Review of Research and Educational Activities

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Education

B.S./B.A. Physics/Math, Ohio University, 1968
M.S. Physics, Stevens Institute of Technology, 1972 (completed while in U.S. Coast Guard)
M.A. Geophysical Fluid Dynamics, Princeton University, 1975
Ph.D. Geophysical Fluid Dynamics, Princeton University, 1977

Positions Held

Instructor, U.S. Coast Guard (military service: taught electronics and human relations), 1969-1973
Part-time Instructor Math and Physics, New York Institute of Technology, 1972-1973
Research Assistant, Geophysical Fluid Dynamics Laboratory, Princeton University, 1973-1977
Rosenstiel Fellow, Rosenstiel School of Marine and Atmospheric Science, University of Miami, 1977-1978
Professor (Assistant to Full), Department of Geological Sciences, Institute for Marine and Coastal Studies, Hancock Institute for Marine Sciences, University of Southern California (USC), 1978-1996
Co-Director & Co-Founder of USC's Hancock Institute for Marine Sciences (with Patricia Kremer), 1995-1996
Professor Department of Geography and Graduate Program in Marine Sciences, University of California, Santa Barbara, 1996-present
Secretary of the Navy/Chief of Naval Operations Chair in Oceanographic Sciences, 2008-lifetime award

Cumulative List of Publications and Other Detailed Information including Descriptions of Various Resarch Projects –

Please see Curriculum Vita at www.opl.ucsb.edu.

Introduction to the Review

I completed undergraduate degrees in physics and mathematics in 1968 at Ohio University. During my ensuing service in the U.S. Coast Guard, I was fortunate to have had the opportunity to teach electronics (and human relations) and to complete an M.S. degree in physics through evening classes at Stevens Institute of Technology. Toward the end of my service period, I also taught math and physics at the introductory college level (New York Institute of Technology) in the evening. I found teaching to be most rewarding and importantly was introduced to the subject of oceanography by fellow Coast Guardsmen who were studying to be marine technicians. I borrowed the classic book, *The Oceans*, by Sverdrup, Johnson, and Fleming along with books on meteorology and ecology from some of these students. After reading these, I decided to pursue a teaching and research career focusing on environmental problems.

Following completion of my four years of Coast Guard service, I entered the Princeton University Geophysical Fluid Dynamics Program, which was an ideal environment for me as it was physics-based, it placed a heavy emphasis on self-study, and the professors, scientists, and fellow students were exceptionally stimulating. General circulation models of the atmosphere and ocean were being developed for climate studies on the large scale in the same setting where fundamental breakthroughs were being made in equatorial dynamics, weather prediction, and turbulence closure modeling. My Ph.D. thesis (completed under Professor George Mellor) concerned the fundamental problem of transition between turbulence and internal waves, but I also did a class project concerning equatorial waves (under Professor George Philander), resulting in my first *Journal of Geophysical Research* paper.

Upon completion of my Ph.D. at Princeton (1977), I received a competitive Rosenstiel Fellowship from the University of Miami to do research in any area of my choice. I decided to pursue interdisciplinary studies involving physical and biological interactions at a time when disciplinary oceanography was the norm and interdisciplinary research was still rare. Despite this, I followed a career path in interdisciplinary studies. My first interest concerned the interaction of physical and biological processes, particularly through the application of mixed layer models to biological problems. It became evident that interdisciplinary models would require biological data on scales comparable to physical data. At that time, few biological and optical instruments with adequate sampling capabilities were available. However, in the course of the next few years, several advances were made in a new field of study, bio-optics, which has changed the direction of biological, optical , and biogeochemical oceanography and has clearly influenced much of my research. I am currently writing a book with Emanuel Boss (University of Maine) on bio-optical oceanography and its applications.

