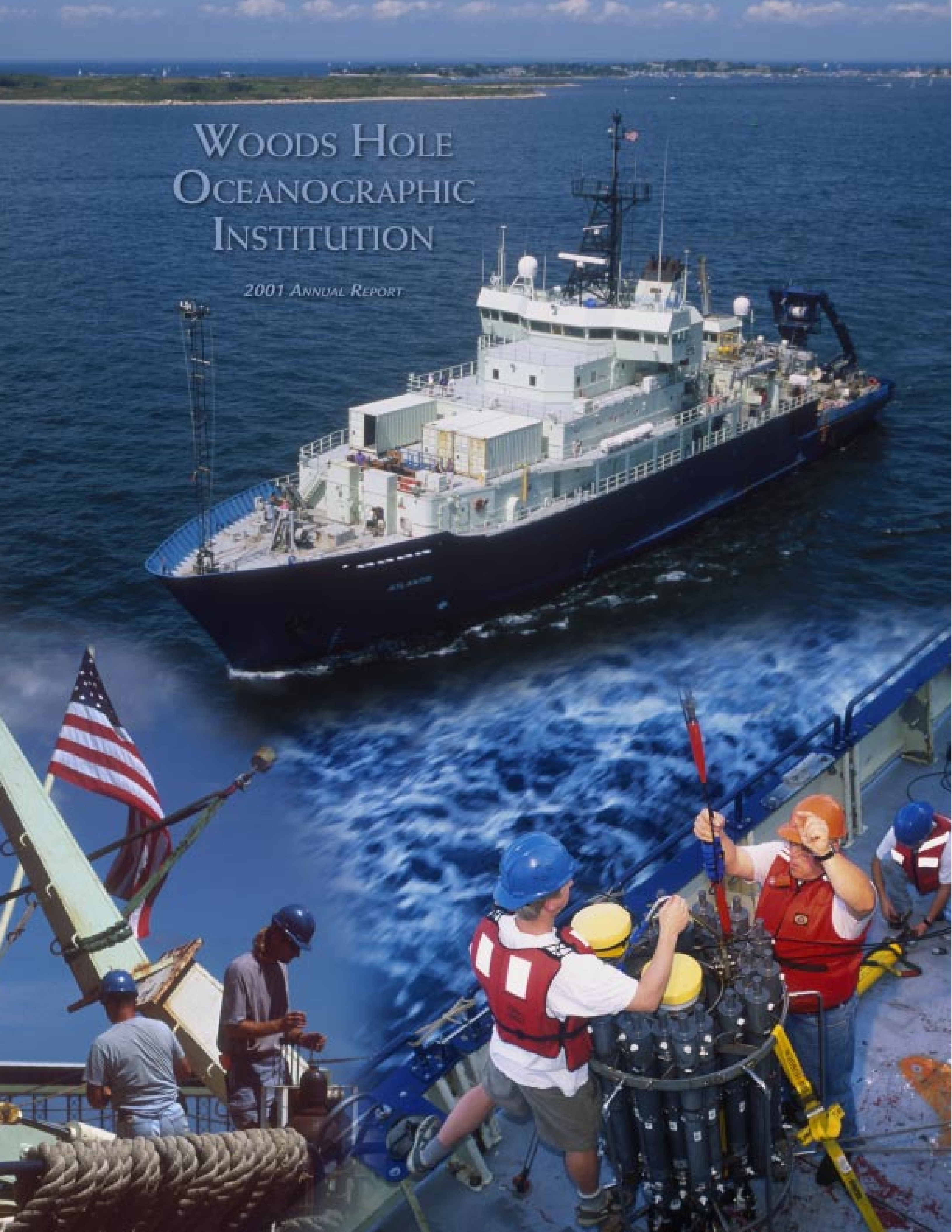
