebmeir, J.M., and Ayers, L.A., ARCSS/OAII Report Number 6, Old Dominion University, Norfolk, VA, 1997.

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Schlosser, P., R. Bayer, G. Bonisch, B. Ekwurzel, M. Frank, S. Khatiwala, W. Maslowski, R. Newton, and W.M. Smethie, Jr., "New Insights into the Circulation and Freshwater Balance of the Arctic Ocean Derived from Multi-tracer Data Sets," *Proceedings of the Rosario Symposium on Polar Processes and Global Climate,* p.239, World Climate Research Program Office, Oslo, Norway, 1997.

Semtner, A.J., "Global Ocean and Polar Regions: A Modeling Perspective," *Proceedings of the Global Change Workshop on Polar Processes,* pp. 56-61, D. Martinson, (ed.), American Meteorology Society, Boston, MA., 1997.

Semtner, A.J., "Modeling Ocean Climate Variability with Emphasis on Polar Processes," *Proceedings of the Rosario Symposium on Polar Processes and Global Climate,* pp.64-66, World Climate Research Program Office, Oslo, Norway, 1997.

Zhang, Y., Maslowski, W., and Semtner, A. J., "High Resolution Arctic Ocean and Sea Ice Simulations: Ice Model Design and Early Results," 1997, provisionally accepted.

Zhang, Y., Maslowski, W., and Semtner, A., "Sea Ice Transport and Production, and Their Impact on Heat Flux in a High Resolution Arctic Ice-Ocean Model," *Arctic System Science Ocean-Atmosphere-Ice Interactions All Hands Meeting and Planning Workshop,* p. 68, Codispoti, L.A., Grebmeir, J.M., and Ayers, L.A. (eds.), ARCSS/OAII Report Number 6, Old Dominion University, Norfolk, VA, 1997.

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Zhang, Y. and Hunke, C., "Recent Change of Arctic Sea Ice in a High Resolution Ice-Ocean Model Forced with 1979-93 ECMWF Reanalysis," *Proceedings of the Rosario Symposium on Polar Processes and Global Climate*, pp. 301-303, World Climate Research Program Office, Oslo, Norway,1997.

CONFERENCE PRESENTATIONS:

Maslowski W., Zhang, Y., and Semtner, A.J. "High-Resolution Modeling of Circulation and Processes in the Arctic Ocean with Sea Ice on Parallel Computers," Department of Energy Computer Hardware, Advanced Mathematics, and Model Physics Meeting, San Antonio, TX, March 1997.

Maslowski, W., Zhang, Y., and Semtner, A.J., "High-Resolution Modeling of Circulation and Processes in the Arctic Ocean with Sea Ice," World Climate Research Programme Arctic Climate System Study Sea Ice Thickness Workshop, Monterey, CA, April 1997.

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Maslowski, W., "Advanced Modeling of the Circulation and Processes in the Arctic Ocean with Sea Ice in Support of Global Climate Studies," Arctic Consortium of the U.S. 9th Annual Meeting, Washington, DC, June 1997.

Maslowski, W., Zhang, Y., and Semtner, A., "Modeling Freshwater Sources, their Distribution, and Sinks in the Arctic Ocean," World Climate Research Program Arctic Climate System Study Symposium on Polar Processes and Global Climate, Orcas Island, WA, November 1997.

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DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Environmental Quality, Computing and Software

KEYWORDS: Ice/Ocean Circulation, Ice-Ocean Modeling, Model Validation

COMPARISONS OF THE LOS ALAMOS NATIONAL LABORATORY (LANL) PARALLEL OCEAN PROGRAM (POP) MODEL AND WOCE OBSERVATIONS

Julie L. McClean, Research Assistant Professor
Albert J. Semtner, Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: To validate the very realistic global sixth-degree Los Alamos National Laboratory (LANL) Parallel Ocean Program (POP) model with observational data collected during the World Ocean Circulation Experiment (WOCE). This project is ongoing.

SUMMARY: Over the duration of the WOCE experiment (past 6 years), data were collected over extensive spatial and temporal scales in all ocean basins to provide a description of the global ocean circulation. The devised sampling strategy used one-time and repeat hydrography sections, current meter arrays, subsurface floats, volunteer observing ships (VOS), surface drifters, tide gauges, and satellite measurements in such a way to complement each other and provide more realizations in time and space. Subsets of this data were used to validate the POP model. In the Pacific, Eulerian and Lagrangian statistics from surface drifters were compared with co-located POP fields. Aspects of the overturning and interbasin thermohaline circulation such as the mean and variability of heat and water mass transports, water mass characteristics and their pathways were examined in the light observations, in particular those from WOCE. Efforts were concentrated in the South Pacific and South Atlantic oceans. In the southern Indian Ocean, the impact of the Indonesian through flow in POP was evaluated by constructing heat and salt budgets.

PUBLICATIONS:

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McClean, J.L., Semtner, A.J., and Zlotnicki, V., "Comparisons of Mesoscale Variability in the Semtner-Chervin Quarter-Degree Model the Los Alamos POP Sixth-Degree Model, and TOPEX/POSEIDON Data," *Journal of Geophysical Research,* 102(C11), 25203-25226, 1997

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CONFERENCE PRESENTATIONS:

McClean, J.L., Maltrud, M., and Semtner, A.J., "Comparisons of the LANL POP Model and Observations in the South Atlantic," World Ocean Circulation Experiment South Atlantic Workshop, Brest, France, 16-20 June 1997.

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McClean, J.L. and Maltrud, M., "Overturning and Interbasin Thermohaline Circulation in the LANL POP Model," 1998 Ocean Sciences Meeting, San Diego, CA, 9-13 February 1998.

THESIS DIRECTED:

Lemon, M.R., "Comparison of Los Alamos National Laboratory (LANL) Parallel Ocean Program (POP) Model Fields with Pacific Surface Drifter Measurements," Master's Thesis, Naval Postgraduate School, September 1997.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Ocean Circulation, Model Validation, Model/Data Synthesis

ROLE OF TIDAL FORCING IN DETERMINING THE INTERNAL WAVE SPECTRUM IN THE LITTORAL OCEAN

Jeffrey D. Paduan, Associate Professor
Department of Oceanography
Sponsors: Office of Naval Research and Naval Postgraduate School

OBJECTIVE: The goal of this project is to develop a method, using a three-dimensional primitive equation model with realistic bathymetry, for simulating the internal wave energy produced along the coast by the action of tides.

SUMMARY: This project is investigating the nature of internal wave spectra in the littoral ocean environment using existing moored velocity time series and simulated coastal time series produced by a three-dimensional, primitive equation numerical model with realistic bathymetry forced by tidal-period sea level oscillations. The project has very specific goals that relate to the Littoral Internal Wave Initiative (LIWI), which seeks to quantify the physics of oceanic internal waves on the continental slope and shelf and to develop predictive models of their spectral characteristics. Initial studies are being conducted in the Monterey Bay region, where there are many near-bottom current meter records. Furthermore, the topography of the Monterey Submarine Canyon is known to produce very strong, bottom-intensified internal tides, which are the main subject of the numerical model simulations.

PUBLICATIONS:

Kelly, K.A., Beardsley, R.C., Limeburner, R., Brink, K.H., Paduan, J.D., and Chereskin, T.K., "Variability of the Near-Surface Eddy Kinetic Energy in the California Current Based on Altimetric, Drifter, and Moored Current Data," *Journal of Geophysical Research*, in press.

Petruncio, E.T., Rosenfeld, L.K., and Paduan, J.D., "Internal Tides in a Submarine Canyon: Part I: Observations from Monterey Bay," *Journal Physical Oceanography*, in press.

THESIS DIRECTED:

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DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Modeling and Simulation

KEYWORDS: Ocean Currents, Tides, Internal Tides

MODELING THE RESPONSE OF MONTEREY BAY TO DIURNAL WIND AND TIDAL FORCING

Jeffery D. Paduan, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The goal of this project is to validate a coastal ocean model using observations of strong diurnal and semidiurnal processes around Monterey Bay.

SUMMARY: This is applying new technologies to Navy coastal modeling activities. It includes validation of the Monterey Bay (MOB) coastal ocean model developed by L.N. Ly and the Princeton Ocean Model (POM) against observed diurnal current variations in Monterey Bay. The more recently developed Monterey Bay model includes data processing routines, a grid generation routine, a grid-model coupling package, and visualization routines. Its curvilinear, coastline-following (coastline fitted) orthogonal and nearly orthogonal, multi-block grid options represent a new advance in coastal ocean modeling. The system also includes a hybrid vertical grid that combines aspects of z-level and s-coordinate grids to better model surface and bottom boundary layers. MOB and the more widely used POM are being forced with diurnal winds and tidal sea level oscillations observed in Monterey Bay and compared against surface current observations from a network of high frequency (HF) radar sites along the coast.

PUBLICATIONS:

Fernandez, D.M., Graber, H.C., Paduan, J.D., and Barrick, D.E., "Mapping Wind Direction with HF Radar," *Oceanography*, Vol. 10, No. 2, pp. 93-95, 1997.

Paduan, J.D. and Cook, M.S., "Mapping Surface Currents in Monterey Bay with CODAR-Type HF Radar," *Oceanography*, Vol. 10, No. 2, pp. 49-52, 1997.

Paduan, J.D. and Graber, H.C., "Introduction to High Frequency Radar: Reality and Myth," *Oceanography*, Vol. 10, No. 2, pp. 36-39, 1997.

Paduan, J.D., Cook, M.S., and Fernandez, D.M., "Two-Dimensional Diurnal to Monthly Period Surface Currents in Monterey Bay from CODAR-type HF Radar," *Proceedings of the IEEE International Geoscience and Remote Sensing Symposium,* Singapore, pp. 1814-1816, August 1997.

CONFERENCE PRESENTATIONS:

Paduan, J.D., Rosenfeld, L.K., and Cook, M.S., "Diurnal Surface Current Fluctuations in Monterey Bay from CODAR-Type HF Radar," Monterey Bay National Marine Sanctuary Research Symposium, Santa Cruz, CA, March 1997.