Following a year at the University of Miami, I accepted an Assistant Professor position at the University of Southern California (USC). USC had recently hired biological and geochemical oceanographers, who were anxious to interact with a physical oceanographer. Being the lone physical oceanography professor at USC and having keen interests in interdisciplinary studies, I formed close relationships with biological and geological oceanographers and began to work in the areas of marine biology, optics, biogeochemistry, and geology. Over the years, I have been able to attract excellent students and research associates to my group (described in vita). Most developed interdisciplinary interests and expertise. Several have become leading practitioners and proponents of interdisciplinary oceanographic research. My 18 years of research at USC were exceptionally diverse and, of course, highly interdisciplinary. Thus, my research funding has been derived from almost all possible agencies in physical, biological, optical, geological, and biogeochemical oceanography and ocean technology. I enjoy identifying important and societally relevant scientific problems, writing papers and books, directing graduate student research, and finally sharing my research discoveries and experiences with large numbers of undergraduates, graduate students, and colleagues on the international level.

Teaching has been one of my favorite activities, but I have also been involved in and often led major interdisciplinary national and international programs and have developed an international network of collaborators; this has been especially rewarding for my students as well as myself. I feel that one of my more important attributes is my ability to help bring the best out of students and colleagues, whether serving as a leader or as a participant. I have encouraged students to pursue research areas that they prefer, sometimes leading to work with and direction by other faculty members. I feel that this flexibility has been enriching for my students as well as our group as "disciplinary and idea boundaries" simply do not exist for us.

The accomplishments described in my vita and this personal statement clearly represents our group's (Ocean Physics Group, OPG, at USC, and Ocean Physics Laboratory, OPL, at UCSB) team efforts, which have often been enabled or enhanced by our many collaborators. During my career, I have attempted to give credit to, and help to advance the careers of, my students and other members of our group as well as our colleagues. Thus, there are often many co-authors on our papers, frequently with first authorship by students, post-doctoral fellows, research associates, and engineers. I am proud that many of the past and present members of the OPG and OPL continue to work on projects and write papers together and with my present group as well as to network with each other to identify research and career opportunities.

My appointment to the faculty of UCSB began in January 1996. Since much of our group's activity is observational and based upon instrumentation and new technologies, the first year at UCSB required our group to accomplish several logistical tasks including finding off-campus space, moving instrumentation, office materials, etc. from USC to UCSB, purchasing new laboratory equipment, office furniture, and computers, setting up telephone and computer communication links, and transferring grants and contracts. At the same time, we were conducting two major field programs, the Bermuda Testbed Mooring (BTM) program (I was lead-PI) and the Coastal Mixing and Optics (CMO) program (I was co-editor of *Journal of Geophysical Research* Special Volume for CMO). Our group responded to the challenges of the move, adapting to a different administrative structure, and maintaining continuity of our field intensive research programs.

During the past decade, our research has focused on development of new technologies, observationally based research, and modeling. Our group is well known for developing innovative interdisciplinary instrumentation that allows observations on time scales from a few minutes to several years. Much of our work focuses on interactions among physical, bio-optical, and biogeochemical processes. Our research spans both coastal and open ocean waters and often contributes to the advancement of remote sensing of the oceans. We have led three major technological development programs recently: Office of Naval Research (ONR) National Ocean Partnership Program (NOPP) Ocean-Systems for Chemical, Optical, and Physical Experiments (O-SCOPE with sites at Ocean Station P in the North Pacific, Bermuda, and off Monterey, California), NSF/ONR/NASA Bermuda Testbed Mooring (BTM) program, and NOPP NSF Multi-disciplinary Ocean Sensors for Ecosystem Analyses and Networks (MOSEAN) program (sites off Hawaii and Santa Barbara). I have been a major proponent of the philosophy of the NOPP style of projects, which encourages collaborations among academic and research institutions, government laboratories, and the private sector. The BTM program is also a research program. I have also led the ONR Hyperspectral Coastal Ocean Dynamics Experiment (HyCODE) research program (sites in Bahamas, West Florida Shelf and off New Jersey), and the ongoing ONR Radiance in a Dynamic Ocean (RaDyO) program Other research programs that we have played major roles in include High Latitude Time Series (HiLaTS, using three moorings in the North Pacific off Japan) with U.S. and Japanese collaborators and a project in the Gulf of California with Mexican and UK collaborators. NSF also funded a study of eddies off the Hawaiian Islands (E-Flux). Our research over the past decade has been conducted in the North Pacific off Canada, off Hawaii, and off Japan, in the North Atlantic, and off the east and west coasts of the U.S. Our research is leading to better understanding of episodic and extreme events such as internal solitary waves, hurricanes, and mesoscale eddies. These phenomena have been vastly undersampled previously, and thus their importance and contributions to oceanic variability have remained as major enigmas for our science. Nonetheless, our cutting-edge technologies and analyses are proving critical in solving these problems. We are actively promoting the use of data assimilation modeling and remote sensing to complement *in situ* observations in order to address problems that encompass time and space scales spanning over ten orders of magnitude.