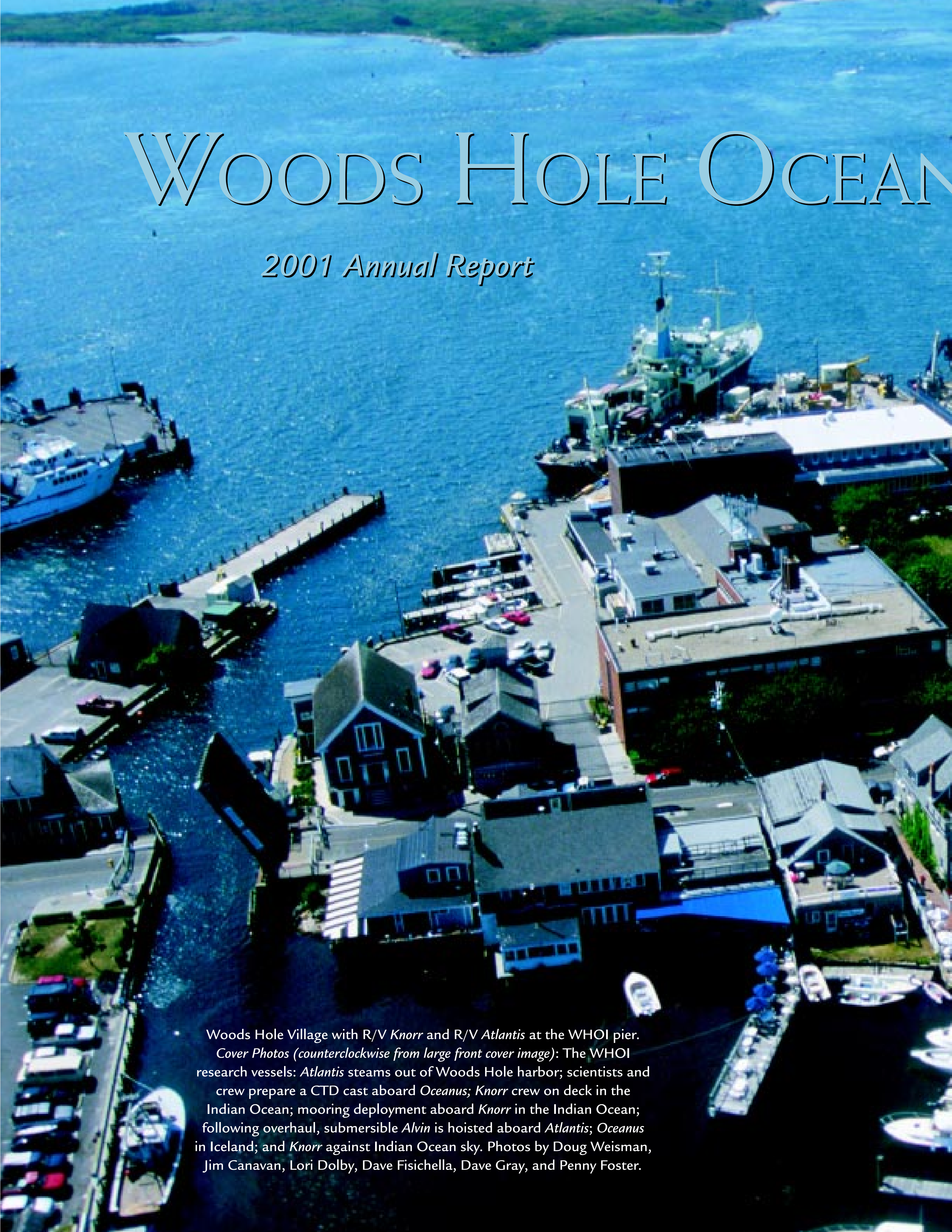
Woods Hole Oceanographic Institution