THESIS DIRECTED:

Smith, M.S., "Comparison of Trajectories Generated by the NOAA Oil Spill Model to Trajectories Produced Using HF Radar-Derived Surface Currents in Monterey Bay," Master's Thesis, September 1997.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments, Modeling and Simulation

KEYWORDS: HF Radar, Ocean Currents, Tides, Sea Breeze

VARIABILITY OF THE SURFACE CIRCULATION AND TEMPERATURE IN THE ADRIATIC SEA

Pierre-Marie Poulain, Assistant Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The main goal of this project is to make effective drifter measurements of sea surface currents and sea surface temperature (SST) in the global Adriatic Sea in order to describe the spatial characteristics and the temporal variability of the surface circulation and the SST at inertial to seasonal scales. A related objective is to investigate some aspects of the response of the surface circulation and SST to atmospheric and boundary forcings. In particular, our goal is to study the characteristics of the wind-driven currents in relation to the surface wind forcing, obtained from wind measurements and from atmospheric model products. Another aim is to explore the role of eddies (versus mean currents) in transporting momentum and heat.

SUMMARY: The observational phase of this project began in August 1997 with the deployment of 20 CODE drifters and one GDP/MINIMET throughout the Adriatic Sea by colleagues of the Osservatorio Geofisico Sperimentale, Trieste, Italy. In-situ wind observations were made following the release of the GDP/MINIMET drifter. One CODE drifter was repetitively deployed and recovered off Ancona, Italy, in the area sampled by a newly-installed CODAR system in order to compare the surface velocity estimates obtained by the HF radar and CODE drifters.

The drifter data have been downloaded from Service Argos on a daily basis. After some pre-processing and data reduction, graphical representations of the drifter statistics, of the drifter trajectories and the temperature time series, etc. have been produced and updated every day in a dedicated world wide web page (http://oc.nps.navy.mil/~drifter). In four months, the drifters provided remarkable information on the circulation spatial structure and temporal variability both in the Adriatic Sea and in the northern Ionian Sea.

In order to complete a year-long monitoring of the Adriatic Sea, additional seasonal deployments are planned until spring 1998. The entire drifter data set will be interpreted and results will be published as part of the continuation of this project into 1998 and 1999.

CONFERENCE PRESENTATIONS:

Poulain, P.-M., Gacic, M., Sellschoop, J., and Niiler, P., "Recent Lagrangian Measurements of Surface Circulation in the Adriatic and Ionian Seas," American Geophysical Union 1998 Ocean Sciences Meeting, San Diego, CA, 9-13 February 1998.

Scarazzato, P. Ursella, L., Kovacevic, V., Gacic, M., Manca, B., Poulain, P.-M., and Fragiacomo, C., "Progress in the Adriatic Sea Oceanography," International Conference on the Progress in Oceanography of the Mediterranean Sea, Rome, Italy, 17-19 November 1997.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Marginal Seas and Straits, Circulation

OCEANOGRAPHIC MEASUREMENTS IN THE ADRIATIC AND IONIAN SEAS

Pierre-Marie Poulain, Assistant Professor
Department of Oceanography
Sponsor: Naval Postgraduate School

OBJECTIVE: The main objective of this continuing project is to make effective drifter measurements of surface currents in the Strait of Sicily and the Ionian Sea in order to describe the variability of the surface circulation mesoscale structures and gain knowledge on their dynamics. A related goal is to analyze and interpret oceanographic data sets (mainly drifter measurements) collected by the PI in the Adriatic and Ionian Seas over the last few years.

SUMMARY: During 1997, a total of 17 satellite-tracked drifters were successfully released in the Strait of Sicily from research vessels conducting hydrographic surveys and from ships of opportunity (ferries). As the drifters moved eastward with the prevailing Atlantic-Ionian Stream (AIS), they provided remarkable information on the circulation spatial structure and temporal variability both in the Strait of Sicily area and in the northwestern Ionian Sea. The structure of the AIS extending into an anticyclonic gyre in the northern Ionian and continuing as a strong meridional jet in the northeast Ionian is in good agreement with geostrophic circulation maps produced in the late 1980s. Seasonal variability of the surface circulation is also evident. In summer, the meandering AIS appears to be a strong and robust sub-basin scale feature south of Sicily. In contrast, the currents are dominated by smaller mesoscale eddy patterns in winter.

The drifter data were pre-processed and the drifter movements were depicted on a dedicated web page (http:// oc.nps.navy.mil/~drifter) on a daily basis. In order to continue the long-term continuous monitoring of the Strait of Sicily circulation, additional deployments are planned in winter 1998. The entire drifter data set will be interpreted and results will be published as part of the continuation of this project into 1998.

PUBLICATIONS:

Kovacevic, V., Gacic, M., and Poulain, P.-M., "Eulerian Current Measurements in the Strait of Otranto and in the Southern Adriatic," *Journal of Marine Systems*, in press.

Poulain, P.-M. "Drifter Observations of Surface Circulation in the Adriatic Sea," *Journal of Marine Systems*, 1998, in press.

Poulain, P.-M. and Zanasca P. "Lagrangian Measurements of Surface Currents in the Northern and Central Adriatic Sea," *Ecosystems Research Report, The Adriatic Sea,* EU/Environment Series, Brussels, Belgium, in press.

Poulain, P.-M. and Zanasca, P. "Drifter and Float Observations in the Adriatic Sea (1994-1996) - Data Report," SACLANTCEN Memorandum, SM-340, SACLANT Undersea Research Centre, La Spezia, Italy, 1998, in press.

CONFERENCE PRESENTATIONS:

Pinto, R. L, Poulain, P.-M., and Chu, P., "A P-Vector Approach for Determining Absolute Geostrophic Circulation in the Strait of Otranto and the Southern Adriatic," American Geophysical Union 1998 Ocean Sciences Meeting, San Diego, CA, 9-13 February 1998.

Poulain, P.-M., Zambianchi, E., Sellschopp, J., and Ribera, M., "Lagrangian Measurements of Surface Circulation in the Straits of Sicily," Joint IAMAS/IAPSO Assemblies, Melbourne, Australia, 1-9 July 1997.

Sellschopp J, Robinson, A. R., Onken. R., Warn-Varnas, A., and Poulain, P.-M., "Quasi Permanent Flow Structures in the Sicilian Channel," XXII General Assembly of the European Geophysical Society, Vienna, Austria, 21-25 April 1997.

Zambianchi, E. and Poulain, P.-M., "Surface Circulation in the Straits of Sicily: A Lagrangian Description," International Conference on the Progress in Oceanography of the Mediterranean Sea, Rome, Italy, 17-19 November 1997.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Marginal Seas and Straits, Water Masses, Circulation

LAGRANGIAN MEASUREMENTS IN ICELANDIC WATERS

Pierre-Marie Poulain, Assistant Professor
Department of Oceanography
Sponsor: North Atlantic Treaty Organization

OBJECTIVE: The main objective of this project is to analyze drifter observations in the Icelandic waters collected by the SACLANT Undersea Research Centre, La Spezia, Italy in 1991-1995 and by the Marine Research Institute (MRI) of Reykjavik, Iceland (1995-1998) in order to define the main pathways of the surface circulation and describe their eddy and seasonal variabilities. A related goal is to use and combine satellite thermal imagery with the in-situ drifter measurements to provide the most complete description of the mesoscale variability.

SUMMARY: The SACLANT drifter data set was combined with relatively cloud-free thermal infrared satellite images between October 1992 and September 1993 to describe the dynamic and thermal structures of the Iceland-Faroe Front system. The in-situ and remotely sensed data combined satisfactory to provide the best pictures of the frontal variability.

The drifter data sets up to the end of 1996 were processed to create low-passed, uniformly sampled trajectories. Seasonal maps of mean currents and eddy kinetic energy were produced. The Lagrangian nature of the drifters was exploited to estimate decorrelation time and length scales and eddy diffusivities in selected regions.

This project will continue into 1998 as more drifters will be released by MRI in winter 1998. Final processing and data interpretation (statistical analyses) will be conducted at the end of 1998 and early 1999 when all the drifters will have ceased to operate.

THESIS DIRECTED:

Arends, C.J., "Iceland-Faroe Front Structure and Variability," Master's Thesis, Naval Postgraduate School, June 1997.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Upper Ocean Circulation, Lagrangian Drifters, Icelandic Coastal Waters

SCIENTIFIC DEVELOPMENT OF A MASSIVELY PARALLEL OCEAN CLIMATE MODEL

Albert J. Semtner, Professor
Department of Oceanography
Sponsor: Department of Energy

OBJECTIVE: To develop detailed models of the global ocean circulation with all relevant physical processes important for prediction, as well as to validate the models against existing observations. To understand the physical processes in the ocean that affect oceanic predictability and climatic fluctuations and change.

SUMMARY: A global ocean model, capable of producing accurate forecasts out to the limits of climate predictability when properly coupled to a valid atmospheric model, has to be well designed and able to run on the advanced supercomputers of the future, which are expected to be of massively parallel design. The present research is moving an eddy-resolving model onto massively parallel computers, for coupled modeling related to CHAMMP. To guide the additional physical development of a comprehensive model, scientific study in three areas is now underway: (1) investigation of the physics of ocean heat transport; (2) inclusion of near-surface oceanic processes relevant to climate; and (3) examination of resolution requirements for ocean modeling. Last year, high-latitude process improvements and analyses of resolution effects were emphasized. A fully validated model was produced at project completion in late 1997.

PUBLICATIONS:

Chervin, R.M., Craig, A.P., and Semtner, A.J., "Meridional Heat Transport Variability from a Global Eddy-Resolving Ocean Model," *Assessing Climate Change*, W. Howe and A. Henderson-Sellers, eds., Gordon and Breach Science Publishers, Roseville, Australia, 1997, in press.

Craig, A.P., Bullister, J.L., Harrison, D.E., Chervin, R.M., and Semtner, A.J., "A Comparison of Temperature, Salinity, and Chloro-Fluorocarbon Observations with Results from a One-Degree Three-Dimensional Global Ocean Model," *Journal of Geophysical Research*, 1997, in press.

