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Summary of Research 1996, Department of Oceanography

Faculty of the Department of Oceanography, Naval Postgraduate School

Office of the Associate Provost and Dean of Research, Naval Postgraduate School.

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Monterey, California 93943-5138

SUMMARY OF RESEARCH 1996

Department of Oceanography

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Prepared for: Naval Postgraduate School
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NAVAL POSTGRADUATE SCHOOL
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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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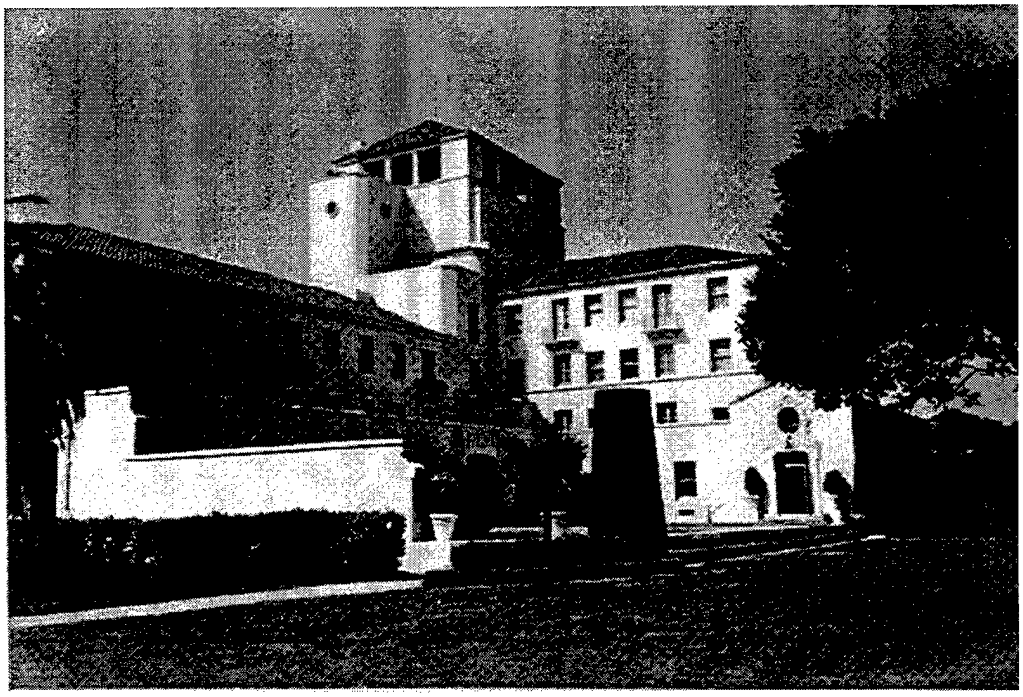
DEPARTMENT OF OCEANOGRAPHY

ROBERT H. BOURKE

CHAIR

THE NAVAL POSTGRADUATE SCHOOL MISSION

The mission of the Naval Postgraduate School is to increase the combat effectiveness of US and Allied armed forces and enhance the security of the USA through advanced education and research programs focused on the technical, analytical, and managerial tools needed to confront defense-related challenges.



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Preface

Research is an integral part of graduate education. At the Naval Postgraduate School (NPS), the goals of research are to:

- Provide a meaningful, high quality, capstone learning experience for our students.
- Keep faculty on the leading edge of advances in defense-related science, technology, management and policy to ensure that the latest information is incorporated into NPS courses and curricula.
- Apply faculty and student knowledge to enhance DoN/DoD operational effectiveness.

Pursuit of these goals increases the technical and managerial capability of the officer corps to keep pace with an increasingly complex defense posture in today's world.

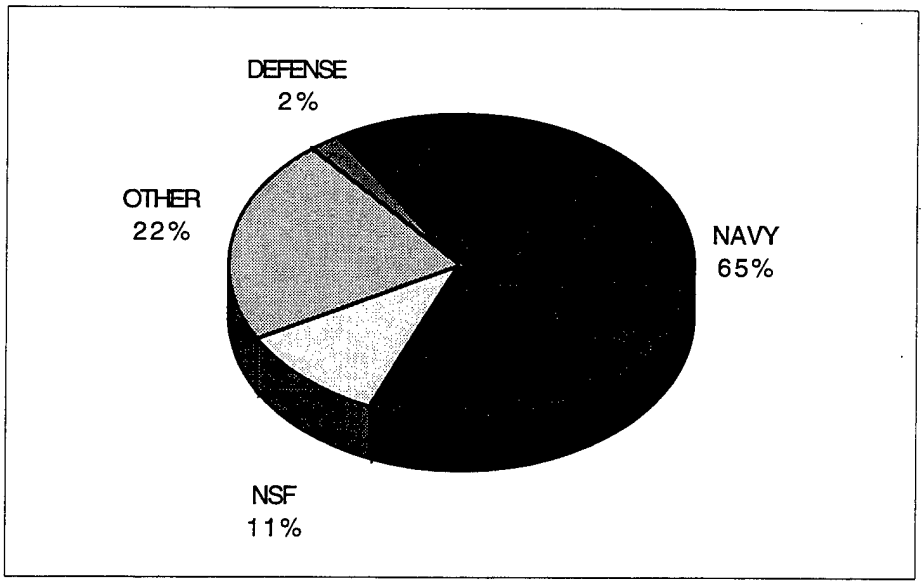
New technologies and policy changes will of course occur, necessitating changes in educational programs and stronger ties between the fleet and the support establishment. NPS must remain poised to face this challenge and to utilize emerging technologies and new policies within its curricula programs. Faculty, therefore, must stay abreast of these developments through a dynamic research program that helps fulfill the School's goals of excellence, uniqueness, and relevance.

The overall research program at NPS has three funded components. The Direct Funded Research and Institute for Joint Warfare Analysis Programs are institutionally funded within the School's operating budget. The Direct Funded Research Program is administered by the Associate Provost and Dean of Research. The Institute for Joint Warfare Analysis Program is administered by the Director of IJWA.

- The Direct Funded Research (DFR) Program provides funding to stimulate innovative research ideas of benefit to the DoN and may be used for cost-sharing with reimbursable research efforts. This funding ensures, in particular, that all Navy-sponsored NPS curricula are equitably supported, that new faculty are provided an opportunity to establish a research program of importance to DoN/DoD and other national security interests, and that faculty and students from across the campus are encouraged to interact with one another.
- The Institute for Joint Warfare Analysis Research 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 faculty research.
- The Reimbursable Research (RR) 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 policy makers throughout the Navy, DoD, and other government agencies as well as with the private sector in defense-related technologies. This ensures that NPS research remains highly regarded by academic peers and government officials and fosters a closer relationship between NPS and other outside organizations.

The three research programs are complementary and ensure that the overall research program is flexible, responsive, balanced and supportive of the unique needs of the military.

In 1996, the level of the research effort at the Naval Postgraduate School was 141 faculty workyears and exceeded 29 million dollars. Eighty percent of the research was funded by reimbursable sponsors and 20 percent was funded by the Naval Postgraduate School. Sixty-five percent of the work was performed for the Navy and the remainder was sponsored by other agencies, both DoD and non-DoD. A profile of the reimbursable program of the Department of Oceanography is provided in Figure 1:



Size of Program: $2,131K

Figure 1. Department of Oceanography - Sponsor Profile

Research at NPS is carried out by faculty in the School's eleven Academic Departments, four Interdisciplinary Groups and the School of Aviation Safety. In the pages that follow, research summaries are provided for projects undertaken by faculty in the Department of Oceanography during 1996. An overview and faculty listing are provided as an introduction. A list of publications is also included, if applicable. Abstracts for thesis advised by department faculty in 1996 complete this research summary.

Questions about particular projects may be directed to the Faculty Principal Investigator listed, the Department/ Group Chair, or the Department Associate Chair for Research. Questions may also be directed to the Research Office. General questions about the NPS Research Program should be directed to the Research Office at (408) 656-2098 (voice) or research@nps.navy.mil (e-mail).

August 1997

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DEPARTMENT SUMMARY

The Department of Oceanography has developed a broad research program focused on physical oceanography to meet the anticipated future needs of the Navy. Our 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.

Our 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 propagations and ambient noise and the impact that the wave climate exert on nearshore processes and beach character as pertains to mine/mine countermeasure and amphibious warfare.

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 observations.

The diverse talents of the faculty of the department are blended by the use of these various techniques to solve problems of common interest. Our 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 our 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 ONR, 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.

C.A. Collins, working with N. Garfield, R. Paquette and E. Carter, continued investigations of the California Inshore Current. 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.

P.C. Chu and R. H. Bourke, under the sponsorship of the Office of Naval Research (ONR), 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.

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.

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.

P.C. Chu, under the sponsorship of the Office of Naval Research, has 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, thermocline strength, ...) from vertical profiles.

P.C. Chu, 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.

N. Garfield is working with investigators from NOAA Pacific Marine Environmental Laboratory to successfully tag subsurface hydrothermal plumes and track them for two month periods.

Under the sponsorship of NELO, N. Garfield and R. Olson are conducting an investigation of nearshore bathymetric estimates derived from hyperspectral visible and infrared data.

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.

L. Ly in cooperation with Dr. P. Luong (NAVOCEANO), under multi-year sponsorship of the ONR 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, L. Ly, J. Paduan and Dr. P. Luong (NAVOCEANO) use the Monterey Bay COS to study the response of Monterey Bay to diurnal wind and tidal forcing.

J.D. Paduan, with funding from ONR, is undertaking studies of coastal circulation problems in Monterey Bay using High Frequency (HF) radar-derived currents and trajectories from satellite-tracked drifting buoys. 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. In the more offshore waters, he is using drifter trajectories from the California Current System to track individual ocean eddy features, and to compute statistics of their occurrences.

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.

C.A. Collins and P.-M. Poulain are analyzing ship-board Acoustic Doppler Current Profiler (ADCP) data collected during various NAVO and NATO/SACLANTCEN hydrographic surveys in the southern Adriatic and the Straits of Otranto areas.

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

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. 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

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 Sponsor is NUWC.

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 ANDES noise model has been modified to consider ice generated noise sources and is in the process of being verified. The sponsor is NPS and the Naval Undersea Warfare Center.

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. The work is funded by ONR.

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.

C.-S. Chiu is organizing 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 it 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.

C.-S. Chiu is studying the vertical structure, generation, propagation, spectral characteristics and acoustic effects of the nonlinear internal solitons on the New Jersey shelf. Data for the study were measured in the 1995 Shallow Water Acoustic Random Medium Experiment (SWARM '95). The work is funded by ONR.

K.B. Smith and 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

L. Le 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.

R.W. Garwood is sponsored by ONR to simulate the response of Lagrangian drifters, buoys, mines and AUV's 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.

A. Guest and R. Garwood have a three-year grant from 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.

R.W. Garwood is also funded by the National Science Foundation with a new four-year grant to study Polar Sea Convective Instabilities.

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 NSF 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.

T.P. Stanton and E.B. Thornton are involved in a program to study dissipation of shoaling surface gravity waves over the continental shelf in the new five-year ONR sponsored "Shoaling Waves" DRI.

Numerical Prediction And Data Assimilation

Under sponsorship of NSF, M. 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.

A.J. Semtner, Jr., under the 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 underway in the ocean using satellite data and model output.

With funding from the National Science Foundation two global 1/4-deg. simulations were made by A.J. Semtner and R. Tokmakian using an improved form of an earlier model and with the best available atmospheric forcing. In addition, satellite altimeter data were used to force the second run, so as to reconstruct the detailed turbulent global circulation of 1992-1996.

W. Maslowski and A.J. Semtner received a grant from Cray Research, Inc. to conduct Arctic Ocean research on massively parallel computers. A very successful 125-year simulation was conducted on a T3D machine in Alaska.

Extensive analyses of model output for the global ocean and regional areas were conducted by J. McClean and A.J. Semtner on 1/4- and 1/6-deg. results under sponsorship of the Department of Energy.

A fully coupled model of the Arctic Ocean and its dynamical ice cover was constructed through guidance of the joint NOAA research of W. Maslowski and Y. Zhang. Simulations with atmospheric forcing of 1979-96 were begun.

Marine Operations

M.P. Jessen and 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 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 reimbursable-funded research projects.

J.R. Clynch, conducted several studies in the application of the Global Positioning System 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 (PAR's). In addition he supported NISE-West in the planning for installation of a DGPS landing system in Antarctica. For the Defense Mapping Agency, J.R. Clynch studied methods of improving solutions from military GPS receivers to geodetic quality.

COASTAL MODELING STUDIES OF EASTERN BOUNDARY CURRENTS

Mary L. Batteen, Associate Professor
Department of Oceanography
Sponsor: Naval Postgraduate School

OBJECTIVES: The overall goals of this research are to investigate the generation, stability, and maintenance of currents and eddies in eastern boundary current (EBC) regions, and to better describe their contributing forcing mechanisms and their relative importance. To achieve these goals, process-oriented modeling studies will be used to explore the roles of wind and thermal forcing, coastal irregularities, and topography in the generation of currents and eddies in EBC regions.

SUMMARY: A high-resolution, primitive equation ocean model has been used to isolate the response of the Chile Current System to equatorward and seasonal wind forcing, and of the California Current System to seasonal wind forcing. In both systems, an equatorward surface current, a poleward undercurrent, upwelling, filaments, meanders, and eddies were simulated. A mixed (baroclinic/barotropic) process was shown to be responsible for the generation of meanders and eddies. The results from these experiments support the hypothesis that wind forcing is an important forcing mechanism for the generation of many of the observed features of EBCs.

PUBLICATION:

Batteen, M.L., Hu, C.-P., Bacon J.L., and Nelson, C.S., "A Numerical Study of the Effects of Wind Forcing on the Chile Current System," Research Activities in Atmospheric and Oceanic Modeling, CAS/JSC Working Group on Numerical Experimentation, Vol. 23, 8.4, February 1996.

Batteen, M.L., Wind-forced Modeling Studies of Currents, Meanders, and Eddies in the California Current System, Journal of Geophysical Research, 102, 985-1010, (accepted for publication).

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Littoral oceanography, ocean modeling, eastern boundary currents

EDDY-RESOLVING MODELING STUDIES OF THE LEEUWIN CURRENT

Mary L. Batteen, Associate Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: The purpose of this research is to study numerically the currents and eddies off Western Australia (W.A.) and Southern Australia (S.A.). The specific objectives were to determine current characteristics in both W.A. and S.A.; to determine dominant instability mechanisms for eddies in both regions; to determine the roles of irregular geometry and topography in the generation of currents and eddies; and to examine the effects from the additional contributions from the North West Shelf (NWS) waters and from salinity. This work is part of a continuing project which began in 1992 and ended in 1996.

SUMMARY: To address these objectives, the previously modeled W.A. domain was expanded to include the S.A. region. Model development included the opening up of the eastern boundary in the vicinity of Esperance (~ 121 E) and the incorporation of an irregular coastline, topography, and salinity into the model.

Two studies were conducted in 1996. The first study explored the impact of climatological ocean thermal forcing, from the Indian Ocean and from the NWS waters, and its effects on the instability mechanisms and current characteristics in the Leeuwin Current System (LCS) off W.A. and S.A. They showed that a poleward and eastward surface current, equatorward undercurrent, meanders and eddies were generated. The addition of the S.A. coastline added a significant amount of horizontal and vertical shear to the region. Maximum current velocities occurred at Cape Leeuwin,

while anticyclonic meanders and eddies occurred at preferred locations in the vicinity of coastal indentations and at Cape Leeuwin. Cold, cyclonic meanders and eddies formed from the limbs of the warm, anticyclonic eddies, and propagated westward as eddy pairs.

The second study explored the additional effect of salinity on the LCS. The question of whether salinity variability is an important consideration for defining the large-scale circulation of the LCS was addressed. Climatological temperature and salinity fields were used to calculate the salinity contribution to density and dynamic height fields in the LCS. While the temperature field was primarily linear, with warmest water to the north, the salinity fields were spatially inhomogeneous. A comparison of density fields, calculated with constant and variable salinity, showed that, off W.A., the density field is primarily determined by temperature. Off S.A., the density field is dependent on warm and salty (subtropical) and fresh and cold (sub-Antarctic) water masses. While the dynamic height fields, calculated with constant and variable salinity, showed similar flow patterns off W.A., different flow patterns were found off S.A.

PUBLICATIONS:

Huang, M.-J., and Batteen, M.L., "The Effect of Salinity on Density in the Leeuwin Current System," Naval Postgraduate School Technical Report, NPS-OC-96-001, June 1996.

Batteen, M.L., and Butler, C.L., "Modeling Studies of the Leeuwin Current System, submitted to Journal of Physical Oceanography, December 1996.