2001 Annual Report



WOODS HOLE OCEAN

2001 Annual Report



Woods Hole Village with R/V *Knorr* and R/V *Atlantis* at the WHOI pier. *Cover Photos (counterclockwise from large front cover image)*: The WHOI research vessels: *Atlantis* steams out of Woods Hole harbor; scientists and crew prepare a CTD cast aboard *Oceanus; Knorr* crew on deck in the Indian Ocean; mooring deployment aboard *Knorr* in the Indian Ocean; following overhaul, submersible *Alvin* is hoisted aboard *Atlantis*; *Oceanus* in Iceland; and *Knorr* against Indian Ocean sky. Photos by Doug Weisman, Jim Canavan, Lori Dolby, Dave Fisichella, Dave Gray, and Penny Foster.

nographic Institution

Contents

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Editor: Vicky Cullen
Designers: Jim Canavan and Jeannine Pires

The initial signs that an El Niño is taking shape are subtle. Trade winds begin to diminish. Warm surface waters start to move gradually eastward across the equatorial Pacific Ocean. But inevitably, momentum builds and culminates in a dramatic oceanic and atmospheric shift that has worldwide repercussions.

When El Niño comes, great schools of anchovies off the coast of Peru know enough to migrate to cooler waters where food is more plentiful. In the face of changing conditions, natural systems periodically adjust so that they can operate most efficiently and effectively.

So, too, must institutions. In years hence, I believe that 2001 will mark the beginning of a time of significant change for the Woods Hole Oceanographic Institution. We have set in motion strategies that inevitably will transform WHOI. They will put the Institution in the strongest position to help solve many of the urgent challenges and answer the needs of the next generation.

Those challenges include many that have fundamental impact on the future of life on Earth: global warming, climate change, pollution, fisheries, water supplies, energy resources, coastal development, and natural disasters such as hurricanes and earthquakes. None of these issues can be addressed, let alone solved, without making significant inroads into learning how our oceans work. All of them are complicated and will require expertise across a broad range of disciplines.

Shelley Lauzon

Director and President Bob Gagosian, second from right, and Associate Director for Marine Operations Dick Pittenger, right, accept a Public Service Commendation from Coast Guard Group Woods Hole officials on April 24, 2001. Captain Russ Webster, left, and Rear Admiral George Naccara cited both WHOI's assistance with a number of highly visible projects, including airplane search and recovery efforts, and a productive long-term relationship in their dockside remarks at the presentation ceremony.

In 2000, we established four Ocean Institutes to focus scientific firepower on areas that have societal ramifications—the ocean and climate change, ocean life, coastal oceans, and deep ocean exploration. The Ocean Institutes represent a new intellectual framework designed to build bridges between a full spectrum of oceanographic and other relevant fields. Their concurrent missions are to catalyze innovative thinking and collaborations that can lead to important discoveries, and to convey these discoveries expeditiously into the public realm, where they can be used to save lives, stimulate economic growth, and enhance our quality of life.

But the best new software does not work optimally without upgrades in hardware. In 2001, wasting no time, we took steps to build the infrastructure required to fulfill our goals.

To tackle a new generation of ocean-related problems, we need the next generation of cutting-edge instruments, and the facilities to house them. To attract, retain, and empower the best scientists, we must provide them with modern, state-of-the-art laboratories. To stimulate interaction among scientists, we seek to create an environment that fosters creativity, collaboration, and breakthrough science.

In spring 2001, after a thoughtful assessment of our needs and a diligent search, we selected two firms to devise a master plan for the future. The architectural firm Ellenzweig Associates of Cambridge, MA, is highly regarded for its laboratory designs, and the Falmouth-based firm Stephen Stimson Associates Landscape Architects also has a national reputation for excellence.

By late summer, the two had developed a master plan to invigorate our Quissett Campus. It starts with a new "ring road" that replaces the current central patchwork of intersecting roadways. A new pedestrian enclave forms the heart of the campus where two new buildings, now in the early planning stages, will be designed to further encourage social and intellectual interaction. One of the buildings is intended to house biogeochemistry—whose name itself indicates the multidisciplinary nature of modern oceanography.

The new buildings will provide 50,000 to 60,000 square feet of much-needed space that will allow budding research initiatives to blossom, including a multidisciplinary effort devoted to marine mammal research. Some scientists will move from our laboratories in Woods Hole village, creating new opportunities to reconfigure space there.

The master plan accommodates

more buildings and improves parking, but, at the same time, preserves and enhances the natural landscape. In some places, it recreates Cape Cod meadows where there are now roads and parking lots. That is one of the reasons that the Boston Society of Landscape Architects awarded its prestigious 2001 Merit Award to WHOI for Stephen Stimson Associates' design.

Construction of the ring road is scheduled to begin in 2002. Our goal is to start construction of two new science buildings in 2003. We have accomplished a great deal in a short time, but Woods Hole Oceanographic Institution has a proud legacy of mobilizing quickly in response to society's needs.

In 1940, on the eve of World War II, WHOI Director Columbus Iselin recognized the vital contributions oceanography could make and offered the Institution's services and facilities to the war effort. Within months, the Oceanographic was transformed from a primarily summertime operation to a year-round endeavor. Its staff quintupled, and Woods Hole oceanographers made fundamental discoveries, invented new instruments, trained naval personnel, and helped save countless lives.