While much of our observational activity has focused on interdisciplinary moorings around the world, we have made strides in new sampling technologies involving autonomous underwater vehicles (AUVs) with successful collaborative studies using two different AUVs (Autosub (Southampton Oceanographic Centre, UK)) and (Odyssey (MIT)) during experiments near the BTM site and in Massachusetts Bay, respectively. Our research and technological developments have become increasingly important internationally as evidenced by the various activities described in my vita. In particular, we have developed interactions and/or collaborations with oceanographers in several countries including the United Kingdom, France, Japan, Taiwan, China, Turkey, New Zealand, Germany, and Italy. The impact of our research is reflected in the number and significance of our publications. In addition, it is worth noting that the ideas and thrust of our research and technological endeavors, which were previously considered rather radical and often challenged, are being adopted by many and appear to be approaching mainstream.

Review of Specific Research Activities

<u>Overview</u>

Our research is directed toward interdisciplinary oceanographic and environmental problems including: upper ocean dynamics, bio-optics, ecology, biogeochemistry and global climate change, coastal water pollution, bottom boundary layers, and sediment resuspension. Recent efforts have emphasized studies of physical/biological processes and interactions on time scales from minutes to the interannual, yet some of our work retains focus on fundamental physics at the air-sea interface and in the upper and bottom layers of the ocean. Our group is studying both open and coastal ocean domains simultaneously. We continue to expand both disciplinary and interdisciplinary efforts toward multi-platform (*in situ* and remote sensing) observational networks for science, monitoring, and modeling with application to coastal pollution and global climate change. Our work often involves innovative development and use of new technologies. An important aspect of our work has concerned the development of instrumentation and techniques for linking *in situ* and remote sensing observations, particularly through use of mooring-based measurements for groundtruthing (calibration/validation) ocean color satellite sensors. Our optical systems are also proving useful for attacking fundamental problems such as optical closure (i.e., quantifying relationships between inherent and apparent optical properties (IOPs and AOPs) and testing radiative transfer models, and ocean visibility and imaging). Our innovative sampling technologies and their optimal utilization are especially important, as the oceans remain so sparsely sampled; new ocean discoveries require novel direct observations. The instrumentation we deploy allows us to explore the physical, optical, biological, geological, and chemical environment and complex couplings at unprecedented time scales (minutes to years) allowing us to discover new processes and to quantify and model these processes. Our work is changing the way scientists are thinking in terms of the importance of episodic and high frequency phenomena. These were previously under- or unsampled and thus generally assumed unimportant. This is clearly not the case according to our results. New paradigms are being generated because of our measurements, analyses, and modeling studies (examples are presented in our publications). Although much of our work is observational in nature, we also utilize (and contribute to) satellite remote sensing and numerical modeling methods. Several students have done theses using our unique data sets in combination with numerical models. It is worth noting that our data sets are made available quickly after collection and are being used by many investigators worldwide to interpret their results and to develop complex physical (e.g., air-sea interaction for hurricanes and monsoons) and interdisciplinary (e.g., biogeochemical, radiative transfer, imaging, sediment resuspension) models. Data telemetry and sampling methods are key technical thrusts along with sensor and system development by our group. These aspects are becoming more valued as ocean prediction is becoming more feasible.

The impact of our research is evident in several ways including high productivity in the refereed literature, large and diverse extramural funding, extensive advisorial activity, and demand for our students and expertise. Many of our experiments utilize a variety of observing platforms and our mooring results are often essential for the proper interpretation of data collected from the other platforms. Thus, the impact of our work is often multi-faceted, enabling, and multiplicative.