Maltrud, M.E., Smith, R.D., Semtner, A.J., and Malone, R.C., "Global Eddy-Resolving Ocean Simulations Driven by 1985-94 Atmospheric Fields: Part I, Mean Circulation and Variability," *Journal of Geophysical Research*, 1997, provisionally accepted.

Maslowski, W., Parsons, A.R., Zhang, Y., and Semtner, A.J., "High-Resolution Arctic Ocean and Sea Ice Simulations: Part I, Ocean Model Design and Early Results," *Journal of Geophysical Research*, 1997, submitted.

McClean, J.L., Semtner, A.J., and Zlotnicki, V., "Comparisons of Mesoscale Variability in the Semtner-Chervin Quarter-Degree Model, the Los Alamos POP Sixth-Degree Model, and TOPEX/POSEIDON Data," *Journal of Geophysical Research*, 102, 25203-25226, 1997.

Ramp, S.R., McClean, J.L., Collins, C.A., Semtner, A.J., and Hayes, K.A.S, "Observations and Modeling of the 1991-1992 El Niño off Central California," *Journal of Geophysical Research*, 102, 5553-5582, 1997.

Semtner, A.J., Introduction to "A Numerical Method for the Study of the Circulation of the World Ocean," *Journal of Computational Physics*, 135,149-153 1997.

Semtner, A.J., "Very high-Resolution Estimates of Global Ocean Circulation, Suitable for Carbon-Cycle Modeling," *Proceeding of the Snowmass Global Change Institute on the Global Carbon Cycle*, Office of Interdisciplinary Earth Studies, Boulder, CO, 1997, in press.

Semtner, A.J., "Global Ocean and Polar Regions: A Modeling Perspective," *Proceedings of the Global Change Workshop on Polar Processes*, pp. 56-61, D. Martinson (ed.), American Meteorology Society, Boston, MA, 1997.

Semtner, A.J., "Modeling Ocean Climate Variability with Emphasis on Polar Processes," *Proceedings of the Rosano Symposium on Polar Processes and Global Climate* pp. 246-248, World Climate Research Program Office, Oslo, Norway, 1997.

Zhang, Y., Maslowski, W., and Semtner, A.J., "High-Resolution Arctic Ocean and Sea Ice Simulations: Part II, Ice Model Design and Early Results," *Journal of Geophysical Research*, 1997, accepted.

PRESENTATIONS:

"Recent Research Results on Ocean Simulation, Comparison with Observation, and Improvements in Predictions Methods," was presented in various forms in the following venues: Santa Barbara, CA, 20 February 1997; DoE-CHAMMP, San Antonio, TX, 3-6 March 1997; U.S.-JAPAN Workshop, Honolulu, HI, 10-13 March 1997; NSF Ocean Meeting, Boulder, CO, 7-8 April, 1997; ACSYS Conference, Monterey, CA, 9-10 April 1997; ARCSS OAII, Virginia Beach, CA, 8-10 May 1997; SIAM Meeting, Albuquerque, NM, 16-18 June 1997; FNMOC Coupled Models, Monterey, CA, 9-10 July 1997; ACSYS Conference, Orcas Island, WA, 3-6 November 1997; Antarctic Meetings, Tucson, AZ, 1-4 December 1997.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Numerical Modeling, Ocean Prediction, Parallel Computing

SIMULATIONS AND RECONSTRUCTIONS OF GLOBAL OCEAN CIRCULATION WITH WELL-RESOLVED EDDIES FOR THE WOCE OBSERVATIONAL PERIOD 1991-97

Albert J. Semtner, Professor
Department of Oceanography
Sponsor: National Science Foundation and Naval Postgraduate School

OBJECTIVE: The goal is to further improve on the realism of numerical models of global three-dimensional ocean circulation with important currents and eddies resolved, to conduct simulations using the best available atmospheric forcing, and to assimilate satellite altimeter data in certain of the studies. This 5-year project runs until 1999.

SUMMARY: A model had been developed with 1/4 x 2/5 deg lat/lon grid and 20 vertical levels, with proper representation of coastlines and depths. Last year, a number of physical and numerical improvements were made, and ECMWF reanalyzed winds and heat and moisture fluxes were prepared as forcing. The model was used to simulate conditions of 1979-93, starting from earlier 1985-96 operationally forced calculations and applying the new fields of daily winds and fluxes. A massive amount of model output was compared with both in-situ and satellite observations and found to be in excellent agreement with what actually happened. The agreement of predicted surface height variability with that observed by NASA's superb TOPEX satellite altimeter was especially impressive. In addition, satellite data-assimilation efforts were completed which included the height data from both TOPEX and ERS satellites over the period 1992-95. Those results show improvements in the timing and amplitude of current fluctuations, as well as statistical improvements in the mean and variability—all calibrated against actual observations. Higher resolution models are being developed for use in further research.

DISSERTATION DIRECTED:

Tokmakian, R., "Assimilation of Satellite Altimeter Data into a Global Eddy-Resolving Model," Doctor of Philosophy Dissertation, Naval Postgraduate School, June 1997.

PUBLICATIONS:

Chervin, R.M., Craig, A.P., and Semtner, A.J., "Meridional Heat Transport Variability from a Global Eddy-Resolving Ocean Model," *Assessing Climate Change*, W. Howe and A. Henderson-Sellers, eds., Gordon and Breach Science Publishers, Roseville, Australia, 1997, in press.

Craig, A.P., Bullister, J.L., Harrison, D.E., Chervin, R.M., and Semtner, A.J., "A Comparison of Temperature, Salinity, and Chloro-Fluorocarbon Observations with Results from a One-Degree Three-Dimensional Global Ocean Model," *Journal of Geophysical Research*, 1997, in press.

Maltrud, M.E., Smith, R.D., Semtner, A.J., and Malone, R.C., "Global Eddy-Resolving Ocean Simulations Driven by 1985-94 Atmospheric Fields: Part I, Mean Circulation and Variability," *Journal of Geophysical Research*, 1997, provisionally accepted.

Maslowski, W., Parsons, A.R., Zhang, Y., and Semtner, A.J., "High-Resolution Arctic Ocean and Sea Ice Simulations: Part I, Ocean Model Design and Early Results," *Journal Geophysical Research*, 1997, submitted.

McClean, J.L., Semtner, A.J., and Zlotnicki, V., "Comparisons of Mesoscale Variability in the Semtner-Chervin Quarter-Degree Model, the Los Alamos POP Sixth-Degree Model, and TOPEX/POSEIDON Data," *Journal of Geophysical Research*, 102, 25203-25226, 1997.

Ramp, S.R., McClean, J.L., Collins, C.A., Semtner, A.J., and Hayes, K.A.S, "Observations and Modeling of the 1991-1992 El Niño off Central California," *Journal of Geophysical Research*, 102, 5553-5582, 1997.

Semtner, A.J., Introduction to "A Numerical Method for the Study of the Circulation of the World Ocean," *Journal of Computational Physics,* 135,149-153 1997.

Semtner, A.J., "Very High-Resolution Estimates of Global Ocean Circulation, Suitable for Carbon-Cycle Modeling," *Proceeding of the Snowmass Global Change Institute on the Global Carbon Cycle*, Office of Interdisciplinary Earth Studies, Boulder, CO, 1997, in press.

Semtner, A.J., "Global Ocean and Polar Regions: A Modeling Perspective," *Proceedings of the Global Change Workshop on Polar Processes,* pp. 56-61, D. Martinson (ed.), American Meteorology Society, Boston, MA, 1997.

Semtner, A.J., "Modeling Ocean Climate Variability with Emphasis on Polar Processes," *Proceedings of the Rosano Symposium on Polar Processes and Global Climate* pp. 246-248, World Climate Research Program Office, Oslo, Norway, 1997.

Zhang, Y., Maslowski, W., and Semtner, A.J., "High-Resolution Arctic Ocean and Sea Ice Simulations: Part II, Ice Model Design and Early Results," *Journal of Geophysical Research*, 1997, accepted.

PRESENTATIONS:

"Recent Research Results on Ocean Simulation, Comparison with Observation, and Improvements in Predictions Methods," was presented in various forms in the following venues: Santa Barbara, CA, 20 February 1997; DoE-CHAMMP, San Antonio, TX, 3-6 March 1997; U.S.-JAPAN Workshop, Honolulu, HI, 10-13 March 1997; NSF Ocean Meeting, Boulder, CO, 7-8 April 1997; ACSYS Conference, Monterey, CA, 9-10 April 1997; ARCSS OAII, Virginia Beach, CA, 8-10 May 1997; SIAM Meeting, Albuquerque, NM, 16-18 June 1997; FNMOC Coupled Models, Monterey, CA, 9-10 July 1997; ACSYS Conference, Orcas Island, WA, 3-6 November 1997; Antarctic Meetings, Tucson, AZ, 1-4 December 1997.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Numerical Modeling, Ocean Prediction

UNDERSTANDING SEASONAL TO DECADAL CLIMATE CHANGES THROUGH THE COMBINED USE OF IMPROVED MODELS AND SATELLITE DATA

Albert J. Semtner, Professor
Robin Tokmakian, Research Assistant Professor
Julie McClean, Research Assistant Professor
Department of Oceanography
Sponsors: National Aeronautics and Space Administration and Cal Tech Jet Propulsion Laboratory

OBJECTIVE: The goal is to use improved models and satellite data to understand climate changes on seasonal, interannual, decadal, and interdecadal time scales. The models to be used are capable of reproducing the mean ocean currents with correct magnitude and length scales, as well as the forced and spontaneous variability on many time scales.