Batteen, M.L., and Huang, M.-J., "The Effect of Salinity on Density in the Leeuwin Current System," submitted to Journal of Geophysical Research, December 1996.

CONFERENCE PRESENTATION:

Batteen, M.L., and Braccio, P.G., "On the Effects of Coastal Irregularities on Eastern Boundary Current Systems," Eastern Pacific Ocean Conference, Timberline Lodge, OR, September 1996.

THESIS DIRECTED:

Huang, M.J., "The Effect of Salinity on Density in the Leeuwin Current System," Master's Thesis, Naval Postgraduate School, June 1996.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Littoral oceanography, coastal modeling, eastern boundary currents

CHAIR IN ARCTIC MARINE SCIENCE

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

OBJECTIVE: The Chief of Naval Research has established at the Naval Postgraduate School (NPS) a Chair in Arctic Marine Science. 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 IPA's and proposals and setting up visits and seminars for the Chair incumbent.

Due to funding limitations, the Chair was left vacant during FY96. CAPT Lawson Brigham USCG (Ret.) was selected as the Chairholder at that time and currently is serving in the Chair during FY97. To celebrate the 20th anniversary of the Arctic Chair a special session was convened at the Fall Annual American Geophysical Union meet-

ing on 17 December 1996. Thirteen of the nineteen Chairholders were present. Each speaker provided an overview of the advances made in the past 20 years in their particular field of polar marine science and the thrust that future programs should be directed towards in the next five to ten years.

CONFERENCE PRESENTATION:

Bourke, R.H., "History of the ONR Chair in Arctic Marine Science," 1996 Fall Meeting of American Geophysical Union, 17 December 1996, San Francisco, CA, abstract in: EOS, Trans., AGU, 77(46), F416, 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Arctic Ocean, sea ice

DEVELOPMENT OF AN ARCTIC LOW FREQUENCY AMBIENT NOISE MODEL

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

OBJECTIVE: The goal of this multiyear 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: Previous efforts, based on drifting ice-mounted ambient noise buoys, have shown the importance of wind speed, proximity to land and angular rotation of the ice pack due to the passage of a storm as being predominant factors in causing noise levels to exceed 95 percentile levels. During the past year the ANDES directional ambient noise model, designed for use in mid-latitude waters, was modified to reflect ice-generated noise due to the passage of storms. A source level spectral density was constructed based on analysis of the drifting buoy data. A source level matrix was devised that depended on wind speed, proximity to land and angular rotation of the wind field. Initial tests have indicated that these parameters and their assigned values reproduce the noise field quite well during both loud and quiet periods. We are now testing the parameterization scheme against several storms to determine its robustness. We also plan to test our model against data to be collected in fall 1996 from a submarine in Arctic waters. Future plans are to modify and use the PIPS model to compute the ice stress and deformation rate and relate this to noise level.

CONFERENCE PRESENTATION:

Wilson, J.H., Bourke, R.H., Ehret, L., and Collins, D.A., "A Low-Frequency Arctic Ambient Noise Model to Estimate Extreme Noise Events," Fall Meeting of the American Geophysical Union, 15 December 1996, San Francisco, CA, abstract in: EOS, Trans., AGU, 77(46), F381, 1996.

THESIS DIRECTED:

Collins, D.A., "Development of a Low Frequency Ambient Noise Storm Model of the Arctic Ocean," Master's Thesis, Naval Postgraduate School, December 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Arctic, ambient noise, storms, sea ice, ANDES

IMPACT OF BOTTOM REVERBERATION AND ENERGY SPREADING LOSS ON AN/SQS-53C PERFORMANCE IN SHALLOW WATER

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

OBJECTIVE: This is the third year 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 newly designed ALFS helicopter dipping sonar in shallow water.

SUMMARY: 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. These estimates were compared with measured data collected by *USS STUMP*. The comparisons were initially poor and required the acquisition and development of a full Hamilton geoacoustic model of the sedimentary subbottom.

An investigation into the cause and quantification of the time stretching of the echo level in shallow water, termed energy spreading loss (ESL), has recently been completed by Tanaka (1996). 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. The time domain Finite Element Parabolic Equation model, FEPE_SYN, was used to assess ESL. Model runs demonstrated that the shape of the pulse was modified during propagation in the shallow water column, splitting into several normal mode arrivals due to differences in group speeds among the modes. The time spread energy did not exhibit a gaussian distribution as previously assumed. ESL was found to initially increase rapidly with range out to an environmentally-dependent critical range (about 1000 m) but increased much more slowly thereafter. The difference between TL and ESL for sand and silt/clay bottom sediments is inversely related and very distinct, with ESL being large (5 to 10 dB) over highly reflective (i.e., sand) bottoms. In shallow water ESL is only weakly dependent on the shape of the sound speed profile because of the strong influence of acoustic energy with the upper and lower boundaries, regardless of profile shape.

PUBLICATION:

Scanlon, G.A., Bourke, R.H., and Wilson, J.H., "Estimation of Bottom Scattering Strength from Measured and Modeled Mid-Frequency Sonar Reverberation Levels," IEEE Journal of Ocean Engineering, 21(4), 440-451, 1996.

CONFERENCE PRESENTATIONS:

Tanaka, A., Wilson, J.H., and Bourke, R.H., "Impact of the Environment on Energy Spreading Loss in Shallow Water at High Frequencies," Third Joint Meeting: Acoustical Societies of America and Japan, Honolulu, HI, 4 December 1996, abstract in: Journal of the Acoustical Society of America, 100(4, Part 2), 2703, 1996.

THESIS DIRECTED:

Tanaka, A., "An Analysis of Energy Spreading Loss Associated with Tactical Active Sonar Performance in a Shallow Water Environment," Master's Thesis, Naval Postgraduate School, June 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Active sonar, energy spreading loss, shallow water, reverberation, geoacoustic models, AN-SQS/53C

RESEARCH OPPORTUNITIES FOR PROGRAM OFFICERS (ROPO) FOR DR. STEVEN R. RAMP'S "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 a month during the summer of 1996 wherein he completed the analysis and writing of the results obtained from several cruises to investigate the circulation of the CCS, namely the Point Sur Transect program and the Farallones Shelf/Slope Circulation study. He commenced analysis of the data from the ONR-funded Eastern Boundary Current Accelerated Research Initiative.

PUBLICATION:

Ramp, S.R., McLean, J.L., Collins, C.A., Semtner, A.J., Jr., and Hays, K.A.S., "Observations, Equations and Modeling of the 1991-92 El Nino Off Central California," Journal of Geophysical Research, (accepted).

CONFERENCE PRESENTATION:

Ramp, S.R., McLean, J.L., Collins, C.A., and Semtner, A.J., Jr., "Observations and Modeling of the 1991-1992 El Nino Off Central California," Ocean Sciences Meeting, February 1996, San Diego, CA, abstract in: EOS, Transactions, American Geophysical Union, 76(3), OS182, 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: California Current System, eastern boundary currents, fronts and eddies

DATA ANALYSIS FOR THE SWARM EXPERIMENT

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

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.

PUBLICATION:

"An overview of the 1995 SWARM Shallow Water Internal Wave Acoustic Scattering Experiment," IEEE Journal of Oceanic Engineering, 1996 (accepted).

CONFERENCE PRESENTATIONS:

Chiu, C.-S., Lynch, J.F., Orr, M., Taube, D.W., and Ng, S.L., "Observations, Characterizations, and Acoustic Effects of Nonlinear Internal Waves on the Mid-Atlantic Bight Continental Shelf," 3rd Joint Meeting, Acoustical Societies of America and Japan, Waikiki, HI, 2-6 December 1996.

"The New Jersey Shallow Water Acoustic Random Media Propagation Experiment," ONR/ARPA Shallow-Water Acoustic Workshop, Stennis Space Center, MS, 1-3 October 1996.

THESIS DIRECTED:

Taube, D.W., "Observations and Characterizations of Nonlinear Internal Waves on the Mid-Atlantic Bight Continental Shelf," Master's Thesis, Naval Postgraduate School, June 1996.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments

KEYWORDS: Internal solitons, shallow-water acoustics

DEVELOPMENT OF THE POINT SUR OCEAN ACOUSTIC OBSERVATORY

Ching-Sang Chiu, Associate Professor
Department of Oceanography
Sponsors: University of Washington, Cornell University and Monterey Bay Aquarium Research Institute

OBJECTIVES: The objectives are: (1) to preserve the functionality of the Point 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 1996, the development of the Point Sur Ocean Acoustic Observatory (OAO) in the Monterey Bay National Marine Sanctuary for the purpose of undersea research was continued. The four sponsoring organizations 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. The 1996 OAO research projects include nuclear test ban treaty monitoring, ocean circulation studies, and marine mammal studies.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments

KEYWORDS: Coastal acoustics, SOSUS, dual-use

MIDDLE ATLANTIC BIGHT FIELD STUDY

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

OBJECTIVES: In collaboration with Woods Hole Oceanographic Institution (WHOI), the objectives of this multi-year, multi-institutional field study in the Middle Atlantic Bight are: (1) To obtain a high resolution description of the spatial and temporal evolution of the shelf-break front, and to clarify the mechanisms by which eddies are formed and detached, (2) To determine the mean and seasonally varying circulation of the adjacent slope water, and characterize

the mesoscale fluctuations in relation to shelf-break processes, (3) To determine the effects of basic mean shelf-break frontal thermal structure on the propagation of sound from the continental slope to the continental shelf, (4) To relate the temporal and spatial variability of acoustic propagation from the continental slope to the continental shelf with the associated variability of the shelf-break front, and (5) To make fully three-dimensional tomographic images of the region of the shelf-break front for use in the physical oceanographic studies.

SUMMARY: The measurement program of this study includes two intensive three-week experiments, one in July (summer) 1996 and the other one in February (winter) 1997. The summer experiment was successfully completed. A comprehensive data set was collected by a suite of new observational tools. These include SeaSoar, remote sensing and an acoustic tomography array consisting of three transceivers and two vertical hydrophone arrays straddling the shelf-break front. The processing and analysis of the summer data are currently in progress. Specifically, the Naval Postgraduate School 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.

PUBLICATION:

Chiu, C.-S., Miller, C.W., and Lynch, J.F., "Optimal Mode Filtering of Bandpass Signals Using an Undersized, Sparse Vertical Hydrophone Array: Theory and a Shallow-water Experimentation," IEEE Journal of Oceanic Engineering, 1996 (accepted).

CONFERENCE PRESENTATIONS:

Chiu, C.-S., "3-D Acoustic Effects," 2nd PRIMER Workshop, Woods Hole, MA, 23 May, 1996.

PRIMER Group (R.C. Beardsley, K.H. Brink, M.J.,Caruso, C.-S. Chiu, G.G. Gawarkiewicz, J.F. Lynch, J.H. Miller, R. Pickart, A.R. Robinson and K.B. Smith), "Shelfbreak PRIMER - an Integrated Acoustic and Oceanographic Field Study in the Middle Atlantic Bight," ONR/ARPA Shallow-Water Acoustic Workshop, Stennis Space Center, MS, 1-3 October, 1996.

Smith, K.B., and Chiu, C.-S., "Three-dimensional effects on broadband pulse propagation near the mid-Atlantic Bight," 3rd Joint Meeting: Acoustical Societies of America and Japan, Waikiki, Hawaii, HI, 2-6 December 1996.

THESES DIRECTED:

D'Agostino, A.F., "Three Dimensional Acoustic Effects in the Middle Atlantic Bight," Master's Thesis, Naval Postgraduate School, June 1996.

Pierce, D.D., "Range-Dependent Passive Source Localization using Data from the Barents Sea Tomography Experiment," Ph.D. in Engineering Acoustics, Naval Postgraduate School, June 1996.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments

KEYWORDS: Frontal dynamics, shallow-water acoustics, coastal tomography

USA-CHINA CONFERENCE ON SHALLOW WATER ACOUSTICS

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

OBJECTIVE: The objective of the conference is to identify the outstanding basic research topics in shallow-water acoustics which might form the basis of a joint USA-China experiment in the Yellow Sea.

SUMMARY: Sponsored by the ONR Underwater Acoustics Program and hosted by the Superintendent of NPS, the Principal Investigator convened and chaired a three-day Joint USA-China Conference on Shallow-Water Acoustics in December, 1995 at NPS. The attendees included the top-notch acoustical oceanographers and underwater acousticians from the two countries (9 Chinese and 12 Americans). Several outstanding research topics in coastal ocean acoustics which are of common interest to both countries, such as the effects of internal waves and sediment structure on sound transmission, were identified and discussed. The scientific approaches, logistic issues, available technology, environmental conditions and sites for a potential collaborative experiment in the Yellow Sea to study the topics identified were also discussed and assessed. A plan of action was recommended.

PUBLICATION:

Chiu, C.-S., and Denner, W.D., "Report on the Office of Naval Research USA-China Conference on Shallow-Water Acoustics, 19-21 December 1995," Naval Postgraduate School Technical Report NPS-OC-97-001PR.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments

KEYWORDS: Shallow-water acoustics

ANALYSIS OF THE U.S. MASTER OCEANOGRAPHIC OBSERVATION DATA SET (MOODS) FOR THE SURFACE HEAT BUDGET OF THE ARCTIC OCEAN (SHEBA) EXPERIMENT

Peter C. Chu, Associate Professor
Robert H. Bourke, Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The long-term goal is to develop a diagnostic/prognostic system for analyzing polar ocean observational data and simulating physical processes, and in turn to understand the circulation and thermohaline structure. The diagnostic part of the system includes the parametric model, statistical model, and P-vector model. The prognostic part is the primitive ocean circulation model. Our focus is on the western part of the Arctic Ocean including the Beaufort Sea and Chukchi Sea. The scientific/technical objectives of this project are to analyze more than 15,000 historical (1920-93) T, S profiles in the Beaufort Sea and surrounding waters from the Navy's MOODS data in order to provide useful information for the refinement and optimization of the Surface Heat Budget of the Arctic Ocean (SHEBA) Experiment, and to develop a data assimilation system for blending the 2-D SHEBA data with the 4-D historical data.

SUMMARY: (1) Data Analysis Schemes: Only limited quality synoptic data are available for the Beaufort Sea. Therefore, the existing MOODS data was first partitioned according to various geographical and seasonal categories. Categories were based on data taken outside or behind the ice edge, in deep or shallow water, in Barrow Canyon, etc. Then two models were developed: a parametric model for analyzing vertical profiles, and a statistical model for obtaining temporal and spatial decorrelation scales for each sub-region. (2) Data Assimilation Scheme: The MOODS data was assimilated by using the Harvard Ocean Model and obtained temporally varying synoptic T, S fields. (3) A statistical model has been developed to obtain the temporal and spatial decorrelation scales for regional seas. The Beaufort Sea and Chukchi Sea thermohaline temporal and spatial variability has been identified and defined for various seasons and sub-regions in these seas. (4) A parametric model has been developed for obtaining physical characteristics (SST, mixed layer depth, halocline depth, thermocline depth, halocline strength, thermocline strength, ...) from vertical profiles.

This research greatly enhances the understanding of the Beaufort Sea and the surrounding area thermohaline variability and circulation. The models established in this project can be used widely for the other regional seas. The parametric and statistical models have been transferred to the Naval Oceanographic Office for MOODS data processing.

PUBLICATIONS:

Chu, P.C., "The S-Transform for Obtaining Localized Spectra," Marine Technology Society Journal, 29, 28-38, 1996.

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.

CONFERENCE PRESENTATIONS:

Chu, P.C., and Bourke, R.H., 1996, "Beaufort Sea Temporal and Spatial Thermohaline Variability. SHEBA Phase 1," Principle Investigator Meeting, Seattle, WA, 17-18 September 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: S-Transform, Beaufort Sea, thermohaline variability

CIRCULATION AND DIFFUSION STUDIES IN THE SOUTH CHINA SEA

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

OBJECTIVE: The main goal is to develop a nowcast/forecast capability for the semi-enclosed seas for overcoming two major weaknesses in the regional oceanic models, namely, uncertainty in lateral open boundary conditions and large truncation error using sigma coordinate coastal models.

SUMMARY: During the current year the following were developed: (1) an optimization method has been developed for determining open boundary conditions of coastal models, and (2) several new difference schemes (sixth-order difference scheme, high-order compact schemes, and combined compact schemes) to reduce errors in the coastal models.

PUBLICATIONS:

Chu, P.C., Fan, C.W., and Ehret, L.L., "Determination of Ocean Boundary Conditions from Interior Observational Data," Journal of Atmospheric and Oceanic Technology, in press, 1996.