Some specific research areas are highlighted below (also see www.opl.ucsb.edu 'Projects' for up-to-date and detailed information concerning specific research activities):

1. Air-Sea Interaction, Upper Ocean Dynamics, Extreme and Episodic Events, Bio-optics, and Biogeochemical Cycling:

My Ph.D. thesis concerned a fundamental problem of geophysical fluid dynamics: the transition between internal gravity waves and turbulence. This work was used as the basis for our group's laboratory studies concerning the exchange of gas across the air-sea interface. These studies remain of considerable interest, particularly because of the transport of carbon dioxide and other greenhouse gases across the air-sea interface (greenhouse gases and their roles in the climate change problem). In addition, our laboratory experiments were used in joint work with Alice Alldredge (UCSB) to study the effects of turbulence on the strength of "marine snow" and the disaggregation of particles. A theory described in my Ph.D. thesis has been utilized by my thesis advisor George Mellor (Princeton) for a reformulation of his commonly used turbulence closure model. We have used this model and three others to explore the physical processes contributing to the dynamics and thermodynamics of the upper ocean in the wake of Hurricane Felix. This work has additional importance in regard to hurricane dynamics and prediction (e.g., feedbacks, hurricane intensity, and trajectories of hurricanes). We have published a paper in the Journal of Geophysical Research paper concerning the apparent increase in chlorophyll and primary production in the wakes of several hurricanes (Babin et al., 2004). Students Jen Sira and Raphaella Banholzer, Songnian Jiang, and I are currently working with Yi Chao and colleagues (Jet Propulsion Laboratory) on the 4-dimensional modeling of upper ocean response using several of our Bermuda Testbed Mooring data sets.

Our field experiments in the early 1980's utilized R/P FLIP as part of the Optical Dynamics Experiment (ODEX) in the central North Pacific. Our theoretical and observational papers concerning air-sea interaction and upper ocean thermodynamics, dynamics, and bio-optics contributed to an important paradigm shift, namely "variability in biological productivity can significantly affect upper ocean thermal structure, heat budgets, and currents." Further, the potential use of bio-optical time series data for estimating primary productivity was demonstrated. We also pursued the physical/atmospheric longwave radiation problem (part of the World Ocean Circulation Experiment, WOCE) using theoretical, laboratory, and field approaches to better characterize longwave (LW) determinations from buoys and ships. Our results appear to have led to improved field determinations, satellite groundtruthing, and modeling of the LW component of the heat budget.

Over the past two decades years, we have done several experiments utilizing moorings to obtain high temporal resolution (minute-scale), long-term (2-months up to about 10 years) time series to study air-sea interaction, thermodynamics, dynamics, bio-optics, biological productivity, biogeochemistry, and sediment resuspension in diverse ocean regions including: the Arabian Sea, the North Atlantic Ocean off Bermuda and off Iceland, off the east coast of the U.S., the Mediterranean Sea, the central equatorial Pacific, off Hawaii, and off the west coast of the U.S. Processes ranging from the seasonal cycle down through minute-scale cloud fluctuations have been studied for the first time in such detail through these collective research efforts. Our data sets have shown that springtime mixed layer shoaling and phytoplankton blooms can occur within only a few days and can effectively influence each other. This aspect alone represents a major advance as modelers of seasonal productivity had been limited to only a few data sets collected at monthly intervals previously (Menzel and Ryther, 1960, 1961), resulting in aliasing and undersampling. Our group and others have used interdisciplinary physical-biological models to simulate the physical and biological seasonal cycle.

Inertial motions and their effects have been studied theoretically and observationally. Within the past few years we have collected extraordinary data sets as hurricanes have passed over our moorings off Bermuda and south of Cape Cod, Massachusetts. These unique data sets (unobtainable from ships) have been, and are still being, analyzed and modeled. The testing and development of models of the ocean's response and sediment resuspension in the wakes of hurricanes are enabling us to better understand the physics of these highly episodic and energetic phenomena. This research has important implications for hurricane prediction and their effects.