SUMMARY: High-resolution global ocean models and satellite data are being used to define a set of indices that can be used to identify seasonal, interannual, and decadal changes in the climate of the World Ocean. Global models from 1/4-degree out to 1/10-degree grid size forced with reanalyzed wind stress and heat/freshwater fluxes and also having satellite derived bathymetry can be run with and without interannual changes in the buoyancy forcing. The model output is being compared to the TOPEX height fields and other satellite data to investigate variations in the thermohaline and wind-driven

ocean circulation as related to global climate. Realizing that the satellite data is not available over multiple decades, the models provide an environment in which to place either the shorter time series of undersampled height, temperature, and ice data. The models will provide complete fields with which to determine whether or not indices related to surface variables are reasonable estimators of important climatic variations. This was the first year of the project.

PUBLICATIONS:

Maltrud, M.E., Smith, R.D., Semtner, A.J., and Malone, R.C., "Global Eddy-Resolving Ocean Simulations Driven by 1985-94 Atmospheric Fields: Part I, Mean Circulation and Variability," *Journal of Geophysical Research*, 1997, provisionally accepted.

McClean, J.L., Semtner, A.J., and Zlotnicki, V., "Comparisons of Mesoscale Variability in the Semtner-Chervin Quarter-Degree Model, the Los Alamos POP Sixth-Degree Model, and TOPEX/POSEI DON Data," *Journal of Geophysical Research*, 102, 25203-25226, 1997.

Semtner, A.J., "Modeling Ocean Climate Variability with Emphasis on Polar Processes," *Proceedings of the Rosano Symposium on Polar Processes and Global Climate,* pp. 246-248, World Climate Research Program Office, Oslo, Norway, 1997.

Tokmakian, R.J., McClean, J.L., and Semtner, A.J., "Understanding Seasonal to Decadal Climate Changes Using Models and Satellite Data," *AVISO Newsletter*, Toulouse, France, 1997, in press.

Zhang, Y., Maslowski, W., and Semtner, A.J., "High-Resolution Arctic Ocean and Sea Ice Simulations: Part II, Ice Model Design and Early Results," Journal of Geophysical Research, 1997, provisionally accepted.

CONFERENCES PRESENTATIONS:

"Recent Research Results on Ocean Simulation, Comparison with Observation, and Improvements in Predictions Methods," was presented in various forms in the following venues: Santa Barbara, CA, 20 February 1997; DoE-CHAMMP, San Antonio, TX, 3-6 March 1997; U.S.-JAPAN Workshop, Honolulu, HI, 10-13 March 1997; NSF Ocean Meeting, Boulder, CO, 7-8 April 1997; ACSYS Conference, Monterey, CA, 9-10 April 1997; ARCSS OAII, Virginia Beach, CA, 8-10 May 1997; SIAM Meeting, Albuquerque, NM, 16-18 June 1997; FNMOC Coupled Models, Monterey, CA, 9-10 July 1997; ACSYS Conference, Orcas Island, WA, 3-6 November 1997; Antarctic Meetings, Tucson, AZ, 1-4 December 1997.

DISSERTATION DIRECTED:

Tokmakian, R., "Assimilation of Satellite Altimeter Data into a Global Eddy-Resolving Model," Doctor of Philosophy, Naval Postgraduate School, June 1997.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Numerical Modeling

MIXED LAYER TURBULENCE MEASUREMENTS DURING THE ANZONE WINTER FLUX EXPERIMENT: ANZFLUX

Timothy P. Stanton, Research Associate Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: The objectives of this research are to identify and model physical mechanisms responsible for maintaining anomoulously thin winter ice cover over the central Weddell Sea. As large scale, winter-long polynias intermittently form in

this area, the potential exists for massive ocean/atmosphere heat fluxes which can significantly effect the global heat budget and bottom water formation.

SUMMARY: During participation in the ANZFLUX experiment, deployed from the icebreaker *N.B. Palmer* during July and August 1994, two, one-week ice camps were established approximately 500 m from the ship on O(30 cm) ice to make direct heat, salt, and momentum flux measurements in the ocean mixed layer. Analysis is proceeding on the continuous profiling microstructure probe, a turbulence-resolving Broad Band Acoustic Doppler Current profiler, and three near-surface in situ temperature, salinity and 3 component velocity instrument clusters. These data show that strong turbulent coupling between the deep pycnocline and the surface ice occurs during the very high wind stress events which dominated the weather at the measurement site. High mixed layer heat fluxes during these events are further enhanced by dramatic shallowing of the pycnocline due to the presence of eddy features in the Central Weddell Sea. The continuous mixed layer and upper pycnocline profile measurements resolved the evolving mixed layer thermohaline structure, turbulent dissipation rates and very small vertical gradients of temperature and salinity, allowing heat fluxes and pycnocline diffusivity timeseries to be estimated.

An analysis of the pycnocline fluxes estimated from the field observations has been completed in collaboration with investigators at OSU, and submitted to JGR. A paper describing the turbulent structure of the sub-ice mixed layer and unique comparisons of dissipation measurement techniques will be submitted to JGR. These unique comparisons of acoustic doppler measurements of boundary layer turbulence using conventional geometry acoustic doppler profilers demonstrate a new application of acoustic doppler current profilers. A collaborative paper with Miles McPhee on a simple mixed layer flux parameterization is in progress, as is a collaborative paper estimating deep pycnocline fluxes due to double diffusion and cabling.

PUBLICATIONS:

Stanton, T.P., Padman, L., and Robertson, R.A., "Heat Fluxes Through the Permanent Pycnocline in the Eastern Weddell Sea," to *Journal of Geophysical Research,* 1997, submitted.

Stanton, T.P., "Observations of Shear Production and Dissipation Rates in the Upper Mixed Layer in the Weddell Sea," *Journal of Geophysical Research,* 1997, submitted.

CONFERENCE PRESENTATIONS:

McPhee, M.G. and Stanton, T.P., "Relating Flux and Dissipation Measurements in the Ocean Boundary Layer," American Geophysical Union Fall Meeting, 1997.

Padman, L, Stanton, T.P., and Muench, R.D., "Double-Diffusive Convection and Cabbeling in the Weddell Sea," American Geophysical Union Fall Meeting, 1997.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Ocean Mixed Layer, Antarctic Ocean Fluxes, Mixed Layer Dynamics

UPPER OCEAN EFFECTS ON THE SURFACE HEAT BUDGET OF THE ARCTIC

Timothy P. Stanton, Research Associate Professor
Department of Oceanography
Sponsors: National Science Foundation

OBJECTIVE: The objectives of this research are to measure the mixed layer and upper ocean heat fluxes over a one year period in the central Arctic Ocean. This work is a component of the multidisciplinary SHEBA program which has the objectives of improving parameterizations of the coupled atmosphere-ice-ocean system in the Arctic to improve the predic-

tive capabilities of Global Climate Models. Two shorter process studies will focus on the role of ice keels in the surface heat balance, and the heat storage associated with summer leads.

SUMMARY: In October 1997, the SHEBA ice camp was established in the Central Beaufort Sea and an automated CTD and microstructure profiler was deployed to measure turbulent fluxes and the temperature/salinity structure of the upper ocean for a one year period as the ice camp drifted in response to surface wind forcing. The microstructure package was designed and built at NPS, and tested in September in Puget Sound.

Data from the daily profile timeseries are downloaded via a satellite link allowing checks of the extremely delicate micro-temperature sensors to be monitored, and the progress of the experiment to be analyzed. These daily data are assimilated into the database and visualization software allowing student thesis work on the analyses to proceed. More complete processing of the full timeseries has been implemented to accept the DAT tapes as they arrive from the ice station with each cruise rotation. Analysis of the upper ocean salinity structure has revealed evidence of very significant ice melting in the last few seasons, and this work has been submitted to GRL.

A unique, self contained portable ocean heat, salt, and momentum flux instrument has been completed and readied for deployment in an ice keel study in March 1998. This small battery operated instrument measures three component velocities, tilts, heading, temperature, salinity, and pressure allowing mixed layer fluxes to be determined in the ocean mixed layer over periods of up to two months. The flux probe will be used in both process studies mentioned in the objectives.

PUBLICATIONS:

McPhee, M.G., Stanton, T.P., Morison, J.H., and Martinson, D.G., "Freshening of the Upper Ocean in the Central Arctic: Is Perennial Sea Ice Disappearing?" Submitted to GRL, 1997.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Ocean Mixed Layer, Polar Oceans, Mixed Layer Dynamics

SPECTRAL WAVE DECAY DIE TO BOTTOM FRICTION ON THE INNER SHELF

Timothy P. Stanton, Research Associate Professor
Edward B. Thornton, Professor
Sponsor: Office of Naval Research

OBJECTIVES: The objectives of this research are to directly measure wave dissipation as surface gravity waves propagate across continental shelves. Observations of dissipation in the thin oscillatory bottom boundary layer, bottom morphology, and low frequency currents will be used to develop a spectral wave model of dissipation for use in shelf wave models.

SUMMARY: During the startup year of this 5-year DRI, a prototype acoustic doppler profiler (the BCDV) has been completed to measure the velocity structure, Reynolds stresses and shear in the thin wave-forced bottom boundary with cm resolution over an 80 cm range. This instrument was tested in Monterey Bay in May and November 1996, and deployed as a central component of the instrumented sled used at the SandyDuck nearshore experiment in September and October 1997. As the small scale morphology of sandy sediments profoundly affect bottom drag, an automated dual axis, coherent altimeter has been developed to repeatedly map the ripple field over a 2x4 m area centered on the BCDV profile measurement.

During the SandyDuck experiment, the instrumented sled was moved well offshore of the bar each day, presenting a wide range of wave forcing conditions representative of inner shelf conditions. This data set has allowed a preliminary analysis of inner shelf bottom friction and the effects of a mobile sediment bed to be started.

CONFERENCE PRESENTATION:

Stanton, T.P. and Thornton, E.B., "Spectral Wave Decay Due to Bottom Friction on the Inner Shelf," WISE Meeting, San Francisco, CA, April 1997.

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DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Wave Dissipation, Shoaling Waves, Bottom Boundary Layers

INTERNAL WAVE AND TURBULENCE MEASUREMENTS DURING THE COASTAL OCEAN PROCESSES EXPERIMENT: COPE

Timothy P. Stanton, Associate Research Professor
Department of Oceanography
Sponsors: National Oceanic and Atmospheric Administration and Office of Naval Research

OBJECTIVE: The objectives of this research were to define the surface strain and internal mixing effects of high displacement, near-surface internal soliton packets over the continental shelf.