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, in press, 1996.

Chu, P.C., and Fan, C.W., "Sixth-order Difference Scheme for Sigma Coordinate Ocean Models," Journal of Physical Oceanography, in press, 1996.

Chu, P.C., Lu, S.H., and Chen, Y.C., "Temporal and Spatial Variabilities of the South China Sea Warm and Cool Pools," Journal of Geophysical Research, submitted, 1996.

Chu, P.C., and Fan, C.W., "Compact Difference Scheme for Sigma Coastal Ocean Models," Journal of Geophysical Research, submitted, 1996.

Chu, P.C., and Fan, C.W., "Increment Vector Transfer Method for Determining Open Boundary Condition of the Csanady Shelf Model from Interior Values," Proceedings, Coastal Oceanic and Atmospheric Prediction, American Meteorological Society, 150-154, 1996.

Chu, P.C., and Ehret, L.L., "Effects of Stratification and Continental Slope on the Shelf Break Isolation," Proceedings, Coastal Oceanic and Atmospheric Prediction, American Meteorological Society, 22-27.

Chu, P.C., Huang, M.J.,Fu, E.X., "Formation of the South China Sea Warm-core Eddy in Boreal Spring," Proceedings, Eighth Conference on Air-Sea Interaction, American Meteorological Society, 155-159, 1996.

Chu, P.C., Tseng, H.C., and Chang, C.P., "South China Sea Warm Pool Detected from the Navy's Master Oceanographic Observational Data Set (MOODS)," Proceedings, Eighth Conference on Air-Sea Interaction, American Meteorological Society, 176-180, 1996.

CONFERENCE PRESENTATIONS:

Chu, P.C., "Naval Ocean Analysis and Prediction," First Special Operations Force (SOF) METOC Conference, McDill AFB, FL, 11-13 March 1996.

Chu, P.C., "An AXBT Survey of the South China Sea in May 1995," The Third Conference on East Asia and Western Pacific Meteorology and Climate, Chung-Li, Taiwan, 16-18 June 1996.

Chu, P.C., "A New Difference Scheme for Reducing Error in Sigma Coordinate Ocean Models," International Southwestern Atlantic Physical Oceanography Workshop, Sao Paulo, Brazil, 12-14 August 1996.

Chu, P.C., "A Z-Sigma Difference Scheme for Reducing Error in Sigma Coordinate Ocean Models," International POM Workshop, Princeton, NJ, 10-12 June 1996.

Chu, P.C., "An Optimization Method for Determining Open Boundary Conditions of the Coastal Ocean Models," International Southwestern Atlantic Physical Oceanography Workshop, Sao Paulo, Brazil, 12-14 August 1996.

Chu, P.C., "Towards Accurate Littoral Zone Ocean Prediction," U.S.-British Ocean Modeling Workshop, Monterey, CA, 8-10 October 1996.

Chu, P.C., and Fan, C.W., "Increment Vector Transfer Method for Determining Open Boundary Conditions," American Meteorological Society Annual Meeting, Atlanta, GA, 28 January-2 February 1996.

Chu, P.C., and Ehret, L.L., "Effects of Stratification and Continental Slope on the Shelf Break Isolation," American Meteorological Society Annual Meeting, Atlanta, GA, 28 January-2 February 1996.

Chu, P.C., Huang, M.J., Fu, E.X., "Formation of the South China Sea Warm-core Eddy in Boreal Spring," American Meteorological Society Annual Meeting, Atlanta, GA, 28 January-2 February 1996.

Chu, P.C., Tseng, H.C., and Chang, C.P., "South China Sea Warm Pool Detected from the Navy's Master Oceanographic Observational Data Set (MOODS)," American Meteorological Society Annual Meeting, Atlanta, GA, 28 January-2 February 1996.

Chu, P.C., and Fan, C.W., "Sixth-order Compact Difference Schemes for Error Reduction in Ocean Models," American Geophysical Union Fall Meeting, San Francisco, CA, 15-19 December 1996.

Ehret, L.L., Chu, P.C., Edmons, N.L., and Tseng, C.J., "A Three Dimensional Numerical Simulation of the South China Sea Circulation," American Geophysical Union Fall Meeting, San Francisco, CA, 15-19 December 1996.

THESIS DIRECTED:

Edmons, N.L., "Studies of the South China Sea Circulation and Thermal Structure Using a Three Dimensional Numerical Model," Master's Thesis, Naval Postgraduate School, September 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Primitive equation model, open boundary, optimization, compact difference scheme, combined compact difference scheme

ENVIRONMENTAL EFFECTS ON JOINT WARFARE SIMULATIONS

Peter C. Chu, Associate Professor
Department of Oceanography
Sponsor: Naval Postgraduate School-Institute of Joint Warfare Analysis

OBJECTIVE: The objectives of this project are to quantitatively estimate the value added of knowing the environment in joint warfare scenarios and to investigate environmental effects on the joint warfare simulations. In the current year, the sensitivity was tested of the Navy's Research, Evaluation, and Systems Analysis (RESA) wargame to the environment. At the present, realistic environments are being incorporated into high-resolution, high-fidelity wargames of mine warfare.

SUMMARY: The principal investigator has initiated a joint Navy-Army research project 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).

In 1996, the sensitivity of the RESA wargame to the environment was estimated. A NPS student, LT Gottshall (USN), is pursuing an M.S. thesis along this line under the joint supervision of Peter Chu (NPS) and Ted Bennett (NAVOCEANO). RESA was implemented for the western Pacific (near the Sea of Japan) wargaming at various METOC scenarios. The results were presented at the 64th MORSS Conference in Fort Leavenworth, KS, 18-20 June 1996.

The western Pacific RESA wargaming with various METOC scenarios has been transferred to NPS Wargaming Lab for education and training purposes.

PUBLICATION:

Chu, P.C., "Environmental Effects on Naval Warfare Simulation," Leveraging Technology for the Military Analyst, Military Operations Research Society, Alexandria, VA, 105, 1996.

CONFERENCE PRESENTATION:

Chu, P.C., Gottshall, E.L., Halwaches, T., and Bennett, T., "Environmental Effects on Navy RESA Simulations," 64th Military Operations Research Society (MORS) Symposium, U.S. Army Combined Arms Center, Fort Leavenworth, KS, 18-20 June 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: METOC scenario, modeling and simulation, environmental factors

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 finished: (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 our 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, and (5) High accurate difference schemes were developed. The parametric and statistical models has been transferred to the Naval Oceanographic Office for MOODS data processing.

PUBLICATIONS:

Chu, P.C., "The S-Transform for Obtaining Localized Spectra," Marine Technology Society Journal, 29, 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, in press, 1996.

Chu, P.C., Fan, C.W., and Ehret, L.L., "Determination of Open Boundary Conditions from Interior Observational Data," Journal of Atmospheric and Oceanic Technology, in press, 1996.

Chu, P.C., Fralick, C.R., Haeger, S.D., and Carron, M., "A Parametric Model for the Yellow Sea Thermal Variability," Journal of Geophysical Research, in press, 1996.

Chu, P.C., Tseng, H.C., Chang, C.P., and Chen, J.M., "South China Sea Farm Pool Detected from the Navy's Master Oceanographic Observational Data Set (MOODS)," Journal of Geophysical Research, in press, 1996.

Chu, P.C., and Fan, C.W., "Sixth-order Difference Scheme for Sigma Coordinate Ocean Models," Journal of Physical Oceanography, in press, 1996.

Chu, P.C., Lu, S.H., and Chen, Y.C., "Temporal and Spatial Variabilities of the South China Sea Warm and Cool Pools," Journal of Geophysical Research, submitted, 1996.

Chu, P.C., and Fan, C.W., "Compact Difference Scheme for Sigma Coastal Ocean Models," Journal of Geophysical Research, submitted, 1996.

Chu, P.C., and Fan, C.W., "A Three-point Combined Compact Difference Scheme," Journal of Computational Physics, submitted, 1996.

CONFERENCE PRESENTATIONS:

Chu, P.C., "Naval Ocean Analysis and Prediction," First Special Operations Force (SOF) METOC Conference, McDill AFB, FL, 11-13 March 1996.

Chu, P.C., "A New Difference Scheme for Reducing Error in Sigma Coordinate Ocean Models," International Southwestern Atlantic Physical Oceanography Workshop, Sao Paulo, Brazil, 12-14 August 1996.

Chu, P.C., "An Optimization Method for Determining Open Boundary Conditions of the Coastal Ocean Models," International Southwestern Atlantic Physical Oceanography Workshop, Sao Paulo, Brazil, 12-14 August 1996.

Chu, P.C., "Towards Accurate Littoral Zone Ocean Prediction," U.S.-British Ocean Modeling Workshop, Monterey, CA, 8-10 October 1996.

THESIS DIRECTED:

Edmons, N.L., "Studies of the South China Sea Circulation and Thermal Structure Using a Three Dimensional Numerical Model," Master's Thesis, Naval Postgraduate School, September 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: S-Transform, P-vector method, Thermohaline variability, parametric model, statistical model

SHALLOW WATER ANALYSIS AND FORECAST SYSTEM FOR THE SOUTH CHINA SEA

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

OBJECTIVE: The main goal is to establish a nowcast system for regional seas, including the South China Sea. This system will have the capability of diagnosing the three dimensional velocity, temperature, and salinity fields from satellite and sparse in-situ observations. This system will be easily embedded into the prediction system (e.g., Princeton Ocean Model). The combined nowcast/forecast system will greatly enhance existing operational capability.

SUMMARY: During the current year the following tasks were finished: (1) A statistical model has been 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 has been developed and validated. (3) A parametric model has been developed for obtaining physical characteristic, (SST, mixed layer depth, thermocline depth, thermocline strength, ...) from vertical profiles, (4) An optimization method has been developed for determining the open boundary conditions of coastal models, (5) A new diagnostic model (P-vector Model) has been validated, and (6) Synoptic forcing functions has been included into the SWAFS-SCS Model. The parametric and statistical models has been transferred to the Naval Oceanographic Office for MOODS data processing.

PUBLICATIONS:

Chu, P.C., "The S-Transform for Obtaining Localized spectra," Marine Technology Society Journal, 29, 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, in press, 1996.

Chu, P.C., Fan, C.W., and Ehret, L.L., "Determination of Ocean Boundary Conditions from Interior Observational Data," Journal of Atmospheric and Oceanic Technology, in press, 1996.

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Chu, P.C., and Ehret, L.L., "Effects of Stratification and Continental Slope on the Shelf Break Isolation," Proceedings, Coastal Oceanic and Atmospheric Prediction, American Meteorological Society, 22-27.

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Chu, P.C., Tseng, H.C., and Chang, C.P., "South China Sea Warm Pool Detected from the Navy's Master Oceanographic Observational Data Set (MOODS)," Proceedings, Eighth Conference on Air-Sea Interaction, American Meteorological Society, 176-180, 1996.

CONFERENCE PRESENTATIONS:

Chu, P.C., "Naval Ocean Analysis and Prediction," First Special Operations Force (SOF) METOC Conference, McDill AFB, FL, 11-13 March 1996.

Chu, P.C., "An AXBT Survey of the South China Sea in May 1995," The Third Conference on East Asia and Western Pacific Meteorology and Climate, Chung-Li, Taiwan, 16-18 June 1996.

Chu, P.C., "Oceanic Experimental Implementation of SCSMEX," International South China Sea Monsoon Experiment (SCSMEX) Workshop. Chung-Li, Taiwan, 18 June 1996.

Chu, P.C., "A New Difference Scheme for Reducing Error in Sigma Coordinate Ocean Models," International Southwestern Atlantic Physical Oceanography Workshop, Sao Paulo, Brazil, 12-14 August 1996.

Chu, P.C., "An Optimization Method for Determining Open Boundary Conditions of the Coastal Ocean Models," International Southwestern Atlantic Physical Oceanography Workshop, Sao Paulo, Brazil, 12-14 August 1996.

Chu, P.C., "Towards Accurate Littoral Zone Ocean Prediction," U.S.-British Ocean Modeling Workshop, Monterey, CA, 8-10 October 1996.

Chu, P.C., and Fan, C.W., "Increment Vector Transfer Method for Determining Open Boundary Conditions," American Meteorological Society Annual Meeting, Atlanta, GA, 28 January-2 February 1996.

Chu, P.C., and Ehret L.L., "Effects of Stratification and Continental Slope on the Shelf Break Isolation," American Meteorological Society Annual Meeting, Atlanta, GA, 28 January-2 February 1996.

Chu, P.C., Huang, M.J.,Fu, E.X., "Formation of the South China Sea Warm-core Eddy in Boreal Spring," American Meteorological Society Annual Meeting, Atlanta, GA, 28 January-2 February 1996.

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Chu, P.C., "A Z-Sigma Difference Scheme for Reducing Error in Sigma Coordinate Ocean Models," International POM Workshop, Princeton, NJ, 10-12 June 1996.

Chu, P.C., and Fan, C.W., "Sixth-order Compact Difference Schemes for Error Reduction in Ocean Models," American Geophysical Union Fall Meeting, San Francisco, CA, 15-19 December 1996.

Ehret, L.L., Chu, P.C. Edmons, N.L., and Tseng, C.J., "A Three Dimensional Numerical Simulation of the South China Sea Circulation," American Geophysical Union Fall Meeting, San Francisco, CA, 15-19 December 1996.

THESES DIRECTED:

Edmons, N.L., "Studies of the South China Sea Circulation and Thermal Structure Using a Three Dimensional Numerical Model," Master's Thesis, Naval Postgraduate School, September 1996.

Nicklin, M.S., "A Study of the Relationship Between South Asian Monsoon Convection and Tropical Upper Easterly Jet Using INSAT Data," Master's Thesis, Naval Postgraduate School, December 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Primitive equation model, P-vector, S-transform, thermohaline variability, parametric model, statistical model

GLOBAL POSITIONING SYSTEM ADVANCED TECHNIQUES

James R. Clynch, Research Professor
Department of Oceanography
Sponsor: Defense Mapping Agency

OBJECTIVE: The objective of this project is to investigate methods of utilizing Global Positioning System to enhance the acquisition of geographic positions.

SUMMARY: The DoD has purchased a huge number of small GPS receivers known as the Precision Lightweight GPS Receiver (PLGR) for all services. This will likely be the "receiver of opportunity" in quick reaction events. It was not intended to provide geodetic quality results however. The characteristics of this receiver were investigated to determine its potential and techniques developed for improving the accuracy of its coordinates. Several sets of data in controlled moving vehicles were acquired. These were analyzed. It was found that moderately accurate positions (20 cm level) could be obtained even under low dynamic conditions utilizing data provided at the computer interface port of the PLGR. This work also pointed up some generic characteristics of Precise Positioning Service GPS solutions which will have and influence on using any PPS receiver.

DoD KEY TECHNOLOGY: Sensors

KEYWORDS: GPS

GLOBAL POSITIONING SYSTEMS (GPS) AIRBORNE PRECISION APPROACH RADAR VALIDATION SYSTEM

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

OBJECTIVE: The objective of this project is to design a low cost GPS system with off the shelf equipment that can be used to validate at the 1 m level Navy Precision Approach Radar performance and demonstrate that system.

SUMMARY: The requirements for this system require that both a set of flight data and the supporting ground surveys. In addition, the flight data analysis system should be compatible with that used in earlier programs by NISE West. These requirements were met with Ashtech MD-XII receivers. These were obtained and used in the development and demonstration of the system. Off the shelf survey post processing software was not provided as it is available from the vendor directly and not needed the system development.

Much of the work went into determining how to utilize the equipment and development of the software to provide a direct analysis of the radar performance. This was done and the system was tested at Point Mugu NAS in September 1995. A Naval Postgraduate School trajectory generation program was adapted to this project in order to allow the use of different receivers in flight testing. The data from the PT Mugu flight test was analyzed. It was found that the system was capable of calibrating a Precision Approach Radar (PAR) at a level better than 0.1 deg in elevation and azimuth.

DoD KEY TECHNOLOGY AREAS: Sensors, Air Vehicles, Electronics

KEYWORDS: GPS, landing systems, precision approach radars

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 four years. Experimental data at both McMurdo and South Pole on scintillation effects were taken over two years. Demonstration DGPS landing systems were utilized in Antarctica and the results of these demonstrations compared with on board truth systems. The effects of ice motion have been studied and method to accommodate it designed. During 1996 the effort focused on moving the technical evaluations into something that could be purchased. This involved discussions with the FAA, the RTCA, and many vendors. The results of previous work were reported at the Ionospheric Effects Symposium.