Mesoscale features including eddies and fronts have been studied by our group since the 1980's and continue to be of special interest in terms of biogeochemical cycling. The combination of trapped inertial waves and mesoscale features was examined using our early Sargasso Sea data sets. We have reported the first direct measurements of bio-optical and chemical time series as a major eddy passed the Bermuda Testbed Mooring. These observations and their interpretation are especially important in balancing the nutrient budget of the North Atlantic and explaining the role of the biological pump in carbon cycling in the oligotrophic ocean. Our interdisciplinary time series data obtained in the Arabian Sea also indicated the importance of mesoscale features, especially in terms of flux of organic carbon to the deep sea. In addition, the monsoonal cycle was shown to be important for biogeochemical cycling and primary production in the central Arabian Sea. Variability in the penetrative component of solar radiation was demonstrated to be significant as well. From autumn of 2004 through spring of 2005, we conducted an intensive physical-biogeochemical eddy experiment in the lee of the Hawaiian Islands with collaborators as part of an NSF-funded project called E-Flux (see www.opl.ucsb.edu Projects and Publications; Benitez-Nelson et al., 2007; Dickey et al., 2008; Nencioli et al, 2008; Kuwahara et al., 2008; Rii et al., 2008). This experiment is serving as the basis for Francesco Nencioli's PhD dissertation (Nencioli et a l., 2009a,b).

Another geographic area of central interest for interannual variability and global climate change is the equatorial Pacific where we made the first high-resolution time series measurements of bio-optics and physics concurrently. These data were used to compute time series of primary productivity. The primary productivity was shown to be related to equatorial longwaves including tropical instability waves (TIWs) and Kelvin waves. Interestingly, the TIW passages appear to act as natural iron enrichment events. Further, both El Niño and "normal" phases were observed during the 18-month mooring observations, so that we were also able to quantify primary productivity for these two extreme cases.

Although most of our biologically oriented research has focused on the lower trophic levels (e.g., phytoplankton), we have also devoted considerable effort toward research concerning higher trophic levels. In particular, we have contributed to the ideas concerning predator-prey interactions, especially in regard to the effects of turbulence. Some of my earliest committee work (Recruitment Experiment (REX II) Workshop, 1978) involved this problem and population dynamics as they affect fisheries. This activity preceded and contributed to the initiation of the major U.S. and international GLOBEC (Global Ocean Ecosystem Dynamics) programs. I provided community service to these programs until the past few years (Harris et al., 2009). Using acoustic Doppler current profiler (ADCP) backscatter and complementary BTM data sets, Songnian Jiang led our effort to understand the temporal and spatial variability of zooplankton distributions (see Jiang et al., 2007) in relation to various forcing conditions including hurricanes and mesoscale eddies. This research is being further advanced by Houssem Smeti (M.S. student from Tunisia), Maureen Conte, and our group (Smeti et al., 2009).

2. Coastal Processes, Bottom Boundary Layers, Optics, and Pollution:

Some of my first work in the area of coastal oceanography, and in particular bottom boundary layers, utilized a turbulence closure model and a data set collected off the coast of Peru. The results of the work showed excellent agreement between the model and the data indicating one of the few clear examples of a classic bottom Ekman layer. Later, I began work in coastal waters off the Palos Verdes Peninsula (near Los Angeles) where an outfall was discharging about 300,000 gallons of treated sewage daily and where over 100 tons of DDT are buried in sediments off the Palos Verdes Peninsula. The DDT problem has been of special interest as it has been the subject of a multi-million dollar lawsuit and a controversial "capping" experiment is underway. Importantly, our work has been of fundamental scientific value as we have studied the problem of dispersion and mixing as well as sediment resuspension. By sampling very rapidly (minute-scale) and continuously, we discovered a new process for sediment resuspension, an "ocean-bottom pump." The process involves resonantly generated near-bottom, internal solitary waves (ISWs), which are not presently included in models of sediment resuspension. More recent studies in the area by our group and collaborators have entailed mapping of sediment resuspension areas off Palos Verdes. The Palos Verdes studies along with our research off of Honolulu (Mamala Bay) have examined the fate of ocean outfall waters (treated sewage) by using moorings, bottom tripods, and ship tow-yo surveys. Importantly, advanced optical instrumentation has been utilized to allow us to better understand the fundamental processes of dispersion and advection. Our work with AUVs in Massachusetts Bay (site of the Boston municipal sewage outfall) represents a future approach for monitoring, modeling, and managing municipal wastes through adaptive sampling and data assimilation.