SUMMARY: In October 1995, our ocean turbulence group participated in the NOAA ETL sponsored Coastal Ocean Processes Experiment (COPE) by deploying three instrument systems from R/P FLIP for a three week period, 20 km off shore of Northern Oregon. A continuous profiling loose-tethered microstructure profiler measured high resolution temperature, salinity, and dissipation profiles with a 80 second cycle from the surface to a depth of 35 m. A rigid instrument frame suspended from one of FLIP's booms was equipped with five in situ temperature, salinity and 3 component velocity instrument clusters which spanned 3 to 8 m depth, while a high speed broadband ADCP extended the velocity and stress measurements to 50 m depth.

The measurement site had a 60 cph pycnocline at only 5 – 10 m depth, supporting the existence of extremely nonlinear soliton packets which were consistently observed on the leading edge of each seimidiurnal internal tide displacement. The soliton packets had downward isopycnal displacements of up to 25 m from a 6 m start depth, significantly more non-linear than previous observations. A conference presentation was made at the February 98 Ocean Sciences meeting in San Diego and a manuscript describing a 3rd order KdV model of the soliton displacements has been prepared in collaboration with Lev Ostovsky at the NOAA ETL, and has been submitted to GRL. The principal investigator also contributed to a joint paper with Bob Kropfli at NOAA/ETL describing the surface modulation of these solitons on X and K band radar frequencies. A comprehensive analysis of the upper ocean mixing and displacements due to the strong internal tide and solitons is being completed for submission to Journal of Geophysical Research.

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DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Ocean Mixed Layer, Internal Waves, Mixed Layer Dynamics.

NEARSHORE WAVE AND SEDIMENT PROCESSES

Edward B. Thornton, Professor
Timothy P. Stanton, Research Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research and Naval Postgraduate School

OBJECTIVE: To predict the wave-induced three-dimensional velocity field and induced sediment transport over arbitrary bathymetry in the nearshore given the offshore wave conditions.

SUMMARY: The vertical distributions throughout the water column of 3-component mean, wave-induced and turbulent velocities, bubbles, and sediment concentrations were measured during the SandyDuck near shore experiment using an instrumented sled to study. The 3-component velocity field was measured every 5 cm over the bottom 1 m with a downward looking 1.2 MHz bistatic coherent acoustic Doppler velocimeter (1.6 cm resolution at 48 Hz) and in the upper water column with a 300 KHz upward looking coherent bistatic acoustic Doppler velocimeter every 8 cm (8 cm resolution at 48 Hz). In addition, the vertical distribution of the horizontal velocities were measured with an array of 8 electromagnetic current meters. A 2 m cross-shore array of optical backscatter instruments measured the coherence length scale and advection. The small-scale morphology, which acts as hydraulic roughness for the mean flows and perturbs the velocity-sediment fields, was measured from the sled with newly developed, in-house, x-y scanning altimeter, and with an array of 7 sonic altimeters mounted on the back of the CRAB. The primary mechanism for changes in moment flux which drives the near shore dynamics is due to the dissipation of breaking waves, the processes of which are only poorly understood. To improve understanding of breaking waves, the dissipation associated with bubble injection and depth of bubble penetration were measured with the two acoustic systems (1.2 MHz looking down and 300KHz looking up) and with a 3 m vertical array of 8 conductivity cells. An important component of the cross-shore sediment flux is due to the cross-shore mean flow (undertow), which is forced by wave set-up/down; the set-up was measured with an array of 14 manometer and 8 pressure sensors. Undertow is an integral measure of the turbulent Reynold's stresses and wave radiation stresses and acts as a check for the detailed velocity measurements. The data are being compared with models developed under this program and in collaboration with other groups.

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Do KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Near Shore, Waves, Surf

WAVE SURFACE AND BOTTOM BOUNDARY LAYERS IN THE NEARSHORE

Edward B. Thornton, Professor
Timothy P. Stanton, Research Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The objectives of this research are to examine the dynamics of the water column in over the continental shelf and nearshore, regions where forcing is dominated by surface gravity waves and wind. Unique acoustic Doppler instruments will be used to look at a boundary layer turbulent properties.

SUMMARY: Experiments were conducted in Monterey Bay in May and November 1996 with the objective of testing instrumentation to be deployed during SandyDuck and to acquire new data on a near planar beach with near normally incident, long period swell waves. New instrumentation included a manometer/pressure array to measure wave transformation and set-up, a vertical array of 8 conductivity cells to measure void fraction (to infer bubble concentration), and a Bistatic Coherent Doppler Velocimeter (BCDV) to measure the bottom boundary layer. Additional measurements include a vertical arrays of 9 em current meters, and 5 optical backscatter sensors, plus Dave Farmer using an acoustic resonator to measure bubble size. Analysis of the data is progressing.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Waves, Bottom Boundary Layer, Morphology

NEARSHORE CIRCULATION ON VARIABLE BATHYMETRY

Edward B. Thornton, Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: Develop models to predict the evolution of waves and currents in the nearshore due to waves, wind and tidal influences, and the changes in the bathymetry.

SUMMARY: Data previously acquired during the NSTS and Duck field experiments are being processed and made available for this study. The NSTS data were acquired on near-planar beaches at Torrey Pines (1978) and Santa Barbara (1980) CA, while the Duck, NC, data were acquired on a barred beach in a series of experiments Duck85, SUPERDUCK (1986), DELILAH (1990) and DUCK94. The data are of a dense cross-shore array or wave and velocity sensors, alongshore array(s) of velocity sensors, direction wave array(s) offshore, and well-measure bathymetry. Data focuses on when the bathymetry was 3-D.

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DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Waves, Near-Shore, Edge-Waves

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AN ANALYSIS OF THE EFFECTS OF ENERGY SPREADING LOSS AND TRANSMISSION LOSS ON LOW FREQUENCY ACTIVE SONAR OPERATIONS IN SHALLOW WATER

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Energy Spreading Loss (ESL) is qualitatively defined as the reduction in peak power level due to energy spreading of a transmitted acoustic pulse in time. An analysis of the impact of bathymetric geometry and sediment type on ESL and TL associated with the Low Frequency Active/Compact Low Frequency Active (LFA/CLFA) sonar operations was conducted utilizing the FEPE, FEPE_SYN and EXT_TD programs to model the time spreading of the acoustic pulse due to multipath propagation in shallow water. Both a Blackman windowed pulse and a Continuous Wave (CW) pulse were used in this analysis. The Blackman pulse had a center frequency of 244 Hz with a bandwidth of 24 Hz. The CW pulse had a center frequency of 244 Hz with a bandwidth of 0.0625 Hz. Model inputs were a geoacoustic description of the Tanner flank region off the coast of San Diego and a typical late summer sound speed profile taken from the MOODS database. ESL and TL's impact on low frequency active sonar operations was determined as a function of bathymetry, sediment type, sound speed profile, and pulse length. The results showed that ESL is inversely related to pulse duration and at low frequencies is relatively uninfluenced by sediment type. When pulse lengths were reduced to less than 1 second, ESL became appreciable (>6 dB one way) and was an important segment of the active sonar equation. TL was found to be the dominating factor in LFA/CLFA operations for pulse lengths greater than 1 second and was greatly influenced by sediment type and sound speed profile.

ICELAND-FÆROE FRONT STRUCTURE AND VARIABILITY

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During the period June 1991 to August 1993, 107 Argos-tracked drifters, drogued to 15m depth, were released in the Greenland, Iceland, and Norwegian (GIN) Seas. The drifter movements revealed the strong and spatially confined current systems along the Iceland-FÆeroe Front (IFF) and provided tracking of the Norwegian Atlantic Current and the general cyclonic gyre circulation in the GIN Sea.

Of the 107 drifters released, 59 were selected for this study due to their proximity to the IFF. Tracked by the Argos system aboard the NOAA polar orbiters, the drifters provided accurate location and sea surface temperature (SST) data. Interpolated and low-pass-filtered position data were used to construct maps of drifter displacement and surface velocity field estimates and to study the correlation between drifter trajectories and satellite-derived SST frontal features.

Drifter SST data were compared to spatially and temporally coincident satellite retrieved SST data. The individual data sets were in good agreement with each other, resulting in a temperature difference of less than 1°C. Satellite imagery used to estimate surface currents through SST feature tracking provided a snapshot of the flow field over a short time scale.

The drifters revealed a distinct frontal zone (DFF) where the topographically steered flow field approached velocities of 1 m/s. This relatively strong flow became unstable as it propagated eastward and an intense eddy field developed. What began as a stable demarcation between water masses became a flow field dominated by warm and cold instabilities and intrusions. This dynamic transformation occurred over relatively short time (less than 5 days) and distance (several hundred kilometers) scales, testament to the vigorous activity in the IFF. These Lagrangian drifter measurements compose the first comprehensive, accurate near-surface velocity data set in the IFF region.

CHARACTERIZATION OF OSCR HF RADAR DATA IN MONTEREY BAY

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A 53-hour long record of surface current data from the OSCR HF radar system was gathered over Monterey Bay on 6-8 May 1995. In this study,OSCR data is evaluated with regard to semidiurnal (M2) and diurnal (Kl) tidal period fluctuations, the seabreeze, seabreeze influenced flow, and both standard and cannonical-day mean flow patterns. The OSCR data is considered on its own and in comparison to similar data types previously gathered by CODAR, a previously established Monterey Bay HF radar system. Two of three CODAR sites were co-located with the two OSCR sites.

Internal wave influence is observed in the M2 tidal constituent analysis and the seabreeze greatly influences fluctuations of the K1 tidal period. Results from analysis of OSCR data replicated or reinforced data and results from the CODAR system. Initial OSCR data appears not to have been significantly affected by possible distortion of the phased-array beam patterns. However, contamination of OSCR returns by simultaneous activation of the CODAR systems is apparent in the data.