CONFERENCE PROCEEDING:

Clynch, J., and Aarons, J., "High Latitude GPS Observations and Receiver Constraints," Proceedings Ionospheric Effects Symposium, Alexandria, VA, 7-9 May 1996.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Electronics, Sensors

KEYWORDS: GPS, landing systems

CALIFORNIA UNDERCURRENT STUDIES

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

OBJECTIVE: To understand the dynamics and kinematics of the California Undercurrent off Central California. The following questions formed the basis for our investigations. What is the mean pattern of poleward and equatorward flow off Pt. Sur? What are the poleward transports of heat and salt? Is the California Undercurrent continuous along the west coast, or is it a series of discontinuous currents? Is there a reference level that can be used for geostrophic calculations? How can various velocity measuring techniques be used in a consistent manner?

SUMMARY: Past work involved 19 research cruises occupying a transection of CTD and Pegasus stations extending westward from Point Sur. Data from these cruises have been used to define the water mass structure and to determine the current structure between the coast and 200 km offshore. During the last year, work continued on investigating the dynamics of the California Undercurrent, the subsurface nearshore poleward-flowing jet. Analysis of 31 RAFOS floats launched in the eastern Pacific were completed and two manuscripts submitted. Major findings are the dynamics of the Undercurrent and the formation from Undercurrent waters of submesoscale coherent vortices that travel westward in the interior.

PUBLICATIONS:

Collins, C.A., Garfield, N., Paquette, R.G., and Carter, E., "Lagrangian Measurements of Subsurface Poleward Flow between 38 N and 43 N along the West Coast of the United States During Summer," Geophysical Research Letters, 23(18), 2461-2464, 1996.

Garfield, N., Collins, C.A., Paquette, R.G., and Carter, E., "Lagrangian Exploration of the California Undercurrent, 1992-1995," Journal of Physical Oceanography, 1996.

Collins, C.A., Garfield, N., Mascarenhas, A.S., and Spearman, M.G., "Ocean Current Measurements Across the Entrance to the Gulf of California in April and December, 1992," Under revision for Journal of Geophysical Research, 1996, (submitted).

CONFERENCE PRESENTATIONS:

Collins, C.A., Garfield, N., Paquette, R.G., Rago, T.A., "Lagrangian Measurements of Deep (1500 m) Flow Adjacent to California and Oregon," AGU Fall Meeting, San Francisco, CA., EOS 77(46) F344, 1996.

Garfield, N., Collins, C.A., Paquette, R.G., Rago, T.A., and Carter, E., "Lagrangian Measurements of the California Undercurrent Off Central and Northern California," AGU Fall Meeting, San Francisco, CA., EOS 77(46) F344, 1996.

THESIS DIRECTED:

Parker, Heather A., "Variations in Coastal Circulation Off Central California, Spring-Summer of 1993, 1994, and 1995," Master's Thesis, Naval Postgraduate School, December 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Ocean circulation, absolute velocity measurements, Eastern Pacific circulation, Lagrangain subsurface circulation.

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 were made 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. Data are available for January, February, November and December 1993, and for 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.

Preliminary tidal current analysis was conducted using a least-squares regression technique. The results indicate substantial tidal currents (especially for the M2 component) with a magnitude reaching 20 cm/s in the southern Adriatic. This high-frequency current analysis is to be continued in 1997. Tidal signals will be removed and the residual circulation will be mapped using objective analysis methods. The ADCP observations will be compared to other ocean current observations (i.e., from moored ADCP's). Dynamical explanations for the observed circulation patterns will be sought.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Ocean currents, Adriatic Sea, Straits of Otranto

LAGRANGIAN MEASUREMENTS OF A SUBSURFACE HYDROTHERMAL PLUME

Newell Garfield, Research Assistant Professor
Curtis A. Collins, Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: This was a high risk, rapid response, proposal to deploy RAFOS floats in recently formed hydrothermal plumes in order to track the plumes after formation.

SUMMARY: Three floats were prepared for plume tracking. The first effort to tag a plume formed over the Juan de Fuca Ridge was unsuccessful because the plume was not located. A second plume formed over the Gorda Ridge was successfully tagged with a RAFOS float in April 1996. The float surfaced in June, 1996, allowing researchers to relocate the plume for sampling and deployment of another RAFOS float. This float remained in the plume until it surfaced prematurely in November 1996.

CONFERENCE PRESENTATIONS:

Baker, E.T., Massoth, G.J., Lupton, J.E., Walker, S.L., Tennant, D.A., Wilson, C., and Garfield, N., "Time-series Sampling of Hydrothermal Event Plume(s) from the 1996 Gorda Ridge Eruption," AGU Fall Meeting, San Francisco, CA., EOS 77(46) F1, 1996.

Lupton, J.E., Baker, E.T., Garfield, N., Green, R., and Rago, T.A., "Successful Tracking of a Hydrothermal Event Plume with a RAFOS Neutrally-buoyant Drifter," AGU Fall Meeting, San Francisco, CA, EOS 77(46) F1, 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Ocean circulation, mid-ocean hydrothermal plumes, water type tagging and tracking, Lagrangian subsurface circulation

NEAR-SHORE BATHYMETRIC ESTIMATES FROM HYPERSPECTRAL IMAGERS

Newell Garfield, Research Assistant Professor
Department of Oceanography
Richard C. Olsen, Associate Professor
Department of Physics
Sponsor: Navy Tactical Exploration of National Capabilities (TENCAP) Office

OBJECTIVE: To investigate the utility of estimating near-shore bathymetry from hyperspectral visible imagery. The goal is to adapt and extend the methodology and algorithms for extracting bathymetry estimates from hyperspectral visible imagery.

SUMMARY: Bathymetric estimation techniques using LANDSAT multispectral data were found to suffer because there was no way to classify different substrates types and to estimate reflectance values for the different substrates. The major contribution, to date, from this project is an approach to first classify substrate types, and then to estimate the reflectance value for each substrate type. This is done by performing principal component analysis on the full spectral information for the scene. A scene from Lake Tahoe, CA, was used to test the method, and the results show a marked improvement over earlier techniques.

THESIS DIRECTED:

Stuffle, L. Douglas, "Bathymetry from Hyperspectral Imagery," Master's Thesis, Naval Postgraduate School, December 1996.

DoD KEY TECHNOLOGY AREAS: Other (Remote Sensing)

KEYWORDS: Bathymetry, environmental monitoring, remote sensing

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: (i) realistic mixed layer physics, (ii) ice thermodynamics, and (iii) 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 com-

bination 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.

PUBLICATIONS:

Jiang, L., and Garwood, R.W., Jr., "Three Dimensional Simulations of Overflows on Continental Slopes," Journal of Physical Oceanography, Vol. 26, No. 7, 1214-1233, July 1996.

Garwood, R.W., Jr., and Guest, A.A., "Greenland Sea Convection Instabilities," Report of the First ACSYS SEA-ICE/ OCEAN MODELLING WORKSHOP, Hamburg, Germany, 13-15 December 1993, World Climate Research Programme, WCRP Report No. 12, Ed. by P. Lemke, October 1996.

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

CONFERENCE PRESENTATIONS:

Garwood, R.W., Jr., "Organized Structures of Turbulence in the Polar-Sea Oceanic Planetary Boundary Layer," Invited speaker at Workshop on Polar Processes in Global Climate, Cancun, Mexico, 13-15 November 1996.

Garwood, R.W., Jr., "The Turbulent Kinetic Energy Budget and Fluxes in the Labrador Sea Convective Boundary Layer," Invited speaker at ONR Workshop on Labrador Sea Modeling and Drifter Data Assimilation, San Francisco, CA, 17 December 1996.

Jiang, L., and Garwood, R.W., Jr., "Numerical Study of the Denmark Strait Overflow and the Generation of Surface Cyclonic Eddies," Fall Meeting of the American Geophysical Union, San Francisco, CA, Transactions of the American Geophysical Union, Vol. 77, No. 12, OP21A-5, 15-19 December 1996.

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

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 (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: (i) suggesting strategies for drifter deployment, and (ii) 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:

Jiang, Lin, and Garwood, R.W., Jr., "Three Dimensional Simulations of Overflows on Continental Slopes," Journal of Physical Oceanography, Vol. 26, No. 7, 1214-1233, July 1996.

Garwood, R.W., Jr., and Guest, A.A., "Greenland Sea Convection Instabilities," Report of the First ACSYS SEA-ICE/ OCEAN MODELLING WORKSHOP, Hamburg, Germany, 13-15 December 1993, World Climate Research Programme, WCRP Report No. 12, ed. by P. Lemke, October 1996.

Harcourt, R., Jiang, L., and Garwood, R.W., Jr., "Numerical Simulation of Drifters Response to Labrador Sea Convection, Part I: Free Convection," Prepared for the Office of Naval Research, Code 322OM, 56 pp., September 1996.

CONFERENCE PRESENTATIONS:

Garwood, R.W., Jr., "The Turbulent Kinetic Energy Budget and Fluxes in the Labrador Sea Convective Boundary Layer," Invited speaker at ONR Workshop on Labrador Sea Modeling and Drifter Data Assimilation, San Francisco, CA, 17 December 1996.

Harcourt, R.R., "Simulation of Isobaric and Lagrangian Drifters in Free and Forced Convection," ONR Workshop on Labrador Sea Modeling and Drifter Data Assimilation, San Francisco, CA, 17 December 1996.

Harcourt, R.R., Jiang, L., and Garwood, R.W., Jr., "Numerical Simulation of Drifter Response to Labrador Sea Convection," Fall Meeting of the American Geophysical Union, San Francisco, CA, Transactions of the American Geophysical Union, Vol. 77, No. 12, OP11A-6, 15-19 December 1996.

Jiang, Lin, and Garwood, R.W., Jr., "Numerical Study of the Denmark Strait Overflow and the Generation of Surface Cyclonic Eddies," Fall Meeting of the American Geophysical Union, San Francisco, CA, Transactions of the American Geophysical Union, Vol. 77, No. 12, OP21A-5, 15-19 December 1996.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Environmental Quality, Sensors, Surface/Under Surface Vehicles, 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. A suite of numerical models that have been developed for and/or applied to turbulent boundary layer and air-sea interaction problems in the Oceanic Planetary Boundary Layer (OPBL) Laboratory, where a principal goal is the verification and improvement of a generalized mixed layer/entrainment zone parameterization in OGCM's 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 understand the tropical ocean mixed layer system. In this second year of the three-year study, progress has been made in several areas: (1) One-dimensional model development and testing. OPBL1D, the NPS bulk turbulence closure oceanic planetary boundary model has a unique entrainment zone parameterization. It was demonstrated that including entrainment zone physics in tropical ocean prediction is crucial. It was also using microstructure measurements provided by Jim Moum from the Tropic Heat Experiment to verify the mixed layer model results, (2) Extensive development of OGCM/ML, the embedded ocean general circulation-mixed layer model has been done these first two years. 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 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. Also, the diurnal cycle in heat flux needs to be included for realistic vertical transport of heat and momentum, (3) Salinity has been added to the OGCM model and the effects of precipitation on the ocean mixed layer system are being examined using both the 1-D and 3-D models. This allows stochastic simulation of rain events and patchiness in the wind stress associated with mesoscale atmospheric convection, (4) More realistic radiation absorption has been incorporated into the OGCM model, (5) The Large-Eddy Simulation (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 circulations have been shown to develop for mid-latitude cases, even in the absence of surface gravity wave physics. The Langmuir circulations predicted by the LES change their structure with reduced rotation (high Rossby number). The LES model has also been used to verify the constants used in the turbulence closure scheme of the 1-D and 3-D mixed layer modFels, and (6) Additional large eddy simulation experiments have begun to evaluate the role of the northward component of planetary rotation at low latitudes. A very interesting dependence was found of the existence of Langmuir rolls upon the direction of the wind stress, relative to the total planetary rotation vector. Mixing in the oceanic turbulent boundary layer is indeed enhanced for the trade winds and decreased for westerlies.

CONFERENCE PRESENTATION:

Garwood, R.W., Jr., "Large-Eddy Simulation of Turbulence in the Global Oceanic Planetary Boundary Layer," U.S. Delegate and Invited speaker at International Workshop on U.S.-U.K. Modeling, Monterey, CA, 8-10 October 1996,

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

T.H.C. Herbers, Assistant Professor
Department of Oceanography
Sponsor: Office of Naval Research

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 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 will be developed that incorporates the effects of a gently sloping bottom and nonlinear interactions. A directional buoy and an array of bottom pressure recorders will be deployed on the inner shelf offshore of Duck, NC, during the SandyDuck experiment, to test predictions of nonlinear interactions and estimate energy dissipation rates.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Ocean surface waves, nonlinear interactions, continental shelf

NEARSHORE WAVE PROCESSES

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

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 numerical implementation is currently underway. An extensive array of instruments will be deployed on the beach near Duck, NC, during the SandyDuck experiment to test model predictions of wave shoaling.

CONFERENCE PRESENTATIONS:

Feddersen, F., Guza, R.T., Elgar, S., and Herbers, T.H.C., "Cross-shore Structure of Longshore Currents During Duck94," 25th International Conference on Coastal Engineering, Orlando, FL, 2-6 September 1996.

Herbers, T.H.C., and Burton, M.C., "Nonlinear Shoaling of Directionally Spread Waves on a Beach," Journal of Geophysical Research, (submitted).

Lippmann, T.C., Herbers, T.H.C., and Thornton, E.B., "Infragravity Wave Pressure and Velocity Variance in the Nearshore," Journal of Geophysical Research, (submitted).

Norheim, C.A., Herbers, T.H.C., and Elgar, S., "A Stochastic Model for Shoaling Waves," American Geophysical Union Fall Meeting, San Francisco, CA, 15-19 December 1996.

THESIS DIRECTED:

Evangelidis, D.A., "Infragravity Waves on the Continental Shelf," Master's Thesis, Naval Postgraduate School, June 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Ocean surface waves, nearshore processes, surf on beaches

NONLINEAR INTERACTIONS IN OCEAN SURFACE WAVES

T.H.C. Herbers, Assistant Professor
Department of Oceanography
Sponsor: Office of Naval Research

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., Herbers, T.H.C., and Guza, R.T., "Nearshore Observations of Nonlinear Ocean Surface Gravity Waves," Naval Research Reviews, Vol. XLVIII, No. 3, 41-52, 1996.

OTHER:

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, (submitted).

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Ocean surface waves, nonlinear interactions, sea floor pressure

PROPAGATION OF SURFACE WAVES ACROSS THE CONTINENTAL SHELF

T.H.C. Herbers, Assistant 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 recent 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). Directional wave data were collected with a coherent array of pressure sensors in 8 m depth, 1 km from shore (deployed and maintained by the Army Corps of Engineers), and a 3-m discuss buoy in 50 m depth, 100 km from shore (deployed and maintained by the National Data Buoy Center).

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 are low or moderate, the swell energy varied weakly across the shelf, consistent with predictions of a linear propagation model. The attenuation of swell by dissipation (e.g., bottom friction or whitecapping) or scattering processes appears to be weak. During high-energy conditions, strong nonlinear interactions and wave breaking caused a dramatic evolution of wave spectra across the inner shelf.

PUBLICATION:

O'Reilly, W.C., Herbers, T.H.C., Seymour, R.J., and Guza, R.T., "A Comparison of Directional Buoy and Fixed Platform Measurements of Pacific Swell," Journal of Atmospheric and Oceanic Technology, Vol. 13, No. 1, 231-238, 1996.

THESIS DIRECTED:

Hendrickson, E.J., "Swell Propagation Across a Wide Continental Shelf," Master's Thesis, Naval Postgraduate School, March 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Ocean surface waves, continental shelf, swell

SPECTRAL REFRACTION MODEL FOR SHALLOW WATER WAVES

T.H.C. Herbers, Assistant Professor
Department of Oceanography
Sponsor: Naval Research Laboratory

OBJECTIVE: The main objective of this project is to improve predictions of swell transformation over complex nearshore bathymetry.

SUMMARY: In this project a shallow water wave transformation model was implemented to benefit ongoing Navy research and military exercises in the vicinity of Camp Pendleton, CA. The spectral refraction model predicts accurately the effects of complex bathymetric features (e.g., shoals, islands) on the propagation of swell, and thus is a useful addition to the NAVO suite of wave modeling programs.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Wave and surf prediction, refraction, continental shelf

NUMERICAL MODELING OF MONTEREY BAY CIRCULATION

Lin Jiang, Research Assistant Professor
Department of Oceanography
Sponsor: Naval Postgraduate School

OBJECTIVE: This objective of this research is to develop a nowcast/forecast system of the Monterey Bay (MOB) for the Navy based on a state-of-the-art coastal ocean model (Princeton Ocean Model-POM), data assimilation and a grid

generation techniques. The grids used in this study are both orthogonal (rectangular) and curvilinear, coastline-following, nearly-orthogonal which are designed using grid generation technique (GGT). These grids are designed using grid generation technique which improve numerical model efficiency by packing grid where necessary, without increasing the total number of grid points. The data is from all sources, such as satellite products and *in situ* observations, and includes fields for currents, sea surface heights, temperature, salinity, waves, and tides. Various data assimilation schemes are to be tested in the MOB model simulation.