The CMO experiment was devoted to a host of processes, which affect optical variability on the continental shelf south of Cape Cod, MA. Our time series measurements of physical and bio-optical variables have been used for examining physical/bio-optical interactions and sediment resuspension. The passages of packets of internal solitary waves and two hurricanes (Edouard and Hortense) have provided us the opportunity to analyze and model these processes and their effects on particles and their associated bio-optical properties for the first time. In addition, the spectral data sets have been utilized to model the partitioning of the various components of spectral absorption. Simulations of the bottom boundary layer using a turbulence closure model have demonstrated that wave and mixing effects are important for sediment resuspension during the hurricane passages.

Presently, we are conducting the Radiance in a Dynamic Ocean (RaDyO) project. The first phase of RaDyO centered on the testing of newly developed optical and wave sensing instrumentation from the Scripps Institution of Oceanography pier in January, 2008. In September 2008, RaDyO investigators came to the Santa Barbara Channel for the first of two major field experiments. RaDyO instrumentation was deployed from the Research Platform (R/P) FLIP [acronym for FLoating Instrument Platform (see website http://sio.ucsd.edu/voyager/flip/flip2.html)], the research vessel (R/V) Kilo Moana, two autonomous underwater vehicles (AUVs, essentially robotic submarines), a small platform for collecting surfactants at the ocean surface (dubbed Lil Kilo Moana for obvious reasons), and a small airplane. These collective platforms measured a host of ocean processes related to the fundamental problem of light propagation and imaging as affected by waves, turbulence, bubbles, surfactants, and the optical properties of near surface seawater. The next field experiment will be conducted with the same complement of platforms and instruments south of the Big Island of Hawaii (see www.opl.ucsb.edu 'Projects', 'RaDyO' and 'About RaDyO article).

3. Ocean Technologies:

Ocean technology is of special importance because *in situ* interdisciplinary observations of the ocean are so sparse in both time and space. My particular interest in ocean technology resulted from a desire to develop interdisciplinary coupled models of the upper ocean. Our early modeling experiments utilized varying optical water types and provided interesting insights, but few data were available for validation or model development. As mentioned earlier, I realized that special *in situ* optical and biological data were going to be required with sampling at time and space scales comparable to those of the physical variables. The shipboard-profiling mode of sampling was being utilized by many investigators. However, I felt that important breakthroughs would require concurrent physical and biological high-resolution long-term, time series, which would be capable of capturing a nearly complete suite of processes. Clearly, inclusion of important diel, internal gravity wave, inertial, sub-mesoscale, mesoscale, seasonal, and interannual scale processes required such time series. During the Biowatt experiment in the North Atlantic, our group modified an autonomous profiler (cyclesonde) and obtained a minimal set of physical and bio-optical data. Next we developed a prototype multi-variable moored system (MVMS), which was based on a vector measuring current meter (VMCM). We initially modified the VMCM by adding bio-optical and chemical sensors (beam transmissometer, stimulated fluorometer, photosynthetically available radiation (PAR) sensor, and dissolved oxygen sensor). MVMS's have been used for several of the experiments described earlier. We have developed several new optical systems to measure inherent and apparent optical properties spectrally during the Bermuda Testbed Mooring (BTM), Coastal Mixing and Optics (CMO), and HyCODE, RaDyO, NOPP O-SCOPE, and NOPP MOSEAN programs.