ADRIATIC SEA CURRENT OBSERVATIONS USING ACOUSTIC DOPPLER CURRENT PROFILER (ADCP) MEASUREMENTS

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The measurement of absolute subtidal currents throughout the water column is a complex task, especially with the presence of strong high frequency events that continuously perturb the mean flow patterns. Shipboard Acoustic Doppler Current Profiler (ADCP) instruments provide a quick, easy way to measure currents relative to an underway vessel. The goal of this work is to analyze and process six shipboard ADCP data sets to study the absolute mean subtidal Adriatic Sea currents. Horizontal charts and vertical sections are presented for the absolute currents. A comparison with historical data, concurrent drifter and moored current meter observations confirms the validity of the ADCP measurements. These current measurements update regional oceanic models, refine the knowledge of basin circulation patterns, and improve our knowledge on how this circulation affects the remainder of the Mediterranean Sea.

WIND-FORCED MODELING STUDIES OF CURRENTS, MEANDERS, EDDIES, AND FILAMENTS OF THE CANARY CURRENT SYSTEM

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A high-resolution, multi-level, primitive equation ocean model is used to examine the response of an eastern boundary oceanic regime to both wind forcing and irregular coastline geometry. The focus of this study is the coastal region from 30°N to 42.5°N, a portion of the Canary Current System (CCS). To study the generation, evolution, and sustainment of the currents, meanders, eddies and filaments of the CCS, the model is forced from rest using seasonal climatological winds. To investigate the role of irregular coastline geometry, the first experiment uses climatological wind forcing along an idealized "straightened" coastline, while the second experiment uses the same wind forcing along an irregular coastline. In both cases a surface current, undercurrent, meanders, eddies, and filaments are generated. The results obtained while using the irregu-

lar, rather than the idealized coastline, however, show preferred eddy generation locations as well as enhanced growth of meanders, eddies, and filaments. The features produced by the model are consistent with available observations of the CCS. The model results support the hypothesis that both wind forcing and irregular coastline geometry are important mechanisms in the generation of many of the observed features of the CCS.

DEVELOPMENT OF A LOW FREQUENCY AMBIENT NOISE STORM MODEL FOR THE ARCTIC OCEAN

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The development of an ambient noise model for use in ice-covered Arctic waters is the primary goal of this research. The generation of ambient noise is considered to originate from large scale deformation of the ice cover (pressure ridge formation) which is caused on a synoptic scale by convergence of the ice cover due to wind stress/speed associated with the passage of Arctic storms.

The Arctic Storm Noise Model (ASNM) has been developed as a dynamic model to predict the occurrence of extreme noise events. The emphasis is on accurately predicting the large increases or decreases in ambient noise, which observations have shown to be in the order of 20 to 30 dB over a matter of hours.

ASNM was adapted from the Ambient Noise Directional Estimation System (ANDES) for use under the Arctic pack ice. ASNM predictions are compared quantitatively to noise measurements made by ice-mounted drifting buoys in the Arctic basin during the early 1990's. Results showed that for extreme events (<5th or >95th percentile) ASNM is accurate in predicting both the level of ambient noise and the large increases in the noise record.

Due to the encouraging results further improvements are recommended to increase the robustness of the model for potential tactical use by submarine units operating under the Arctic pack ice.

TOWED ARRAY PERFORMANCE IN THE LITTORAL WATERS OF NORTHERN AUSTRALIA

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The goal of this research was to investigate the performance of low frequency passive sonars in the Arafura Sea. Sound speed profiles representative of the wet and dry monsoon seasons and geoacoustic data were inputted into a finite element primitive equation transmission loss model to model the expected propagation at three frequencies, 10, 50, and 300 Hz. Initial detection ranges for several source/receiver depth combinations and geoacoustic areas (deep/shallow water) were compared and evaluated. Results demonstrate that low frequency (~10 Hz) detection ranges suffer due to cutoff frequency problems and to surface–decoupling loss. Propagation in deep water has the added disadvantage of excessive loss of signal power due to spherical spreading considerations. Conversely, higher frequencies (300 Hz) provided extended detection ranges in shallow water due to trapping of energy within the entire 50 m to 100 m water column.

Additionally, investigation into advantages to be gained through advanced signal processing techniques shows that improvements of the order of 10 to 15 dB of detection gain are possible through the utilization of inverse beamforming.

VARIATIONS ON AUTOCORRELATION MATCHING AND THE SIFT LOCALIZATION ALGORITHM

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As part of the existing acoustic transient localization program, a feasibility study was performed to apply existing algorithms to signals at higher carrier frequencies. The coherent matching, autocorrelation matching and SIFT algorithms are time domain Matched Field Processing algorithms based on arrival structures for single hydrophone applications. In previous studies, these algorithms were employed only at lower frequencies using ray propagation models to create the replicas with varying success. This study is meant to investigate the performance of the algorithms at higher frequencies, using both the University of Miami Parabolic Equation (UMPE) Model and the Hamiltonian Raytracing Program for the Ocean (HARPO), to give insight into the previously unexplained inconsistent behavior of the algorithms at low frequencies, to improve and optimize existing algorithms, to point out improvements to existing eigenray extraction programs, and to suggest additional signal processing on the signal. Simulations are performed and synthetic signals are generated using both the HARPO and UMPE models. The arrival structures are investigated and the relation between features in the arrival structures for matching and the physical parameters are identified. Some insight into the performance of the SIFT algorithm is gained which relates matching and physical parameters. Simulations lead to improvements and optimization of the algorithms and give insight into the performance at higher frequencies.

MODELING THE PERFORMANCE OF THE PT SUR HYDROPHONE ARRAY IN LOCALIZING BLUE WHALES

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The acoustic activity of the blue whale is widely documented yet poorly understood. Hypotheses for its vocalizations range from communication, bathymetric echolocation, and echolocation of zooplankton masses. Although extensive documentation of frequency structure and duration exists, a long-term monitoring of where and when the vocalizations are being made must be accomplished to test the validity of these theories.

The Naval Postgraduate School (NPS) Ocean Acoustic Observatory (OAO), which operates a former Sound Surveillance System (SOSUS) at Pt Sur, presents itself as a potentially valuable tool in the detection and localization of Pacific blue whales. By estimating the transmission loss as a function of bearing, range, and frequency and synthesizing the ambiguity surface of various model-data linear correlation localization algorithms, an assessment of the array's expected performance for this purpose was obtained. Important findings of this modeling study include estimated maximum detection ranges are longer than 500 kilometers both seaward and along the continental slope due to array beamforming gains and matched field localization algorithms are accurate and robust in the presence of white noise. The application of the results of this study towards the development of a "real-time," large-area blue whale localization and tracking algorithm is promising.

TIME AND SPACE RESOLUTION AND MIXED LAYER MODEL ACCURACY

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The oceanic turbulent boundary layer is a critical region to understand for oceanic and atmospheric prediction. This thesis answers two fundamental questions: (i) what is the response of the ocean mixed layer system to transient forcing at the air sea surface? (ii) what is the necessary time and space resolution in an ocean mixed layer model to resolve important transient responses?

Beginning with replication of de Szoeke and Rhines' (1976) work, additional physical processes were added to include more realistic viscous dissipation and anisotropy in the three-dimensional turbulent kinetic energy (TKE) budget. These refinements resulted in modification of de Szoeke and Rhines' findings. First, TKE unsteadiness is important for a minimum of 10^5 seconds. Second, viscous dissipation should not be approximated as simply proportional to shear production. Third, entrainment shear production remains significant for a minimum of one pendulum-day.

The required temporal model resolution is dependent on the phenomena to be studied. This study focused on the diurnal, synoptic, and annual cycles, which the one-hour time step of the Naval Postgraduate School model adequately resolves. The study of spatial resolution showed unexpectedly that model skill was comparable for 1 m, 10m and even 20m vertical grid spacing.

DIURNAL VARIATION OVER THE TROPICAL MONSOON REGIONS DURING NORTHERN SUMMER 1991

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This study examines diurnal variation of convection over western India, the Bay of Bengal, Indochina and the northern South China Sea during the 1991 northern summer monsoon using combined Japanese (GMS) and Indian (INSAT) geostationary satellite data, ECMWF 850 hPa wind data, and NCEP sea surface temperature analyses.

The diurnal cycle is examined in terms of spatial and temporal structure prior to onset and during the monsoon. The northern South China Sea is examined to determine how different periods of synoptic influences resulted in an anomalously strong diurnal signal during June. The wind and Sea Surface Temperature (SST) data are used to examine the relationship between the diurnal variation of convection and both low-level convergence and vertical latent heat fluxes.

Convection over west India is most common during May and June and starts as a diurnal system over land that becomes organized and propagates westward over the east Arabian Sea. The Bay of Bengal follows the classic land-sea breeze model and convection is modulated by convergence between the land breeze and large-scale monsoon flow. The diurnal cycle is generally enhanced over the ocean during active phases of convective activity. The maximum latent heat fluxes generally occurs prior to maximum convection due to strong monsoon flow enhancing evaporation.

THE GENERATION AND CHARACTERIZATION OF SURF ZONE AEROSOLS AND THEIR IMPACT ON NAVAL ELECTRO-OPTICAL SYSTEMS

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Aerosols are generated within the surf zone by the breaking of waves along the beachfront. The concentration of aerosols, size, and structure of these plumes are impacted by the air/sea temperature differences, breaker type, and local winds. During the EOPACE I surf experiment at LaJolla, CA, it was observed that under light wind conditions, standing aerosol plumes would develop to heights of 31 meters. Concurrently, transmittance at FLIR wavelengths would be degraded up to 35%. Similar aerosol plume structures were observed during EOPACE II at Moss Landing, CA. These results are used to characterize and forecast standing plume conditions that may impact electro-optical transmission.