SUMMARY: A coastal ocean sigma coordinate model of Monterey Bay with realistic bottom topography and coastlines is developed using the Princeton Ocean Model (POM) and a grid Generation Technique (GGT) to study the horizontal pressure gradient errors associated with the MOB steep topography. The submarine canyon in MOB features some of the steepest topography encountered anywhere in the world's oceans. The MOB model is tested with both orthogonal and curvilinear nearly-orthogonal (CNO) grids. The CNO grid has horizontal resolution which varies from 300 m to 2 km, while the resolution of the orthogonal grid is uniform with x=1.25 km and y=1.38 km. These grids cover a domain of 180 x 160 km with the same number of grid points of 131 x 131. Vertical resolutions of 25, 35 and 45 vertical sigma levels are tested. The truncation error in the MOB models are evaluated in terms of mean kinetic energy and velocity against various grids, vertical, horizontal resolution and distributions, and bottom topography smoothing.

Simulations with various grids show that the GGT can be used as another tool in reducing coordinate errors in coastal ocean modeling besides increasing resolution and smoothing bottom topography. A CNO grid with a high grid density packed along steep slopes and Monterey Submarine Canyon reduces the errors by 40% compared to a rectangular grid with the same number of grid points. The CNO grid is more efficient than the rectangular grid, since it has most of its grids over water. The simulations also show that the vertical resolution with 45 levels reduces the volume-averaged mean kinetic energy (KE) due to truncation error by 55% in comparison with 25 vertical levels. The steep and complicated topography of the MO, where the max. topographic factor TF is equal to 0.55, needs to be smoothed to max. TF=0.24 to reduce 60% of the KE without losing the important topographic features. Experiments with three different distributions (each with 45 vertical levels) confirm that a log distribution of in surface and bottom boundary layers has an velocity error of 11% smaller than two other (uniform and surface log distributions). The presented MOB coordinate model can be used with confidence regarding horizontal pressure gradient error.

PUBLICATION:

Ly, L.N., and Jiang, Lin, "The Pressure Gradient Errors of the Monterey Bay Sigma Coordinate Ocean Model with Various Grids," submitted to Journal of Geophysical Research, 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Coastal ocean modeling, grid generation, data assimilation

NUMERICAL SIMULATION OF DRIFTER RESPONSE TO LABRADOR SEA CONVECTION

Lin Jiang, Research Assistant Professor
Department of Oceanography
Sponsor: Naval Postgraduate School

OBJECTIVE: The objective of this project is to simulate Lagrangian drifter response to oceanic convection. A large-eddy simulation (LES) model is used to predict the fully-turbulent nonhydrostatic evolution of the oceanic flow fields that are typical of the Labrador Sea. These 4-dimensional fields will be archived and used to force a variety of Lagrangian drifter models (LDM's). LDM's that are currently being designed will be used to test strategies and combinations of drifter types to best achieve the overall scientific objectives for the ONR Convection ARI in the Labrador Sea.

SUMMARY: A large-eddy (LES) model was used to predict the fully-turbulent non-hydrostatic evolution of the oceanic flow fields that are typical of the Labrador Sea. Numerical simulations were conducted for two types of

idealized drifters: the D'Asaro type Lagrangian drifter and the isobaric Rossby drifter was conducted. With the pre-computed LES velocity, pressure and salinity fields, the performance of these drifters' models are evaluated. The terms of the turbulent kinetic energy (TKE) budget, heat flux, and temperature variance observed by these drifters are evaluated and compared with the Eulerian measurements from the numerical experiments. The dissipation rate of the TKE is estimated by budget closure from the drifter-observed other TKE equation terms, together with the LES-predicted vertical structure to the budget. The numerical simulation indicates that the Lagrangian drifters can resolve well the turbulent kinetic energy dissipation, the heat flux, and the velocities in the LES simulated fields. The Lagrangian drifter is also able to define the time-dependent vertical and horizontal scales of the convecting plumes. Compared with the Lagrangian drifters the Rossby drifters are heavily biased because it seeks out the convergence zone. In a sense the Rossby drifters are more useful for tracking the convective plumes near the surface. The Rossby drifters are also able to measure the vertical velocity and to define the horizontal and vertical scales of the convecting plumes. Combination of Lagrangian and Rossby drifters will be needed to track the convecting plumes and measure the heat flux correctly. The present simulation does provide some new insight into the response of typical drifters to convective oceanic flow fields and forms a solid basis for the future simulations of the realistic drifters - with more drifter specifications incorporated in the models. Further numerical experiments are needed to determine the relative roles of forced (wind-driven) and free (buoyancy-driven) convection as a function of mixing depth (h), wind stress, and surface cooling in deep convection regimes like the Labrador Sea.

PUBLICATION:

Harcourt, R., Jiang, L., and Garwood, R.W., "Numerical Simulation of Drifter Response to Labrador Sea Convection, Part 1: Free Convection," NPS Technical Report, 1996.

CONFERENCE PRESENTATION:

Harcourt, R., Jiang, L., and Garwood, R.W., "Numerical Simulation of Drifter Response to Labrador Sea Convection," American Geophysical Union Fall Meeting, San Francisco, CA, 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Convection, deep water formation, LES modeling, drifters

NUMERICAL STUDY OF OVERFLOW PLUMES

Lin Jiang, Research Assistant Professor
Department of Oceanography
Sponsor: Naval Postgraduate School

OBJECTIVE: The scientific objective of this proposed two-year study is to understand the three-dimensional features, instabilities, topographic steering effects and variability of the climatically most important overflow in the North Atlantic: the Denmark Strait Overflow. Earlier stream-tube type models of overflow plumes exclude some processes that are found to be very important [Jiang and Garwood, 1995, 1996]. It is intended to determine the roles of turbulent mixing and entrainment, bottom friction, the stratification, topography, variations in the sources water, and large-scale circulation in the processes of descending and interleaving of the Denmark Strait Overflow plumes. An important goal is to use the 3-D numerical results to provide more physically consistent parameters for mixing and entrainment, so that simple parameterizations of overflow plumes can be developed for large-scale ocean circulation models for global climate study. The ultimate goal is to establish a quantitative relationship between the surface cyclonic eddies and the bottom overflow plumes in the Denmark Strait Overflow region. Once this quantitative relationship is established, it may be possible to use satellite altimetry and AVHRR to monitor the Denmark Strait Overflow, which produces most of the North Atlantic Deep Water.

SUMMARY: Three-dimensional features and instabilities of dense overflows from marginal seas onto continental slopes are investigated using a three-dimensional, primitive equation numerical ocean model. The numerical simulations reveal important instability and three-dimensional features of the overflow plumes that has not included in early simulations with a one-dimensional stream-tube model and a two-dimensional plume model. It is shown that the large primary plume breaks into a number of smaller sub-plumes on the offshore side of the plume due to instabilities which are manifested as growing topographic Rossby waves over the slope. The observed high temporal and spatial variabilities in the Denmark Strait Overflow could be caused by the inherent dynamic instabilities as revealed by the numerical simulations. The simulations indicate that the initial overflow velocity and width, the properties of the source water, the planetary rotation, and the slope steepness play major roles in determining the scales of the breaking-away sub-plumes and the across-slope penetration of the large plume. The model simulations also show that a chain of surface cyclonic eddies form and travel almost parallel to the isobaths toward the right and downstream of the plumes' source. These eddies provide a surface signature of the sinking, breaking-away sub-plumes, as a result of vortex stretching in the upper part of the water column. Such surface features may have been observed in satellite IR imagery along the East Greenland continental shelfbreak by Bruce (1995), and it may be possible to use satellite imagery to monitor the Denmark Strait Overflow, which produces most of the North Atlantic Deep Water.

PUBLICATIONS:

Jiang, L., and Garwood, R.W., 1996, "Three-dimensional Simulations of Overflows on Continental Slopes," Journal of Physical Oceanography, 26, 1214-1233.

Jiang, L., and Garwood, R.W., 1996, "Effects of Topography and Ambient Stratification on Overflow Plumes over Continental Slopes," submitted to Journal of Geophysical Research.

CONFERENCE PRESENTATION:

Jiang, L., and Garwood, R.W., "Numerical Study of the Denmark Strait Overflow and the Generation of Surface Cyclonic Eddies," American Geophysical Union Fall Meeting, San Francisco, CA, 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Overflows, modeling, climate change, mixing, entrainment

AIR-SEA-WAVE INTERACTION

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 ONR sponsor under 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 FY96 we focus on using recently developed air-sea-wave interaction models of semi-empirical turbulence theory for studying energy and momentum transfer in the air-sea system, and investigating influences of waves on air-sea fluxes, turbulent structure (including turbulence kinetic energy budget and dissipation distributions), dynamical structure of atmospheric/oceanic boundary layers, and air-sea interaction characteristics. The work in FY96 is also focused on validation of numerical model results by comparison to available datasets. The result of the study is published in our new series of publications.

PUBLICATIONS:

Ly, L.N., "A Numerical Algorithm for Solving a Coupled Model of the Air-Sea-Wave Interaction," Mathematical and Computer Modelling, Vol. 27(7), 19-32, 1996.

Ly, L.N., "A Numerical Study of Aerodynamic Roughness Lengths as Seen from Above and Below in Air-Sea-Wave Coupling," Boundary-Layer Meteorology, 1996 (submitted).

Ly, L.N., " Numerical Modeling of Turbulent Dissipation in the Upper Layer of the Ocean," Journal of Geophysical Research, 1996, (submitted).

CONFERENCE PAPER:

Ly, L.N., "Modeling of Ocean Wind Wave Effects on Air-Sea Fluxes and Turbulence Using a Coupled Model of Air-Sea-Wave Interaction," American Meteorological Society (AMS), Eighth Conference on Air-Sea Interaction, Proceedings, 10-12, 1996.

CONFERENCE PRESENTATIONS:

Ly, L.N., "Modeling of Ocean Wind Wave Effects on Air-Sea Fluxes and Turbulence Using a Coupled Model of Air-Sea-Wave Interaction," American Meteorological. Society (AMS), Eighth Conference on Air-Sea Interaction, Atlanta, GA, January 1996.

Ly, L.N., "Numerical Modeling Dissipation Distribution in the Upper Oceanic Turbulent Layer," 1996 Office of Naval Research Workshop on Free-Surface and Wall-Bounded Turbulence and Turbulent Flows, California Institute of Technology, Pasadena, CA, February 1966.

Ly, L.N., "On Air-Wave-Sea Interaction Modeling and Coastal Ocean Modeling Using Numerical Grid Generation Technique," National Science Foundation Workshop of U.S./Russia Cooperation on Ocean Technology, Moscow, Russia, May 1996.

Benilov, Yu, A., and Ly, L.N., "On an Analytical Model of the Upper Oceanic Turbulent Layer Under Surface Breaking Waves," Transactions, OS32A-08, AGU Fall Meeting, San Francisco, CA, December 1966.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Other (Environmental Effects, Environmental Physics and Software)

KEYWORDS: Ocean wave effects, air-wave-sea interaction theory, air-wave-sea Modeling, air-sea interaction, boundary layers, environmental turbulence

COASTAL OCEAN MODELING

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

OBJECTIVE: Research is for the development of a capability to derive analyzed time varying ocean fields in coastal environments based on available data and ocean dynamics. The data is from all sources, such as satellite products and *in situ* observations, and includes fields for currents, sea surface heights, temperature, salinity. The coastal models are developed based on the most recent version of the Princeton Ocean Model (POM), grid generation and multi-block grid techniques, and data assimilation techniques. The models have curvilinear, nearly-orthogonal, coast-following grids, to better simulate regions with complicated coastlines, bathymetry, and boundary conditions. The model has complete thermodynamics and mixed layer physics.

A key component of the research is to form a nowcast/forecast system which will produce the 4-D analyzed ocean structure for the Monterey Bay (MOB) as a prototype for a Navy system of coastal environments using available data from all sources, data assimilation technique and coastal ocean models. This capability also allows for the generation of virtual coastal oceans useful for various applied sciences, including undersea acoustic and environmental applications.

SUMMARY: This multi-year project is applications of numerical grid generation of multi-block and curvilinear nearly-orthogonal techniques of Computational Fluid Dynamics (CFD) to the Monterey Bay (MOB) modeling. The research is to develop a coastal ocean system for the MOB which couples a state-of-the-art coastal ocean model to a grid package of curvilinear nearly-orthogonal grids to better handle complex coastlines and topography. The research is also to develop a system of capability in producing nowcasts/forecasts based on available data using data assimilation techniques. This is be done in combination with a coastal modeling effort using a state-of-the-art coastal model, the Princeton Ocean Model (POM), and Grid Generation Technique (GGT). FY96 mode of the project emphasizes nowcasts/forecast.

PUBLICATIONS:

Ly, L.N., and Jiang, L., "The Horizontal Pressure Gradient Error in the Monterey Bay Sigma Coordinate Ocean Model," Journal of Geophysical Research, 1996, (submitted).

Ly, L.N., and Luong, P., "A Coastal Ocean Circulation System and Its Application to the South China Sea," VACETS Technical Journal, 1966, (accepted).

Ly, L.N., and Luong, P., "A Coastal Ocean Circulation System with Breaking Waves and Numerical Grid Generation," Applied Mathematical Modelling (Simulation and Computation for Engineering and Environmental Systems), 1996, (submitted).

CONFERENCE PRESENTATIONS:

Ly, L.N., and Luong, P., "Grid Generation Technique: A New Advance in Coastal Ocean Modeling: Monterey Bay Simulation," Transactions, OS32A-03, AGU Fall Meeting, San Francisco, CA, December 1996.

Ly, L.N., and Luong, P., "Application of the Grid Generation Technique in Coastal Ocean Modeling," Hydrosoft-96, Second International Conference on Environmental Modeling, Penang, Malaysia, August 1996.

Ly, L.N., "Coastal Ocean Modeling Using Princeton Ocean Model (POM) and Grid Generation," International POM User Group Meeting, Princeton University, NJ, May 1996.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Other (Environmental Effects)

KEYWORDS: Nowcast/forecast systems, data-model combination, coastal ocean modeling, numerical grid generation, data assimilation

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: i) to develop an eddy resolving coupled Arctic ocean-icemodel with proper connections to surrounding subpolar ocean environments, and ii) 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 earlier work supported by other sponsors. In this ongoing study a coupled ice-ocean model was developed 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. Daily surface forcing will utilize 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 120 years has been completed and it will continue for a total of at least 200 years including implementation of a 9-km and 40 level grid. The equilibrium circulation with decadal variability will be analyzed to understand the physics of the Arctic Ocean and its sea-ice cover. Model results will 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:

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," Bulletin of the American Meteorology Society, (submitted).

Zhang, Y., Maslowski, W., and Semtner, A.J., "High resolution Arctic Ocean and Sea Ice Simulations: Ice Model Design and Early Results," (submitted).

CONFERENCE PRESENTATIONS:

Maslowski, W., Parsons, A.R. Semtner, A.J., and Zhang, Y. "Features of the Arctic Ocean Circulation - as Simulated by an Advanced Arctic Ocean Model," EOS Transactions, American Geophysical Union, 76(3), Ocean Sciences Abstracts, 106, January 1996.

Maslowski, W., Semtner, A.J., and Zhang Y., "Advanced Modeling Studies of the Arctic Ocean and Sea Ice - Toward Better Understanding of the Arctic System," Arctic System Science (ARCSS) Program Modeling Workshop, Boulder, CO, January 1996.

Maslowski, W., "Modeling Arctic Sea Ice with a High-resolution Coupled Ice-ocean Model," ONR Sea Ice Mechanics Workshop, Seattle, WA, April 1996.

Maslowski, W., Zhang, Y., and Semtner, A.J., "Modeling the Coupled Arctic Ocean-Sea Ice-Atmosphere System - Ocean Circulation from New Results," Arctic System Science (ARCSS) Program All-Hands Workshop, Snowbird, UT, May 1996.

Maslowski, W., Zhang, Y., and Semtner, A.J., "High-performance Modeling of the Arctic Ocean and Sea Ice," International Workshop on Software Engineering and Code Design in Parallel Meteorological and Oceanographic Applications, Semi-Ah-Moo, WA, September 1996.