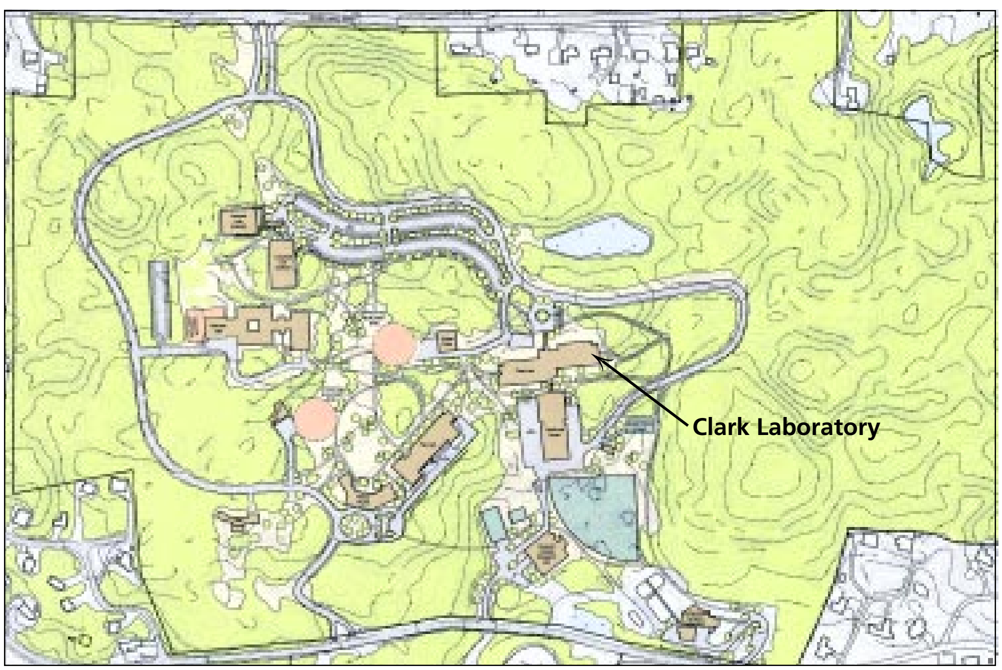
In the mid 1960s—as a high-level national commission was poised to recommend ambitious new exploration of the oceans and its potential resources, and a germinating environmental awareness spurred new, urgent questions about the degradation of coastal regions—WHOI Director Paul Fye seized the opportunity to purchase the 166-acre Fenno property and create our Quissett Campus. He also nurtured an unprecedented educational partnership with the Massachusetts Institute of Technology to establish a joint graduate program in oceanography that would provide top-flight training to new ocean science leaders.

Another era is beginning. We recognize the signs and our obligation to society. Our Institution is already mobilizing to answer the call.

—**Robert B. Gagosian**, Director and President

Tom Kleindinst

Director Bob Gagosian, right, and Senior Associate Director Jim Luyten, left, discuss WHOI campus planning with Massachusetts legislators, The Honorable Thomas Birmingham and Senator Therese Murray, during their visit in August 2001.



Stephen Stimson Associates Landscape Architects

Improvements to the Quissett Campus will begin with a "ring road" to facilitate a pedestrian corridor and create a more academic campus atmosphere. A Trustees Campus Planning Committee and a staff advisory committee worked during 2001 with members of the Directorate and architectural and landscape firms toward a long-term campus plan to enhance the Institution's research and education programs.

Comments from the Director of Research

It is common today to hear that "all of the interesting science is at the boundaries between disciplines." Though such a generality cannot be true, this expression does capture the feeling that many scientific problems of current interest involve complex systems and that their solutions may require cooperation among several scientific disciplines. Studies of the Georges Bank ecosystem, for example, include detailed examination of food chain biology, nutrient supply, sunlight's role, and dispersion or concentration of populations of fish, predators, and larvae by currents. There are problems of comparable complexity in almost every area of ocean science. Graduate students are often drawn to them, and they are of interest to policy makers and the public.

To facilitate interdisciplinary research and to enhance communication of the results, the Institution established four Ocean Institutes in May 2000. Institute Directors were named the following October. They are: the Ocean Life Institute (Larry Madin, Biology), the Coastal Ocean Institute (Ken Brink, Physical Oceanography), the Deep Ocean Exploration Institute (Susan Humphris, Geology & Geophysics), and the Ocean and Climate Change Institute (Bill Curry, Geology & Geophysics).