COMPARISON OF LOS ALAMOS NATIONAL LABORATORY (LANL) PARALLEL OCEAN PROGRAM (POP) MODEL FIELDS WITH PACIFIC SURFACE DRIFTER MEASUREMENTS

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Model fields from the Los Alamos National Laboratory (LANL) Parallel Ocean Program (POP) 1/6 degree global circulation model are compared to measurements from over 1300 satellite-tracked surface drifters that were deployed in the tropical Pacific (20N to 20S), between 1979 and 1994, during the TOGA Pan-Pacific Current Study. Geographic averages of 5-day averaged drifter velocity estimates for 2-deg. latitude x 8-deg. longitude bins are compared to similarly binned 3-day model snapshots from September 1992 to October 1994. Eulerian comparisons of the model mean velocities and their observed counterparts show that the model u mean is slightly higher in the equatorial region, while the model v mean is 50% greater in this region. Model SST mean values are 20% less than observed values in the eastern equatorial Pacific. Model variability is about 20% less than the observed quantity in equatorial regions, and 50% less poleward of l0S and 10N. Both model and observed velocity and SST covariance fields imply a net heat convergence toward the equator with the largest values in the region of instability waves north of the equator. Model velocity fields are used to produce simulated Lagrangian trajectories for uniform and nonuniform deployment strategies. Autocorrelation, time and length scales, diffusivity, and polarization are calculated and ensemble-averaged by 5 deg. latitude bands for comparison with drifter-based Lagrangian statistics. Time and length scales are too long and diffusivities too low compared to observations, but data sampling in the simulated fields was biased by trajectories that overlap current regimes. These differences, in both Eulerian and Lagrangian comparisons, may be related to the lack of a surface mixed layer, inadequate representation of wind forcing, still too coarse grid resolution, and deficiencies in simulating the mean structure of the density field in the model. They are also partly related to lack of weighted averages to account for non-uniform drifter sampling.

SET-UP UNDER A NATURAL WAVE

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Field measurements from a cross-shore array of two pressure sensors to measure waves and eight manometer tubes to measure mean water elevation are used to examine set-down/up across the surf zone. The manometer tubes are connected to differential pressure transducers onshore allowing continuous set-down/up measurements. Flume measurements of set-down/up are also examined. Measured values are compared with numeric set-up values incorporating roller theory describing wave breaking. The model has two free parameters, B representing the vertical fraction of the wave covered by the roller and y a scaling parameter for wave steepness. Optimal values of both are chosen by model fitting. Inclusion of the surface roller improves the set-up model fit to both beach and flume measurements.

MONITORING TEMPERATURE VARIABILITY ALONG THE CALIFORNIA COAST USING ACOUSTIC TOMOGRAPHY

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The electronic emissions of a low-frequency sound source placed by the Acoustic Thermometry of Ocean Climate (ATOC) project on Pioneer Seamount were monitored by a bottom-lying receiver on Sur Ridge from April 1996 to February 1997. The processed signals show a stable arrival pattern that was repeated in all the transmissions during the 11 months. Using the processed data, a tomographic analysis to study the coastal ocean variability along this California transmission path was conducted. Systematically, the analysis involved forward acoustic modeling of the arrival structure using ray theory, associating the observed arrivals with the modeled arrivals, extracting the travel times of the arrivals, inverting the travel times for temporal and spatial temperature changes, and interpreting the observed temperature variations. In particular, the tomographic estimate was compared to the temperature and wind measurements from an in situ mooring deployed by the Monterey Bay Aquarium Research Institution (MBARI). The comparison showed that the tomographic estimate is of high quality and that the observed temperature variations were linked to coastal upwelling and downwelling events. The data, methods, and result, demonstrating fully the feasibility of using tomography to study coastal temperature variability in central California on a long-term basis, are presented.

A SIMULATION STUDY OF ACOUSTIC VARIABILITY DUE TO INTERNAL SOLITARY WAVES ON THE MID-ATLANTIC CONTINENTAL SHELF

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During the summer of 1995, a multi-institutional field study called Shallow-Water Acoustic Random Medium (SWARM) was conducted in the Mid-Atlantic Bight continental shelf region off the coast of New Jersey. Environmental and acoustic sensors were deployed as part of SWARM to measure and characterize the internal waves and their impact on the spatial and temporal coherence of the acoustic transmissions. As part of the environmental monitoring network, two bottom-moored, upward-looking acoustic Doppler current profilers (ADCPs) were deployed. Large-amplitude, non-linear, internal soliton wave packets were observed to propagate shoreward from the shelfbreak. Based on the ADCP observations, a

kinematic model of the soliton wave packets was developed to synthesize the corresponding temporal and spatial fluctuations in the sound-speed field. Using a coupled normal-mode sound propagation model and the synthesized sound speed variations, the variability of sound pressure and of the modal amplitudes for a 224 Hz CW transmission were simulated. The auto and cross-correlations of sound pressure at different depths, and of the modal amplitudes at a fixed range, were computed in an effort to estimate the vertical and temporal scales of the fluctuating sound field. The simulation method, the simulated acoustic variability as well as the results of the correlation analysis are presented and discussed in this report.

A STUDY OF SOUTH ASIAN MONSOON CONVECTION AND TROPICAL UPPER EASTERLY JET DURING NORTHERN SUMMER 1991

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This work studies the 1991 northern summer monsoon over India and surrounding areas using Japanese (GMS) and Indian (INSAT) geostationary satellite data, the ECMWF objective re-analysis, and the NMC sea surface temperature analysis. Monthly and weekly mean fields are first used to examine the development of the monsoon over the entire domain and to identify the timing of the onset over India. Latent heat fluxes are shown to be important in the monsoon development process. The relationship between the synoptic variations of a convective index derived from satellite data and the upper tropospheric easterly jet show two possible effects of cumulus convection on the easterly jet. The first is a forcing of the jet maximum near southern India when convection flares up to the north in the monsoon trough. This is believed to be the result of the Coriolis acceleration of the southward outflow of the local Hadley cell. The second is a damping of the upper jet by cumulus momentum transport that occurs at the same location as the jet maximum. This second effect is most clearly shown in regions of strong vertical shear.

A STOCHASTIC MODEL FOR SHOALING WAVES

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Boussinesq-type equations for weakly nonlinear, weakly dispersive waves have been used extensively to model wave shoaling on beaches. Deterministic Boussinesq models cast in the form of coupled evolution equations for the amplitudes and phases of discrete Fourier modes (Freilich and Guza, 1984) describe the shoaling process accurately for arbitrary incident wave conditions, but are numerically cumbersome for predicting the shoaling evolution of continuous spectra of natural wind-generated waves. Here an alternative stochastic formulation of a Boussinesq model (Herbers and Burton, 1996, based on the closure hypothesis that phase coupling between quartets of wave components is weak) is implemented that predicts the evolution of a continuous frequency spectrum and bispectrum of waves normally incident on a gently sloping beach with straight and parallel depth contours. The general characteristics of the model are examined with numerical simulations for a wide range of incident wave conditions and bottom profiles. Stochastic and deterministic Boussinesq model predictions are compared to field observations from a cross-shore transect of bottom pressure sensors deployed on a barred beach near Duck, NC, during the recent DUCK94 Experiment. Predictions of the two models are similar and describe accurately the observed nonlinear shoaling transformation of wave spectra.

VARIATIONS IN COASTAL CIRCULATION OFF CENTRAL CALIFORNIA, SPRING-SUMMER 1993, 1994, 1995

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In situ measurements of hydrographic, wind, and Acoustic Doppler Current Profiler (ADCP) data, along with satellite imagery, were collected off central California during the upwelling season of three successive years, 1993, 1994, and 1995. The survey was conducted three times in the late spring of each year within 75 km of the coastline from Point Reyes south to Cypress Point, along a region of irregular coastline and bathymetry. The upwelling circulation was found to be distinct from the California Current System and unlike circulation defined in recent conceptual models for this region. Persistent or recurring circulation features were observed throughout the upwelling season that acted as dynamic boundaries to this system. A varied response by upwelling centers in this region to a fairly uniform wind field was also observed. Water upwelled within this system is considered to recirculate and mix, retained within the system for a relatively long period of time. This long retention period of upwelled water is thought to promote the high productivity associated with coastal upwelling. The circulation patterns found in this region, and the dynamic boundaries to the principal equatorward current may represent upwelling circulation at multiple locations in this and in other eastern boundary current systems, inshore of the principal equatorward current.

LAGRANGIAN MEASUREMENTS OF EDDY CHARACTERISTICS IN THE CALIFORNIA CURRENT SYSTEM

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During the Eastern Boundary Current program in 1993, 96 Argos-tracked surface drifters, drogued to 15 m depth, and satellite thermal imagery were used to provide a description of the mesoscale features in the California Current System off the northern California coast. The drifter movements and satellite images revealed a highly energetic series of filaments and eddies that dominated the summer flow field off the coast, similar to those noted in the earlier CODE, OPTOMA, and CTZ studies. Winter mesoscale activity in the region was less energetic, with the principal feature being the poleward-flowing Davidson Current.

Translation rates for mesoscale eddies were deduced from drifter trajectories in the summer period. Translation rates, vorticity, divergence, and eddy center positions were also estimated for a cyclone and anticylone sampled in July and September, respectively, by constraining observed drifter velocities to a linear Taylor expansion in the least square sense. Translation rates from this technique were similar to those observed from previous shipboard surveys and drifter motions. Using observations over 7 (12) days, the cyclonic (anticyclonic) eddy was determined to have a translation rate of 3.7 (4.2) cm/s to the southwest. The least square technique, applied to shorter time periods, however, provided unreliable estimates of eddy properties when drifters were not evenly distributed around the eddy.

ANALYSIS OF MODAL TRAVEL TIME VARIABILITY DUE TO MESOSCALE OCEAN STRUCTURE

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This dissertation examines the effects of ocean mesoscale variability on acoustic arrival time patterns for two separate ocean environments. First, for an open ocean environment away from strong boundary currents, the effects of randomly phased linear baroclinic Rossby waves on acoustic travel time are shown to produce a variable overall spreading in the arrival pattern, primarily producing a delay in the later, axial arrivals. Second, using the state-of-the-art Semtner-Chervin eddy resolving global ocean circulation model coupled with the University of Miami Parabolic Equation (UMPE) acoustic propagation model, the effects of a fluctuating frontal region created by the California Current on the temporal, spatial and seasonal variability in the individual modal arrivals of the first thirty modes over a one-model-year time span is assessed. The mesoscale bias variability is also examined by comparing the various peak arrival times for the range-averaged environment to that of the range-dependent environment. To support this work, approximate "wide angle PE mode functions" were newly developed which form a different basis set for modal expansion from that obtained using standard normal mode theory. These new mode functions provide the proper basis set for modal expansion of the field computed by wide-angle PE models.