Maslowski, W., Zhang, Y., Semtner, A.J., and Newton, B., "Circulation in the Arctic Marginal Seas from a High Resolution Coupled Arctic Ocean/Sea Ice Model," EOS Transactions, American Geophysical Union, 77(46), Fall Meeting Abstracts, 376, November 1996.

Newton, B., Maslowski, W., Schlosser, P., and Martinson, D.G., "A High Resolution Model of Fresh Water Distribution in the Arctic Ocean," EOS Transactions, American Geophysical Union, 77(46), Fall Meeting Abstracts, 378, November 1996.

Paluszkiewicz, T., Maslowski, W., Hibler, L.F., and Skyllingstad, E.D., "Evaluation of Deep Convection in an Arctic Ocean Model by T-S Census," EOS Transactions, American Geophysical Union, 76(3), Ocean Sciences Abstracts, 106, January 1996.

Zhang, Y., Maslowski, W., and Semtner, A.J., "Arctic Sea Ice Simulated by a High Resolution Coupled Ice-Ocean Model," EOS Transactions, American Geophysical Union, 76(3), Ocean Sciences Abstracts, 31, January 1996.

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 PARALLEL OCEAN PROGRAM 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). To create a synthesis of model output and data for interpretative and dynamical studies in specific ocean basins. This project is ongoing; its inception date was October 1996.

SUMMARY: Over the duration of the WOCE experiment (past 6 years), data was 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 as to complement each other and provide more realizations in time and space. Since the inception of this project (10/96), eastern Pacific hydrographic data and tropical Pacific surface drifter data have been used to validate the high resolution (1/6 degree) global ocean model with realistic forcing known as the LANL POP model. Model temperature and salinity fields co-located with the WOCE hydrography showed good agreement except that some water masses were underestimated in the model, possibly due to inadequate represenation at their formation sites. A synthesis of model fields and data are underway for a interpretative study. Model and drifter statistics were calculated and compared and showed that the model reproduced the structure of both the mean and variability fields, but overestimated the former and underestimated the latter by a factor of about two.

CONFERENCE PRESENTATIONS:

McClean, J.L., Maltrud, M., and Semtner, A.J., "Pacific Ocean circulation in the LANL POP 1/6 degree model: comparisons with WOCE hydrography and observed flow fields," Eos, Transactions, American Geophysical Union, 77(46), November 1996.

Lemon, M.R., McClean, J.L., and Paduan, J.D., "Comparison of Los Alamos National Laboratory (POP) 1/6 degree model fields with Pacific Surface drifter measurements," Eos, Transactions, American Geophysical Union, 77(46), November 1996.

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

KEYWORDS: Ocean circulation, model validation, model/data synthesis

COMPARISON OF PHASED-ARRAY AND DIRECTION-FINDING HIGH FREQUENCY RADAR SYSTEMS

J.D. Paduan, Assistant Professor
Department of Oceanography
Sponsor: Naval Postgraduate School

OBJECTIVE: The goal of this project is to improve understanding of the remote sensing of ocean surface currents using High Frequency (HF) radar systems by comparing observations obtained from two different systems deployed around Monterey Bay.

SUMMARY: These research efforts have focused on comparison of two types of shore-based HF radar systems designed to measure surface currents using radar backscatter. The two types of systems differ in their antenna designs. Direction-finding systems, such as the CODAR-type systems operated by the Monterey Bay HF Radar Consortium, use small, co-located antennae to determine angle-to-target from the relative signal strengths on each antenna. Phased-array systems, such as OSCR and the new Stanford University system, use a linear, 16-element antenna spread over ~80 m of coastline to determine angle-to-target from phase differences between antenna elements. This study is using data from Monterey Bay obtained for both types of systems to compare their performances.

CONFERENCE PAPER:

Fernandez, D.M., and Paduan, J.D., "Simultaneous CODAR and OSCR Measurements of Ocean Surface Currents in Monterey Bay," Proceedings, IEEE IGARSS '96, Vol. 3, pp. 1746-1750, Lincoln, NE, May 1996.

CONFERENCE PRESENTATIONS:

Paduan, J.D., Rosenfeld, L.K., and Cook, M.S., "Diurnal Surface Current Fluctuations in Monterey Bay from CODAR-type HF Radar," American Geophysical Union, San Francisco, CA, 15-19 December 1996.

Petruncio, E.T., Rosenfeld, L.K., and Paduan, J.D., "Internal Tide Generation and Propagation in a Submarine Canyon," American Geophysical Union, San Diego, CA, 12-16 February 1996.

Petruncio, E.T., Rosenfeld, L.K., and Paduan, J.D., "Internal Tide Propagtion in Monterey Submarine Canyon," Monterey Bay National Marine Sanctuary Research Symposium, Monterey, CA, 9 March 1996.

THESES DIRECTED:

Petruncio, E.T., "Observations and Modeling of the Internal Tide in a Submarine Canyon," Ph.D. Dissertation, Naval Postgraduate School, September 1996.

Boyer, K.F., "Characterization of OSCR HF Radar Data in Monterey Bay," Master's Thesis, Naval Postgraduate School, December 1996.

DoD KEY TECHNOLOGY AREAS: Sensors, Environmental Quality

KEYWORDS: HF radar, ocean currents, Bragg scatter

LAGRANGIAN MEASUREMENTS OF EDDY CHARACTERISTICS IN THE CALIFORNIA CURRENT

J.D. Paduan, Assistant Professor
Department of Oceanography
Sponsors: Office of Naval Research

OBJECTIVE: This project is part of an ongoing effort to observe mean and eddy currents in the ocean off the U.S. west coast using satellite-tracked drifting buoys. The long-range goal is to develop forecast models for the formation, movement, and decay of ocean eddies.

SUMMARY: This program is part of a larger coordinated effort to study the eddy field in an eastern boundary current sponsored by the Office of Naval Research. Field observations took place in 1993 and 1994 with quarterly deployments of 8 surface drifters placed along an offshore line at 39.5 degrees north latitude (39.5N). The first instruments were placed at 125 degrees west longitude (125W) with approximately 40 km between subsequent deployment sites. The second component of the experiment involved intensive study of one cyclone and one anticyclone to expose flow structures and decay rates. A method was developed and implemented to filter high frequency inertial motions from the trajectories in order to avoid aliasing them into estimates of mesoscale properties. A least square model fit was applied to both eddy features to determine translation, rotation, and decay rates.

CONFERENCE PRESENTATIONS:

Kelly, K.A., Beardsley, R.C., Limeburner, R., and Paduan, J.D., "A Comparison of Topex/Poseidon Altimeter Data and Near-surface Drifters in the California Current," American Geophysical Union, San Diego, CA, 12-16 February 1996.

Lemon, M.R., McClean, J.L., and Paduan, J.D., "Comparison of Los Alamos National Laboratory (POP) 1/6 Degree Model Fields with Pacific Surface Drifter Measurements," American Geophysical Union, San Francisco, CA, 15-19 December 1996.

Limeburner, R., Kelly, K.A., Beardsley, R.C., 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 Curent Data," American Geophysical Union, San Francisco, CA, 15-19 December 1996.

OTHER:

The principal investigator presented results of this and other drifting buoy programs to the 8th planning meeting of the World Ocean Circulation Experiment-Surface Velocity Program, Chateau de BONAS, France, 14-16 May 1996.

DoD KEY TECHNOLOGY AREAS: Sensors, Environmental Quality

KEYWORDS: Eddies, ocean currents, Lagrangian drifters

REAL-TIME ENVIRONMENTAL NETWORK INFORMATION AND ANALYSIS SYSTEM (REINAS)–INTEGRATION OF OCEAN PRODUCTS

J.D. Paduan, Assistant Professor
Department of Oceanography
W.A. Nuss, Associate Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: The goals of this project are to integrate, evaluate, and expand the use of real-time and retrospective oceanographic data within the Real Time Environmental Information Network and Analysis System (REINAS).

SUMMARY: During the first 4 years of program development, REINAS was heavily invested in networked meteorological observations. There was also a significant effort on the part of atmospheric scientists to aid in this networking effort, and to evaluate and expand the usefulness of the database and visualization products under development. The same level of input from oceanographic observations and scientists was absent from the REINAS effort. This project involves ocean scientists in the REINAS development effort. Analysis of available oceanographic data—such as HF radar-derived surface currents and moored current and temperature profiles—were conducted using queries to the REINAS database, and requirements for improvements and additions to oceanographic data load paths are being detailed. Initial steps toward the addition of oceanographic model output from the Princeton Ocean Model (POM) to the REINAS database have been made. The goal is to provide ocean model data over the REINAS domain in a manner parallel to the existing atmospheric model component.

PUBLICATIONS:

Paduan, J.D., and Rosenfeld, L.K., "Remotely Sensed Surface Currents in Monterey Bay from Shore-based HF Radar (CODAR)," Journal of Geophysical Research, Vol. 101, 20669-20686.

Paduan, J.D., Pickett, M.H., and Cook, M.S., "Comparison of Drifting Buoy and HF Radar (CODAR) Ocean Surface Currents in Monterey Bay, CA," NOAA Technical Report, MBNMS 96-01, March 1996.

CONFERENCE PRESENTATIONS:

Fernandez, D.M., and Paduan, J.D., "Satellite Synthetic Aperture Radar, CODAR, and *in situ* Measurements of Oceanic Features in Monterey Bay," 43rd Eastern Pacific Ocean Conference, Timberline, OR, 24-27 September 1996.

Paduan, J.D., Rosenfeld, L.K., and Cook, M.S., "Remotely Sensed Surface Currents from the Monterey Bay HF Radar Network," Monterey Bay National Marine Sanctuary Research Symposium, Monterey, CA, 9 March 1996.

DoD KEY TECHNOLOGY AREAS: Sensors, Environmental Quality

KEYWORDS: HF radar, ocean currents, Bragg scatter

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 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 P.I. in the Adriatic and Ionian Seas over the last few years.

SUMMARY: A total of 20 satellite-tracked drifters were successfully released in the Strait of Sicily between March and October 1996 during hydrographic surveys of opportunity. 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 drifter data were pre-processed and the drifter movements were depicted on a dedicated web page on a daily basis. Among the various surface features revealed by the drifter tracks, the main pathway of the AIS and its corresponding high speed currents are the most robust and well-sampled patterns resolved by the drifter experiment. In order to complete a two-year monitoring of the Strait of Sicily, additional seasonal deployments are planned until summer 1997. The entire drifter data set will be interpreted and results will be published as part of the continuation of this project into 1997.

The surface drifter data set available in the Adriatic Sea between December 1994 and February 1996 was analyzed to study the Adriatic surface circulation characteristics. Maps of mean current and eddy variability were produced. Selected observations were interpreted in various regions of the basin in terms of wind-forcing and seasonal variability.

PUBLICATIONS:

Gacic, M., Kovacevic, V., Manca, B., Papageorgiou, E., Poulain, P.-M., Scarazzato, P., and Vetrano, A., "Thermohaline Properties and Circulation in the Otranto Strait," Bulletin de l'Institut Oceanographique, Monaco, CIESM Sciences Series 2, Special Vol. 17, pp. 117-145, 1996.

Poulain, P.-M., "Drifter Observations of Surface Circulation in the Adriatic Sea," Journal of Marine Systems, (submitted).

Poulain, P.-M., Gacic, M., and Vetrano, A., "Current Measurements in the Strait of Otranto Reveal Unforeseen Aspects of its Hydrodynamics," EOS, 77(36), 345-348.

CONFERENCE PRESENTATIONS:

Poulain, P.-M., "Surface Circulation in the Adriatic and Ionian Basins As Measured by Lagrangian Drifters," American Geophysical Union 1996 Ocean Sciences Meeting, San Diego, CA, 12-16 February 1996.

Poulain, P.-M., "Drifter Observations in the Strait of Otranto," Third Otranto Workshop, Lipari, Italy, 18-20 April 1996.

Poulain, P.-M., and Zanasca, P., "Lagrangian Measurements of Surface Currents in the Adriatic," Final Conference of the Eutrophic Limits of the Northern Adriatic Programme, Portonovo, Italy, 23-27 April 1996.

Poulain, P.-M., "Surface Circulation in the Adriatic and Ionian Basins As Measured by Lagrangian Drifters," XXI General Assembly of the European Geophysical Society, The Hague, The Netherlands, 6-10 May 1996.

Poulain, P.-M., "Surface Circulation in the Adriatic and Ionian Basins As Measured by Lagrangian Drifters," Eighth Meeting of the WOCE/CLIVAR Surface Velocity Programme Planning Committee, Bonas, France, 14-16 May 1996.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Marginal seas and straits, water masses, circulation

UPWELLING FRONTS: COLLISION WITH INTERTIDAL ZONE AND BARNACLE RECRUITMENT IN CALIFORNIA

Leslie Rosenfeld, Research Assistant Professor
Department of Oceanography
Sponsor: Monterey Bay Aquarium Research Institute

OBJECTIVE: The objective of this project is to test the hypothesis that the spatial distribution of larvae of intertidal barnacle species in the water column is controlled by the position of upwelling fronts, and that the timing of larval recruitment to the intertidal zone is related to the position of these fronts.

SUMMARY: During April-August of 1993 and 1994, a study was undertaken off central California to test the above-stated hypothesis. This subcontract from a NSF grant supported the physical oceanographic aspects of the project. Almost 700 CTD casts were made along three transects during six cruises. These data have been processed and submitted to NODC. Surface temperature and salinity and vertical profiles of horizontal velocity were collected continuously. Data from two thermistor moorings were obtained. Additional ancillary data, including AVHRR, wind, and coastal temperature and salinity, were collected. All of the above data, as well as a detailed discussion of the methods used to acquire and process them is presented in a data report.

The spatial distribution of larvae of coastal species of barnacles is consistent with the initial hypothesis, in that larvae are concentrated nearshore during and just after wind relaxations, while they are found far offshore during strong upwelling. The temporal history of recruitment is not so easily explained. There were very few recruitment events, and while some appear to be associated with relaxations, there were many relaxations during which no significant recruitment occurred.

PUBLICATION:

Paduan, J.D., and Rosenfeld, L.K, "Remotely Sensed Surface Currents in Monterey Bay from Shore-based HF Radar (CODAR)," Journal of Geophysical Research, 101: 20,669-20,686, 1996.

CONFERENCE PAPERS:

Bjorkstedt, E.P., Grantham, B.A., Shkedy, Y., Roughgarden, J., and Rosenfeld, L.K., "Remotely Sensed Ocean Currents: Agreement with Satellite Observations of Coastal Upwelling and Ecological Implications," EOS Transactions, American Geophysical Union, 77, OS158, 1996.

Grantham, B.A., Bjorkstedt, E.P., Shkedy, Y., Roughgarden, J., and Rosenfeld, L.K., "Coastal Upwelling Zones and the Distribution of Meroplanktonic Larvae: Implications for Laval Recruitment," EOS Transactions, American Geophysical Union, 77, OS158, 1996.

Roughgarden, J., Shkedy, Y., Grantham, B.A., Bjorkstedt, E., and Rosenfeld, L., "Barnacle Larvae in Relation to Mesoscale Features in the California Current Off Central California," EOS Transactions, American Geophysical Union, 77, OS157, 1996.

Rosenfeld, L.K., Hatcher, G.A., Anderson, T.E., Roughgarden, J., Shkedy, Y., Grantham, B.A., and Bjorkstedt, E.P., "Upwelling Fronts Off Central California," EOS Transactions, American Geophysical Union, 77, OS157, 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Upwelling, fronts, recruitment

HIGH-PERFORMANCE MODELING OF THE ARCTIC OCEAN CIRCULATION IN TURBULENT EQUILIBRIUM

Alber J. Semtner, Professor
Wieslaw Maslowski, Assistant Professor
Department of Oceanography
Sponsor: University of Alaska, Fairbanks

OBJECTIVE: To greatly improve on the realism of numerical simulation of three-dimensional Arctic ocean circulation, with important currents and eddies resolved for the first time ever. To do this by exploiting the power of massively parallel computers, especially the CRAY T3D at the Arctic Region Supercomputing Center in Fairbanks.

SUMMARY: It was proposed to design a high-resolution model of the Arctic Ocean which is optimized to run on the massively parallel CRAY T3D and to simulate the realistic thermohaline circulation of the Arctic Ocean even before it has been adequately observed. This effort will conclusively demonstrate the power of high-performance Cray computers to solve realistic fluid dynamical problems in oceanography. Many scientific and practical applications can then be made with the model. Already, a model with 18-km grid spacing and 32 levels has been built and run for a major simulation of 25 years. Results for the full Arctic region plus subpolar North Atlantic are looking extremely realistic and are generating much interest and acceptance from polar oceanographers. Analysis of results and the distribution of output in the form of video animations is in progress.