The Bermuda Testbed Mooring (BTM) program, which was sponsored by NSF, ONR, and NASA, provided the oceanographic community with a deep-water platform for testing new instrumentation from 1994-2007. Scientific studies also utilize data collected from the BTM. Surface instruments have collected meteorological and spectral radiometric data from the buoy tower and measurements at depth have included: currents, temperature, and bio-optical, chemical, and acoustical variables. The BTM captures a broad dynamic range of oceanic variability (minutes to years). During the BTM program, several new sensors and systems have been tested by U.S. and international groups. These include new measurements of pCO_2, dissolved oxygen, nitrate, trace elements, several spectral inherent and apparent optical properties, ^{14}C for primary production, and currents. Our NASA SIMBIOS study using the BTM demonstrated that moorings-of-opportunity can be effectively used to collect very large volumes of accurate spectral radiometric data. Already these data sets have been used to evaluate the performance of the SeaWiFS ocean color satellite sensors. Several of the scientific results described earlier (Hurricane Felix and eddy passages) and more recently data collected during the passage of Hurricane Fabian (September, 2003) were made possible through the BTM program; also, a large number of investigators have used and still are using the program for science and technology.

The HyCODE project focused on higher spectral resolution (nanometer scale resolution across the visible spectrum) measurements, which we use to develop relationships between IOPs and AOPs and ultimately to identify and quantify the various contributions to the optical signals (e.g., phytoplankton by species groups, detrital materials, dissolved matter, etc.). These data sets are also important for validation and algorithm development for the Navy hyperspectral imagers flown in aircraft. This work entailed cooperative efforts with specialized companies. An example of a highly collaborative, integrative activity is the National Ocean Partnership Program (NOPP) Ocean-Systems for Chemical, Optical, and Physical Experiments (O-SCOPE) project. Investigators came from universities, private research institutions, government laboratories, and private industry. Important advances resulting from the O-SCOPE work include the development of new mechanisms for reducing the adverse effects of biofouling, new chemical sensor capabilities, and telemetry of data from remote sites. The NOPP MOSEAN project (sites off Hawaii and Santa Barbara) built upon O-SCOPE and expanded its objectives to develop additional *in situ* chemical and hyperspectral optical sensors.

Educational Summary

I feel that I have an enthusiastic and motivational teaching style. Most students seem to relate easily to me, perhaps because I really enjoy and value them. I attempt to excite students about the ocean and the environment, emphasizing 1) the uniqueness and importance of the ocean, 2) the relevance of oceanography to society in general, 3) implications of pollution using real world examples from our work off the California, Hawaiian, and Massachusetts coasts, and 4) that everyone can make a difference through personal actions and through involvement with various environmental organizations. One reason that I feel that my efforts are so important is that I have had the opportunity to educate such a large number of students, many of whom have made and will be making key environmental decisions.

Both undergraduate and graduate education are important components of my teaching and advising activities. The two are highly complementary with our research programs, which have provided opportunities for direct involvement with cutting edge scientific studies, several in diverse geographic regions (e.g., Arabian Sea, Bermuda, Hawaiian Islands, Mediterranean Sea, equatorial Pacific, east and west coasts of the U.S., and others). The classroom experience is also greatly enhanced by our field activities. I have taught one of the major entry-level courses (Oceans and Atmospheres) throughout my career (typically 250-350 students per class). Several students have indicated that they selected Geography or Environmental Studies majors based on my courses. Other new courses have also been developed.

I have utilized my two Great Pyrenees dogs, Kiki and Teddy, in teaching about polar explorers and oceanographers who have employed dogs in their research and work at sea and onshore (see www.opl.ucsb.edu 'Education.' They have joined me for Geography 3a classes and high school visits. They are described in an educational paper concerning Fridtjof Nansen submitted to Oceanography ('Standing on the shoulders of giants to teach 21st century oceanography').

The graduate education aspect has also proven successful with the production of some excellent graduate students. In summary, I am proud of the quality and quantity of the students I have taught during my career. The statistics show that I have now taught over 5,000 undergraduates, and served on over 100 graduate committees; 22 graduate (M.S. and Ph.D.) degrees have been completed under my supervision. Fourteen advanced research scientists have done research in our laboratory. In addition, I have directed several undergraduate research projects. It is worth noting that the professional staff of our group (e.g., engineers, post-doctoral fellows) works very closely with our students so that they are well trained in all aspects of field oceanography (our group has participated in 150 research cruises. Finally, I co-authored an introductory textbook with a co-author, Sean Chamberlin (Exploring the World Ocean, 2007, McGraw-Hill). I am also working on another textbook on applications of bio-optics to oceanography with Emanuel Boss of the University of Maine.