COMPARISON OF TRAJECTORIES GENERATED BY THE NOAA OIL SPILL MODEL TO TRAJECTORIES PRODUCED USING HF RADAR-DERIVED SURFACE CURRENTS IN MONTEREY BAY

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High Frequency radar-derived surface current data was examined for use in oil spill trajectory prediction in Monterey Bay. Trajectories produced by the NOAA/HAZMAT On-Scene Spill Model (OSSM), using different combinations of surface currents and winds, were compared to trajectories generated using HF radar-derived surface currents. Currents examined included output from the NOAA circulation model and canonical-day averages of the HF radar-derived current maps, either as spatially constant but temporally varying currents (time file) or spatially varying two-hourly current patterns (grids). Results from OSSM using the NOAA circulation model currents did not compare favorably with HF radar-derived trajectories inside Monterey Bay. OSSM produced realistic overall trajectory patterns throughout the Bay using the canonical-day grid current files and, to a lesser degree, canonical-day time file currents. Both OSSM and HF radar-derived trajectories show sensitivity to release time. In the afternoon, trajectories display rapid southeastward flow. At night, currents are weaker. The week's worth of direct surface current data used in this study was found to be representative of the seasonal summertime pattern in Monterey Bay and provided realistic current patterns for use in OSSM for initial trajectory prediction in lieu of real-time HF radar-derived surface currents.

USE OF SHIP-MOUNTED ACOUSTIC DOPPLER CURRENT PROFILER DATA TO STUDY MESOSCALE OCEANIC CIRCULATION PATTERNS IN THE ARCHIPIELAGO DE COLON (GALAPAGOS ISLANDS) AND THE GULF OF THE FARALLONES

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Ship-mounted acoustic Doppler current profiler (ADCP data are used to study regional ocean patterns around the biologically rich regions of the Archipiélago de Colón (Galápagos Islands) and the Gulf of the Farallones to test the assumptions about the circulation derived primarily from hydrographic samples. West of the Galapagos, an equatorial undercurrent transport ~7 Sv was present in November 1993, which decelerated within 30 km of the archipelago, shoaled, and diverged with a strong deflection to the southwest. A method of removing tidal velocities from ADCP measurements by creating an empirical model of the tides and using it to predict and subtract the tides in described. It is shown that in the Gulf of the Farallones, a large number of observations, typically more than acquired on one cruise, are necessary to reduce tidal model error. Detided ADCP data are used to describe the circulation in the Gulf under various wind conditions. Over the continental slope, surface-to-depth poleward flow is present throughout the year. During wind relaxations, poleward flow strengthens and warmer, fresher water is transported onshore.

DEEP MIXED LAYER ENTRAINMENT

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A bulk turbulence-closure mixed layer model is generalized to allow prediction of very deep polar sea mixing. The model includes unsteady three-component turbulent kinetic energy budgets. In addition to terms for shear production, pressure redistribution, and dissipation, special attention is devoted to realistic treatment of thermobaric enhancement of buoyancy flux and to Coriolis effects on turbulence. The model is initialized and verified with CTD data taken by R/V *Valdivia* in the Greenland Sea during winter 1993-1994. Model simulations show: (i) mixed layer deepening is significantly enhanced when the thermal expansion coefficient's increase with pressure is included; (ii) entrainment rate is sensitive to the direction of wind stress because of Coriolis; and (iii) the predicted mixed layer depth evolution agrees qualitatively with the observations. Results demonstrate the importance of water column initial conditions, accurate representation of strong surface cooling events, and inclusion of the thermobaric effect on buoyancy, to determine the depth of mixing and ultimately the heat and salt flux into the deep ocean. Since coupling of the ocean to the atmosphere through deep mixed layers in polar regions is fundamental to our climate system, it is important that regional and global models be developed that incorporate realistic representation of this coupling.

BATHYMETRY FROM HYPERSPECTRAL IMAGRY

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This work used hyperspectral imagery to derive shallow water depth estimates. A technique to classify substrates and estimate reflectance values for the substrate types is the major contributions of this work. This was accomplished by masking different bottom types based on spectra, effects that were not included in previous methods. HYDICE data was taken over Lake Tahoe on June 22, 1995. The high altitude of the lake provided a low aerosol content within the atmosphere. This allowed for relatively straightforward atmospheric corrections. This was substantially easier than in an oceanic environment. The atmospheric radiative transfer code MODTRAN3.0 was used to model the atmospheric conditions at the time of the experiment. The radiative transfer code HYDROLIGHT3.5 was used to model the attenuation coefficients of the relatively clear water of the lake. Minimal river input and low chlorophyll concentrations made it simpler to determine these values. Making use of the full spectral content of data within the optical range, multiple substrates were differentiated and masked off. This allowed for an estimation on wet substrate reflectance and a straightforward calculation of bottom depth.

BUBBLE INJECTION BREAKING WAVES

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Wave energy dissipation due to bubble penetration and inferred turbulent penetration from breaking waves in the surf zone is related to the total energy of dissipation. Bubble injection is inferred from void fraction measurements obtained using a 2.3 meter vertical array of eight conductivity sensors extending from the bottom through the water surface. Potential energy and dissipation associated with bubble injection are calculated and compared with total wave dissipation. Total wave dissipation is calculated from the energy flux balance measured using an array of seven pressure sensors in the surf zone.

Percent of total wave potential energy of the bubbles due to spilling breakers is on the order of 0.18% to 0.62%, consistent with past measurements in the surf zone. Percent of the bubble potential energy dissipation rates to total wave dissipation in the cross-shore direction is on the order of 8% to 20%. The potential energy dissipation is largest immediately after injection, decaying exponentially after that. Bubble potential energy dissipation results within 1.2 seconds even for void fraction events greater than 36% and usually in less than 1.0 seconds. Energy dissipation was found linearly related (0.95 correlation coefficient) with the ratios of wave height to water depth, a measure of the percent of breaking waves within the surf zone.

THE ASSIMILATION OF SATELLITE ALTIMETER DATA INTO A GLOBAL EDDY RESOLVING OCEAN MODEL

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Two assimilation experiments have been conducted using the Semtner/Chervin Parallel Ocean Climate Model at 1/4° resolution to investigate the dynamical changes which occur with the application of the nudging method to incorporate sea surface height observations (with associated vertical corrections to temperature and salinity) into a global eddy resolving ocean model. The first experiment used a previous model run as the observational field to determine if the assimilation technique, nudging, produced significant changes in the simulated fields to adjust the model to the observed fields when starting at a statistically different initial condition. The twin experiment has shown that the model does respond to the inclusion of the observed fields. Both the surface fields and subsurface fields have been adjusted towards these synthetic observations. The second experiment involved the use of a combined altimetric sea surface height anomaly field from the ERS-1 and the T/P satellites. The surface height fields are extended vertically by using the Levitus 94 monthly climatological fields. This dissertation has shown that assimilation of surface height data and an associated vertical adjustment to temperature and salinity, modifies both the surface and subsurface fields. Changes can be seen in both prognostic and diagnostic quantities (such as heat content and meridional overturning) while remaining dynamically consistent with the numerics of the model itself. Comparison of the simulated fields with in situ observations of temperature and salinity show that the model has adjusted towards observation not included in the assimilation process.

A STUDY OF THE SURFACE HEAT BUDGET OF THE WEDDELL SEA USING A RADIATIVE TRANSFER MODEL DURING THE AUSTRAL WINTER 1994

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This study uses rawinsonde soundings and irradiance measurements taken in the Weddell Sea during the 1994 ANZFLUX experiment. A radiative transfer model was used to determine the influence of aerosols, cloud droplet size, and water content on the radiative heat budget of the Weddell Sea. The modeled irradiances were compared with observations, and the model calculated the upward longwave irradiance from the Weddell Sea ice pack. Turbulent heat fluxes were calculated and combined with radiative terms to provide a net heat flux at the ice surface. While turbulent heat flux is the major factor affecting the Weddell Sea's heat budget in windy conditions, during calm conditions longwave radiative transfer becomes important. The modeled downward irradiances were compared to results obtained from empirical equations developed for the Weddell Sea during the winter. The atmosphere above the Weddell Sea appears to have an aerosol structure similar to marine environments. Stratus clouds over the Weddell Sea appear to be made up of cloud droplets with an effective radius of 2.5 microns and a water concentration close to 0.05 grams per cubic meter. The dominant terms in the surface heat budget are the longwave irradiances with the upward longwave term being the largest.

MODELING STUDIES OF WIND AND THERMOHALINE FORCING ON THE CALIFORNIA CURRENT SYSTEM

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A high-resolution, multi-level, primitive equation model is initialized with climatological data to study the combined effects of wind and thermohaline forcing on the ocean circulation of the California Current System (CCS). The ocean circulation is generated by the model using a combination of climatological wind stress and thermohaline forcing. In the first experiment, the effects of thermohaline forcing alone are evaluated, in the second experiment, previously conducted, the effects of wind forcing are isolated, while in the third experiment, the combined effects of wind and thermohaline forcing are looked at. The results from the combined experiment show that even though the effects of wind forcing dominate the CCS, the additional effects of the thermohaline forcing results in the following: the seasonal development of a poleward surface current and an equatorward undercurrent in the poleward end of the model region; an onshore geostrophic component, which results in a temperature front and stronger surface and subsurface currents between Cape Mendocino and Point Arena; and a region of maximum eddy kinetic energy inshore of ~125°W between Cape Mendocino and Point Arena, associated with the temperature front. These model simulations are qualitatively similar to recent hydrographic, altimetric, drifter, and moored observations of the CCS.

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