PUBLICATIONS:

Maslowski, W., Parsons, A.R., Semtner, A.J., and Y. Zhang, "Features of the Arctic Ocean Circulation — As Simulated by an Advanced Arctic Ocean Model," EOS Transactions, 76, Ocean Sciences Abstracts, 106, 1996.

Maslowski, W., Zhang, Y., and Semtner, A.J., "Advanced Modeling Studies of the Arctic Ocean and Sea Ice — Toward Better Understanding of the Arctic System," Proceedings of the ARCSS Modeling Workshop, Arctic Research Consortium of the U.S., Fairbanks, AK, 1996, in press.

Semtner, A.J., "Converging Toward Realism in Arctic Ocean Modeling," EOS Transactions, 76, Ocean Sciences Abstracts, 106, 1996.

Zhang, Y., Maslowski, W., and Semtner, A.J., "Arctic Sea Ice Simulated by a High Resolution Coupled Ice Ocean Model," EOS Transactions, 76, Ocean Sciences Abstracts, 30, 1996.

Zhang, Y., Semtner, A.J., and Maslowski, W., "Arctic Sea Ice Variability in a High Resolution Model," Proceedings of the ARCSS Modeling Workshop, Arctic Research Consortium of the U.S., Fairbanks, AK, in press, 1996.

PRESENTATIONS:

"Recent High-Resolution Simulations of Global Ocean and Ice Circulation and Variability" was presented in various forms in the following venues: Regional Model Workshop, Naval Research Laboratory (West), Monterey, CA, 10-11 January 1996; University of Washington, WA, 17-19 January 1996; American Geophysical Union Ocean Sciences Meeting., San Diego, CA, 12-16 February 1996; Arctic System Science Meeting, Snowbird, UT, 1-3 May 1996; NSF Ocean Climate Variability, San Antonio, TX, 10-13 June 1996; NOAA Global Change Symposium, Steamboat Springs, CO, 17-21 June 1996; NOAA Environmental Fisheries Workshop, Pacific Grove, CA, 16-18 July 1996; NCAR Ocean Models Workshop, Boulder, CO, 13-14 August 1996; U.S.A.-U.K. Ocean Prediction Mtg., Monterey, CA, 8-10 October 1996; Arctic Modeling Meeting, Monterey, CA, 6-8 October 1996; Polar Climate Symposium, Cancun, Mexico, 13-15 November 1996; ARCSS Science Steering Committee, Seattle, WA, 22-23 November 1996.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation

KEYWORDS: Numerical modeling, Arctic Ocean, parallel computers

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: (i) investigation of the physics of ocean heat transport, (ii) inclusion of near-surface oceanic processes relevant to climate, and (iii) examination of resolution requirements for ocean modeling. Last year, high-latitude process improvements and analyses of resolution effects were emphasized. A fully validated model will be available by project completion in 1997.

PUBLICATIONS:

Chervin, R.M., Craig, A.P., and Semtner, A.J., "Meridional Heat Transport Variability from a Global Eddy-resolving Model," Assessing Climate Change, eds: W. Howe and A. Henderson-Sellers, Gordon and Breach Science Publishers, Roseville, Australia, 1996, in press.

Maslowski, W., Parsons, A.R., Semtner, A.J., and Y. Zhang, "Features of the Arctic Ocean Circulation — As Simulated by an Advanced Arctic Ocean Model," EOS Transactions, 76, Ocean Sciences Abstracts, 106, 1996.

Maslowski, W., Zhang, Y., and Semtner, A.J., "Advanced Modeling Studies of the Arctic Ocean and Sea Ice — Toward Better Understanding of the Arctic System," Proceedings of the ARCSS Modeling Workshop, Arctic Research Consortium of the U.S., Fairbanks, AK, 1996, in press.

McClean, J.L., and Semtner, A.J., "Comparisons of Mesoscale Variability in the Semtner and Chervin 1/4 degree and the Los Alamos (POP) 1/6 Degree Model and Topex/Poseidon Data," EOS Transactions, 76, Ocean Sciences Abstracts, 80, 1996.

Semtner, A.J., "Converging Toward Realism in Arctic Ocean Modeling," EOS Transactions, 76, Ocean Sciences Abstracts, 106, 1996.

Stammer, D., Tokmakian, R., Semtner, A.J., and Wunsch, C., "How Well Does a 1/4 Degree Global Circulation Model Simulate Large-scale Oceanic Observations?" Journal of Geophysical Research, 101, 25779-25811, 1996.

Zhang, Y., Maslowski, W., and Semtner, A.J., "Arctic Sea Ice Simulated by a High Resolution Coupled Ice Ocean Model," EOS Transactions, 76, Ocean Sciences Abstracts, 30, 1996.

Zhang, Y., Semtner, A.J., and Maslowski, W., "Arctic Sea Ice Variability in a High Resolution Model," Proceedings of the ARCSS Modeling Workshop, Arctic Research Consortium of the U.S., Fairbanks, AK, 1996, in press.

PRESENTATIONS:

"Recent High-Resolution Simulations of Global Ocean and Ice Circulation and Variability" was presented in various forms in the following venues: Regional Model Workshop, Naval Research Laboratory (West), Monterey, CA, 10-11

January 1996; University of Washington, WA, 17-19 January 1996; American Geophysical Union Ocean Sciences Meeting., San Diego, CA, 12-16 February 1996; Arctic System Science Meeting, Snowbird, UT, 1-3 May 1996; NSF Ocean Climate Variability, San Antonio, TX, 10-13 June 1996; NOAA Global Change Symposium, Steamboat Springs, CO, 17-21 June 1996; NOAA Environmental Fisheries Workshop, Pacific Grove, CA, 16-18 July 1996; NCAR Ocean Models Workshop, Boulder, CO, 13-14 August 1996; U.S.A.-U.K. Ocean Prediction Mtg., Monterey, CA, 8-10 October 1996; Arctic Modeling Meeting, Monterey, CA, 6-8 October 1996; Polar Climate Symposium, Cancun, Mexico, 13-15 November 1996; ARCSS Science Steering Committee, Seattle, WA, 22-23 November 1996.

DoD KEY TECHNOLOGY AREAS: 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

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 high-frequency wind fields and monthly heat fluxes were prepared as forcing. The model was used to simulate conditions of 1987-95, starting from earlier 1985-89 monthly-wind-forced calculations and applying new fields of 3-day winds and heat flux. 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. Since then, satellite data-assimilation efforts have been underway to include the height data from both TOPEX and ERS satellites over the period 1992-95. Early results are showing 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.

PUBLICATIONS:

Chervin, R.M., Craig, A.P., and Semtner, A.J., "Meridional Heat Transport Variability from a Global Eddy-resolving Model," Assessing Climate Change, eds., W. Howe and A. Henderson-Sellers, Gordon and Breach Science Publishers, Roseville, Australia, in press, 1996.

McClean, J.L., and Semtner, A.J., "Comparisons of Mesoscale Variability in the Semtner and Chervin 1/4 Degree and the Los Alamos (POP) 1/6 Degree Model and Topex/Poseidon Data," EOS Transactions, 76, Ocean Sciences Abstracts, 80, 1996.

Semtner, A.J., "Converging Toward Realism in Arctic Ocean Modeling," EOS Transactions, 76, Ocean Sciences Abstracts, 106, 1996.

Stammer, D., Tokmakian, R., Semtner, A.J., and Wunsch, C., "How Well Does a 1/4 Degree Global Circulation Model Simulate Large-scale Oceanic Observations?" Journal of Geophysical Research, 101, 25779-25811, 1996.

Tokmakian, R., and Semtner, A.J., "The Synthesis of Satellite Altimeter Data with the Global 1/4 Degree Parallel Ocean Climate Model," EOS Transactions, 76, Ocean Sciences Abstracts, 57-58, 1996.

Tokmakian, R., and Semtner, A.J., "Assimilation of Satellite Altimeter Data in High-resolution Ocean Model," Proceedings of the 1995 Symposium on Operational Oceanography, Paris, France, 79-87, 1996.

Zhang, Y., Semtner, A.J., and Maslowski, W., "Arctic sea ice variability in a high resolution model," Proceedings of the ARCSS Modeling Workshop, Arctic Research Consortium of the U.S., Fairbanks, AK, in press, 1996.

PRESENTATIONS:

"Recent High-Resolution Simulations of Global Ocean and Ice Circulation and Variability" was presented in various forms in the following venues: Regional Model Workshop, Naval Research Laboratory (West), Monterey, CA, 10-11 January 1996; University of Washington, WA, 17-19 January 1996; American Geophysical Union Ocean Sciences Meeting., San Diego, CA, 12-16 February 1996; Arctic System Science Meeting, Snowbird, UT, 1-3 May 1996; NSF Ocean Climate Variability, San Antonio, TX, 10-13 June 1996; NOAA Global Change Symposium, Steamboat Springs, CO, 17-21 June 1996; NOAA Environmental Fisheries Workshop, Pacific Grove, CA, 16-18 July 1996; NCAR Ocean Models Workshop, Boulder, CO, 13-14 August 1996; U.S.A.-U.K. Ocean Prediction Mtg., Monterey, CA, 8-10 October 1996; Arctic Modeling Meeting, Monterey, CA, 6-8 October 1996; Polar Climate Symposium, Cancun, Mexico, 13-15 November 1996; ARCSS Science Steering Committee, Seattle, WA, 22-23 November 1996.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation

KEYWORDS: Numerical modeling, ocean prediction

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

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

OBJECTIVES: 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, the 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, 20Km off shore of Northern Oregon. A continuous profiling loose-tethered microstructure profiler measured high resolution temperature, salinity and dissipation profiles every 40 seconds from the surface to a depth of 35m. 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 8m depth, while a high speed broadband ADCP extended the velocity and stress measurements to 50m depth.

The measurement site had a 60 cph pycnocline at only 5-10m 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 30m from a 5m start depth, significantly more non-linear than previous observations. A conference presentation was made at the February Ocean Sciences meeting in San Diego and a manuscript describing the soliton packets and their effect on the upper ocean has been prepared in collaboration with Lev Ostrovsky at the NOAA ETL, and has been submitted to Science. A more complete analysis of the upper ocean mixing due to the strong internal tide and solitons is in progress.

PUBLICATIONS:

Stanton, T.P., and Ostrovsky, L.A., "Observations of Highly Nonlinear Solitons of the Continental Shelf," Submitted to Science, 1996.

CONFERENCE PRESENTATIONS:

Stanton, T.P., ""Mixed Layer Turbulence Generated by High Amplitude, Tidally Forced Solitons Propagating Across the Continental Shelf," Ocean Sciences Meeting, San Diego, CA, February 1996.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Ocean mixed layer, internal waves, mixed layer dynamics.

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

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

OBJECTIVES: 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 our 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 500m 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 time series to be estimated.

Preliminary analyses of the mixed layer structure during both ice camps were contributed to an overview paper of the ANZFLUX experiment published in BAMS in June 1996. 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 is nearing completion. 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:

McPhee, M, Ackley, S., Guest, P., Huber, B., Martinson, D., Morison, J., Muench, R., Padman L., and Stanton., T., "The Antarctic Zone Flux Experiment," Bulletin of American Meteorological Society, 77, 1221-1232, 1996.

Stanton, T.P., Padman, L., and Robertson, R.A., "Heat Fluxes Through the Permanent Pycnocline in the Eastern Weddell Sea," Journal of Geophysical Research, 1996, (submitted).

CONFERENCE PRESENTATIONS:

Padman, L., McPhee, M.G., and Stanton, T.P., "Ocean Eddy Interactions with Sea Ice in the Eastern Weddell Sea," Ocean Sciences Meeting, San Diego, CA, February, 1996.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Ocean mixed layer, Antarctic Ocean fluxes, mixed layer dynamics

NEAR SHORE CIRCULATION ON VARIABLE BATHYMETRY

E.B. Thornton, Professor
Departmentof Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: Develop models to predict the evolution of waves and currents in the NEAR SHORE 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) California, while the Duck, North Carolina 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.

PUBLICATION:

Reniers, A.J.H.M., Thornton, E.B., and Lippmann, T.C., "Effects of Alongshore Non-uniformities on Longshore Currents Measured in the Field," Journal of Geophysical Research, (submitted).

CONFERENCE PRESENTATIONS:

Reniers, A., Thornton, E.B., and Lippmann, T.C., "Longshore Currents over Barred Beaches," Proceedings Coastal Dynamics'95, American Society of Civil Engineers, 413-424, 1996.

Sancho, F.E., Svendsen, I.A., Dongeren, A.R., and Thornton, E.B., 1996, "Numerical Modeling of Longshore Currents: Comparison with Field Data," Fall Meeting of the American Geophysical Union, San Francisco, CA, 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental effects)

KEYWORDS: Waves, near-shore, edge-waves

NEAR SHORE WAVE AND SEDIMENT PROCESSES

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

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

SUMMARY: The longshore currents maximum observed in the trough of the barred beach during DELILAH is not predicted by present theory. The simplest longshore current models balance cross-shore changes in the alongshore wave momentum (radiation stress) with the alongshore bottom shear stress. Waves break over the bar, reform in the trough and again break on the foreshore. Wave breaking results in changes in the radiation stress predicting two jets, one over the bar and one at the foreshore, which does not agree with the observed current maximum in the trough. Mechanisms investigated to explain this discrepancy include momentum mixing by shear instabilities of longshore

currents, additional alongshore stress due to inclusion of wave rollers to describe wave breaking processes, alongshore pressure gradients associated with inhomogenieties in the alongshore bathymetry, and variations in the bed shear stress due to changes in small-scale morphology in the cross-shore.

PUBLICATIONS:

Whitford, D.J., and Thornton, E.B., "Bed Shear Stress Coefficients for Longshore Currents over a Barred Profile," Journal of Coastal Engineering, 27, 243-262, 1996.

Thornton, E.B., Humiston, R.T., and Birkemeier, W., "Bar/Trough Generation on a Natural Beach," Journal of Geophysical Research, 101 (C5), 12,097-12,110, 1996.

Lippmann, T., Thornton, E.B., and Brookins, H., "Breaking Wave Transformation Using a Roller Model," Journal of Coastal Engineering, 27, 1-20, 1996.

Lippmann, T., and Thornton, E.B., "The Spatial Distribution of Wave Rollers and Turbulent Kinetic Energy on a Barred Beach,"Journal of Geophysical Research, (accepted).

Faria, A.G., Thornton, E.B., Soares, C., and Stanton, T.P., "Bed Shear Stress Coefficients Related to Bed Roughness Across the Surf Zone," Journal of Geophysical Research, (accepted).

Thornton, E.B., Swayne, J.L., and Dingler, J., "Small-scale Morphology Related to Waves and Currents Across the Surf Zone," Marine Geology, (accepted).

CONFERENCE PRESENTATIONS:

Faria, A., Thornton, E.B., and Stanton, T.P., "A Review of the Undertow Problem Using Field Data," Fall Meeting of the American Geophysical Union, San Francisco, CA, 1996.

Faria, A.F., Thornton, E.B., and Stanton, T.P., "Small-scale Morphology Related to Waves and Current Parameters Across the Surf Zone," 25th International Conference on Coastal Engineering, 1996.

Lippmann, T.C., and Thornton, E.B., "Observations of Surf Zone Wave Breaking During Duck94," 25th International Conference on Coastal Engineering, 1996.

Lippmann, T.C., Jorgensen C.F., and Thornton, E.B., "Wave Slopes and Breaking Distributions in the Surf Zone," Journal of Geophysical Research, (submitted).

Morris, B., Thornton, E.B., Stanton, T.P., "Wave Set-up Measured in the Field," Fall Meeting of the American Geophysical Union, San Francisco, CA, 1996.

Tannihill, J., Thornton, E.B., and Stanton, T.P., "Bubble Injection under Breaking Waves," Fall Meeting of the American Geophysical Union, San Francisco, CA, 1996.

Stanton, T.P., and Thornton, E.B., "Reynolds Stress and Small-scale Morphology Measurements During Duck94," 25th International Conference on Coastal Engineering, 1996.

THESIS DIRECTED:

Tannihill, James, "Bubble Injection Under Breaking Waves," Master's Thesis, Naval Postgraduate School, December 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Near shore, waves, surf

WAVE SURFACE AND BOTTOM BOUNDARY LAYERS IN THE NEAR SHORE

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Sponsor: Office of Naval Research

OBJECTIVES: The objectives of this research are to examine the dynamics of the water column in over the continental shelf and near shore, regions where forcing is dominated by surface gravity waves and wind. Unique acoustic Doppler instruments are being 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 (described below). Additional measurements included a vertical arrays of 9 em current meters, and 5 optical backscatter sensors, and an acoustic resonator deployed by Dave Farmer to measure bubble size spectra.

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DRIFTER-BASED VELOCITY STATISTICS IN THE VICINITY OF THE AZORES FRONT

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Surface velocity observations from the Canary Basin of the northeast Atlantic Ocean are studied with emphasis on the region of the Azores Current. Data are based on trajectories of 155 WOCE-standard Lagrangian surface drifters drogued at 15 m depth. Over 52,000 daily velocity estimates are available for the region 45° W, 25° N and 5° W, 45° N for July 1991 through March 1995. A clear view of the mean Azores Current emerges around 34° N with average speeds of ~10 cm/s and eddy kinetic energy ~181 cm^2/s^2. The Current moves eastward beyond Madeira Island to join the southwestward flowing Canary Current. Part of the flow bifurcates west of the Madeira Plateau around 23° W. Eddy kinetic energy in the Canary Current region is only ~80 cm2/s2 even though mean speeds are similar to those in the Azores Current.

Zonal averages of the flow show significant convergence in the meridional velocity north of the Azores Front. A time history of the frontal locations is developed based on SST and drifter information. A methodology is presented for converting drifter observations into along-front and cross-front coordinates. Although these frontal locations do not faithfully track the location of the main subsurface front, particularly in the eastern portion of the domain, mean velocities in frontal coordinates support the hypothesis that large-scale subduction of surface waters in this region is concentrated in a region of convergence associated with the Azores Front, particularly from the north.

THREE DIMENSIONAL ACOUSTIC EFFECTS IN THE MIDDLE ATLANTIC BIGHT

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Under the sponsorship of the Office of Naval Research (ONR) PRIMER program, an integrated acoustic and oceanographic field experiment will be conducted jointly by the Naval Postgraduate School (NPS) and the Woods Hole Oceanographic Institution (WHOI) in the Middle Atlantic Bight (MAB) to study the propagation of sound from the continental slope to the continental shelf. In support of this field study the three-dimensional (3D) effects of the basic mean shelfbreak frontal thermal structure and sloping bathymetry on the planned tomography signal transmissions are modeled using ray methods. Both three-dimensional (3D) and two-dimensional (2D) ray paths and signal arrival structures for an upslope and cross-slope source-receiver geometry are simulated and compared. While the input sound speed field is from a previous summer-time hydrographic section, the input bathymetry is from a recently declassified U.S. Navy DBDB-0.5 data set. Significant 3D environmental effects are found in the modeled cross-slope transmissions, indicating that the physics of horizontal refraction and out-of-the-vertical-plane scattering will be required to properly analyze the acoustic measurements and to construct accurate tomographic maps.

STUDIES OF SOUTH CHINA SEA CIRCULATION AND THERMAL STRUCTURE USING A THREE DIMENSIONAL NUMERICAL MODEL

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The seasonal ocean circulation and thermal structure in the South China Sea (SCS) were studied numerically using the Princeton Ocean Model (POM) with 20 km horizontal resolution and 23 sigma levels conforming to a realistic bottom

topography. A sixteen month control run was performed using climatological monthly mean wind stresses and restoring type salt and heat fluxes as surface forcing terms and observational oceanic inflow/outflow at the open boundaries. The seasonally averaged effects of isolated forcing terms are presented and analyzed from the following experiments: 1) non-linear effects removed, 2) wind effects removed, 3) open boundary inflow/outflow set to zero, and 4) open boundary inflow/outflow doubled. This procedure allowed analysis of the contribution of the isolated parameter to the general hydrology of the SCS and some of its specific features. A coastal jet is identified and analyzed, as are a mesoscale topographic gyre and several counter currents. Non-linearity is shown to be important to the energy and volume transport of baroclinic eddy features, but otherwise insignificant. Boundary transport from open lateral boundaries is determined to be of considerable importance to summer circulation and thermal structure, with little effect found for the winter monsoon hydrology. In general, monsoonal circulation patterns and upwelling phenomena are determined and forced by the wind, while boundary transport effects play a secondary role in determining the magnitude of circulation velocities.

INFRAGRAVITY WAVES ON THE CONTINENTAL SHELF

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The variability of infragravity-frequency (0.004-0.04 Hz) motions on a wide continental shelf was examined with data from a 100km-long transect of bottom pressure recorders extending from the beach (6m depth) to the shelf break (87m depth) near Duck, North Carolina. The observed infragravity motions are a mixture of forced waves, phase-coupled to local wave groups, and (uncoupled) free waves. Although the contribution of forced waves to the infragravity energy increases with both increasing swell energy and decreasing water depth, the shelf is usually dominated by free waves. The observed tree waves are predominantly radiated from nearby beaches. The strong attenuation of infragravity waves observed across the inner shelf is primarily the result of refractive trapping and is well described by a WKB model. Across the flatter, irregular outer shelf the observed attenuation is weaker but increases with increasing swell energy, suggesting that significant damping occurs on the shelf during storms, consistent with earlier studies. At the deepest instrumented sites, weaker correlations between infragravity and swell energy levels, and weaker depth dependence of infragravity energy levels are observed, suggesting that remotely generated waves are important seaward of the shelf break.

SWELL PROPAGATION ACROSS A WIDE CONTINENTAL SHELF

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The effects of wave refraction and damping on swell propagation across a wide continental shelf were examined with data from a transect of bottom pressure recorders extending from the beach to the shelf break near Duck, North Carolina. The observations generally show weak variations in swell energy across the shelf during benign conditions, in qualitative agreement with predictions of a spectral refraction model. Although the predicted ray trajectories are quite sensitive to the irregular shelf bathymetry, the predicted energy variations are surprisingly weak, consistent with the observations. The results indicate that small amplitude swell is not significantly damped on the shelf. However, a large decrease in swell energy levels across the shelf (up to 70%), observed with high-energy incident swell, is not predicted by the energy conserving refraction model. These energy losses are likely caused by bottom friction.

THE EFFECT OF SALINITY ON DENSITY IN THE LEEUWIN CURRENT SYSTEM

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Climatological temperature and salinity fields are used to calculate the salinity contribution to density and dynamic height fields in the Leeuwin Current System (LCS). While the temperature gradient is primarily linear, with warmest water to the north, the salinity fields are spatially inhomogenous. A comparison of density fields, calculated with constant and variable salinity, shows that, off Western Australia the density field is primarily determined by temperature. Off Southern Australia, the density field is dependent on warm and salty (subtropical) and fresh and cold (sub-Antarctic) water masses. While the dynamic height fields, calculated with constant and variable salinity, show similar flow patterns off Western Australia, different flow patterns are found off Southern Australia.

In addition to the analysis of climatological fields, a primitive equation ocean model is used to investigate the role of salinity in the formation of currents and eddies in the LCS. Two identical ocean models, one with a climatological salinity field and the other with no horizontal salinity gradients, are run and compared with each other. Despite the model runs being initialized with similar temperature distributions, there are relatively large temperature and density differences in the Southern Australian region, due to the advection of water masses by the Leeuwin Current.

Based on the climatological analyses and the results of the model experiments, it is concluded that, descriptively and dynamically, both temperature and salinity are essential to accurately characterize the large-scale circulation of the LCS.

WAVE SLOPES AND BREAKING DISTRIBUTIONS IN THE SURF ZONE

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Field measurements from a cross-shore array of nine pressure sensors, spanning the surf zone, are used to examine the evolution of ensemble averaged wave face slopes of ocean waves as they propagate through the breaking region. Averaged wave slopes are determined from time series of the measured sea surface elevation and from an averaged waveform calculated from bispectral coefficients, and compared with predictions from a wave transformation model that includes wave breaking described by rollers. Measured percent wave breaking are used to examine the evolution of third moment and bispectral statistics in relation to breaking patterns.

Shoaling waves gradually transform from peaked, Stokes-like waves to forward pitched asymmetric waves just prior to breaking. Inside the surf zone, wave asymmetry is modified by the breaking distributions and the effects of bottom topography. The observations suggest a relationship between the cross-shore wave breaking distributions and wave slopes. Wave slopes predicted using a calibrated wave transformation model which includes wave rollers are in qualitative agreement with measured wave slopes.

The results showed that strong ESL (5 to 10 dB) existed over a sand (reflective) bottom and was generally invariant with range. ESL was correlated with TL, i.e., areas of high spreading loss were found in regions of high TL. ESL was not as large (3 to 5 dB) over silt/clay (absorptive) bottoms due to the increased absorption of the bottom refracted path thus reducing the number of multipath modes. Broadband pulses were found to exhibit fewer fluctuation than single frequency signals, and generally the total TL loss was a few dB larger than a single cw case. To overcome the ESL, integration techniques based on an accurate prediction model in the post analyzing system are required with a high temporal resolution of the echo energy shape.

OBSERVATIONS AND MODELING OF THE INTERNAL TIDE IN A SUBMARINE CANYON

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Shipboard ADCP and CTD measurements were conducted in Monterey Submarine Canyon in April and October 1994 to determine the propagation characteristics and energy levels of the semidiurnal internal tide. The measurements reveal a bottom-intensified internal tide propagating energy upcanyon. The region of strongest motion is in a beam 150-200 m thick, centered approximately 150 m above the Canyon floor. Along-canyon baroclinic M2 currents are typically 15-20 cms^{-1}, an order of magnitude larger than the estimated barotropic tidal currents. In April 1994, the internal tidal beam is well described by a progressive wave, while in October 1994, the signal is standing along and perpendicular to the beam. The Princeton Ocean Model was used to study the generation and propagation of semidiurnal internal tides in submarine canyons and to investigate their sensitivity to canyon shape. Minor changes in floor slope are found to have a significant impact on the strength of internal tides in a canyon. The numerical experiments reproduce several features of the internal tide that are in qualitative agreement with the observations, including upcanyon energy propagation along the canyon floor, internal tide generation along the canyon rim, and tidal pumping of dense water up onto the shelf near the canyon head.

THE JAN MAYEN CURRENT FROM 1989 AND 1990 SUMMER DATA

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As part of the Greenland Sea Project, a hydrographic survey consisting of 45 CTD stations was conducted in the vicinity of the Jan Mayen Current (JMC) in August 1990 aboard the USNS BARTLETT to further characterize and quantify circulation of the JMC. Comparisons were made with a similar survey performed in September 1989. In the summer of 1990, as in 1989, the JMC appears to be both a portion of the East Greenland Current (EGC) flowing eastward to close the Greenland Sea Gyre (GSG) and anticyclonic meander in the EGC flow north of Jan Mayen. Geostrophic velocities and transports were similar for 1990 and 1989 with typical near-surface speeds of 3 cm/s slowing to 1 cm/s at depth. The total input flow to the JMC from the EGC is estimated at 1.45 Sv for August 1990 compared to 2 Sv during September 1989. Baroclinic calculations for 1990 data indicate that the meander portion of the JMC is concentrated in the upper waters (~ 100 m) with the result that 44% of the upper layer and 25% of the lower layer (~ 100 1000 m) flow contributes to the JMC meander. The remainder, ~ 56% from the surface and 75% from the lower layer, continues eastward as throughput to the GSG. Similarly, in 1989, it was determined that about half of the upper layer flow is involved in the meander with flow becoming more easterly at depth. In 1990, the surface was warmer and fresher, the subsurface temperature minimum was colder, and the volume of water occupied by JMC type water masses was half the amount when compared to 1989 data.

SMALL-SCALE MORPHOLOGY RELATED TO WAVE AND CURRENT PARAMETERS ACROSS THE SURF ZONE

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Small-scale beach morphology (scales < 5 m) height variations were measured by combining the CRAB survey with bed elevation acquired from a 1 MHz sonic altimeter mounted on the CRAB during the October Phase of the DUCK94 experiment. Bedform types were observed using a 500 kHz side-scan sonar also mounted on the CRAB. Corollary waves and currents were measured. Three cases were examined in detail: mild waves and weak longshore currents resulting in wave ripples everywhere; storm waves with strong longshore currents resulting in lunate and straight crested megaripples in the trough of the barred beach; and narrow banded, normally incident waves with a strong rip current resulting in a relatively planar bed everywhere except in the throat of the rip where megaripples were measured. The predictive wave ripple height and length equations of Nielsen (1981) worked reasonably well for mild wave conditions, but did not predict ripples during moderate wave conditions. The wavenumber spectra were generally broad, indicating that newly formed ripples coexisted with residual ripples from the past to form complex, multi-scaled ripple patterns.

AN ANALYSIS OF ENERGY SPREADING LOSS ASSOCIATED WITH TACTICAL ACTIVE SONAR PERFORMANCE IN A SHALLOW WATER ENVIRONMENT

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Energy spreading loss (ESL) is qualitatively defined as the reduction in peak echo level due to energy spreading of the transmitted acoustic pulse in time. An analysis of the impact of shallow water propagation on ESL was performed with the aid of a high performance computer using the FEPE_SYN and EXT_TD programs to compute the spreading of the received pulse due to multipath propagation in shallow water. A Blackman windowed pulse was used to model the transmitted pulse, which was centered at 3.5 kHz, with 200 Hz bandwidth. For input parameters, typical seasonal sound speed profiles and a Hamilton geoacoustic model of Area Foxtrot off the U.S. eastern seaboard was used. ESL's impact on sonar performance was determined as a function of range, source and target depth, sound speed profiles and geoacoustic properties. The impact of shallow water propagation on the correlation of the transmitted and propagated pulses through the quantitative definition of mismatch loss (MML) was also discussed.

The results showed that strong ESL (5 to 10 dB) existed over a sand (reflective) bottom and was generally invariant with range. ESL was correlated with TL, i.e., areas of high spreading loss were found in regions of high TL. ESL was not as large (3 to 5 dB) over silt/clay (absorptive) bottoms due to the increased absorption of the bottom refracted path thus reducing the number of multipath modes. Broadband pulses were found to exhibit fewer fluctuation than single frequency signals, and generally the total TL loss was a few dB larger than a single cw case. To overcome the ESL, integration techniques based on an accurate prediction model in the post analyzing system are required with a high temporal resolution of the echo energy shape.

OBSERVATIONS AND CHARACTERIZATIONS OF NON-LINEAR INTERNAL WAVES ON THE MID-ATLANTIC BIGHT CONTINENTAL SHELF

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During the summer of 1995, an intensive, joint field study called Shallow Water Acoustics in a Random Medium (SWARM '95) was conducted by the Naval Research Laboratories (NRL), Woods Hole Oceanographic Institution (WHOI), University of Delaware (UD), Applied Physics Laboratory of Johns Hopkins University (APL/JHU) and Naval Postgraduate School (NPS), among others, in the Mid-Atlantic Bight continental shelf region off the coast of New Jersey. Environmental and acoustic sensors were deployed as part of SWARM '95 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. A modal, time-series analysis of the data captured by the two ADCPs was performed. Highlights of the results reveal that: the generation mechanism, in this case, is consistent with the lee-wave hypothesis of generation; the phase speed is in good agreement with predicted phase speeds of the first baroclinic mode; and the displacement power spectral density is significantly modified when soliton wavepackets are present.

A SENSITIVITY STUDY OF NUMERICAL SOLUTIONS OF THE SOUTH CHINA SEA OCEAN MODEL TO VARIOUS GRIDS GENERATED BY GRID GENERATION TECHNIQUE

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The sensitivity of numerical solutions of systems of nonlinear flow equations (Navier-Stokes equations) to the grid used is investigated through the use of the South China Sea (SCS) numerical ocean model. Traditionally, rectangular coordinate grids are used in environmental modeling. The advantage of rectangular coordinate grids is their simplicity in the generation process. However, rectangular coordinate grids are not well suited for regions with complex terrain (coastlines and topography) and occasionally lead to poor accuracy in numerical solutions. The grid generation techniques are being introduced to coastal ocean modeling to study the sensitivity of numerical solutions to the grid used and to investigate the enhancement of the modeling process. Grid generation techniques are broadly used in the aeronautical engineering community for solving CFD problems.

One orthogonal (121x191) and two curvilinear nearly-orthogonal grids (121x191 and 151x241) are designed to couple with the SCS numerical ocean model. The grids are designed using the EAGLEView grid generation code developed by the National Science Foundation (NSF) Engineering Research Center (ERC) of Mississippi State University. EAGLEView implements a grid generation technique using mainly elliptic and algebraic generation systems. The designed grids are processed with the SCS numerical ocean model for 200 days to study the sensitivity of numerical solutions to the grid used. The solutions of the temperature and salinity fields are presented and analyzed. The advantages of curvilinear nearly-orthogonal grids are also discussed.

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