Tom Kleindinst

The Martha's Vineyard Coastal Observatory provides a variety of data for scientists involved in the Coastal Ocean Institute/Rinehart Coastal Research Center. The photo shows Mike Purcell, left, and Butch Grant assembling the data-collecting/transmission node for the observatory.

The four institutes share a basic structure and governance. Each Institute Director works with an Advisory Committee of five to six interested members of the Scientific and Technical Staff. An Institute Oversight Committee consists of the Chairs of the five scientific departments, the Director of the Marine Policy Center, and the Vice Presidents for Research, Education, and External Affairs.* The Ocean Institutes operate within the existing WHOI structure; staff have appoinments in the five science departments and the Marine Policy Center and may collaborate under the more fluid institute structure.

The general Ocean Institute plan calls for each group to develop research themes, to appoint Institute Fellows from among the Scientific and Technical Staff, to solicit and fund research proposals associated with the themes, and to support graduate students and postdoctoral researchers. Communication of Ocean Institute research and activities involves symposia, workshops, and other outreach activities.

Ocean Biodiviersity, Health of Ma-

Tom Kleindinst

Forums planned for the Ocean Life Institute include discussion of applications for biomedical tools in the marine sciences. This instrument, the first dedicated marine research CT scanner, was installed in Caryn House in 2001 with funding from the Defense University Research Instrumentation Program and the Office of Naval Research. Darlene Ketten, right, and Kristen Dubet (New England Aquarium) prepare a sea turtle for a diagnostic scan in one of a wide range of uses already found for the scanner.

* Institution Associate Director titles were reformatted as Vice President positions in March 2002.

rine Ecosystems, and New Tools for Ocean Biology were designated as principal themes for the Ocean Life Institute. The biodiversity theme encompasses discovery and characterization of organisms as well as investigation of their origins and ecological functions. The second theme includes identifying indicators for ecosystem health and sustainability and development of new theoretical and analytical methods to assess them. The tool theme covers new sensors, instruments, and analyses for biological properties and processes. As exploratory initiatives, Institute Director Madin and colleagues are developing collaborations with investigators from pharmaceutical industries and participating in planning for a private tropical research facility in Panama.

The Coastal Ocean Institute is building on and expanding the work of the Rinehart Coastal Research Center (see page 35). The theme for its activities focuses on the sources of nutrients in coastal systems and the fate of the consequent organic material. One objective is to develop a national effort to work toward a better understanding of the coastal ocean's role in global nutrient and carbon cycles. A close association with the Institution's Martha's Vineyard Coastal Observatory offers broad capabilities for understanding coastal ocean processes.

Seafloor Observatory Science and Instrumentation is the current broad theme of the Deep Ocean Exploration Institute, which promotes interdisciplinary investigations of the dynamic processes that shape Earth's surface, regulate the chemistry of its oceans, and impact its inhabitants. Institute supported projects include deep submergence vehicle technology, improving time-series measurements in the deep sea, design of chemical sensors and acoustic communications systems for observatories, and implications of seafloor earthquakes for observatories. The institute co-sponsored the spring Geodynamics Seminar on "Plume-Ridge Interactions."

Tom Kleindinst

The Ocean and Climate Change Institute sponsored the new "Station W" observatory mooring, set at the edge of the Gulf Stream in fall 2001. Ryan Schrawder, left, and Scott Worrilow, test the mooring's profiler on the WHOI pier.

The goal of the Ocean and Climate Change Institute is to evaluate and understand the role of the oceans in climate change with the objective of improving long-term climate forecasts. Its current focus is on the Atlantic Ocean, and 2001 activities included sponsoring establishment of "Station W." This is a moored profiling system located along the western boundary of the Gulf Stream at the single most important position for understanding how changes in ocean circulation affect major ocean-atmosphere systems. Institute Director Curry was involved in developing and funding a strategy for long coring to increase the efficiency of US research vessels in retrieving sediments for study of historic climatology.


Brian Tucholke

WHOI faculty and MIT/WHOI Joint Program students examine an outcropping of the Lava Creek Tuff, a 600,000-year-old ash flow on the Yellowstone plateau, during the Deep Ocean Exploration Institute-sponsored Geodynamics Seminar field trip in summer 2001.

The Ocean Institutes provide a flexible framework for interdisciplinary research, fostering creativity, innovation, and breakthrough science. They offer students a rich, productive educational environment, and they will provide a forum for dialogue between the public and the scientific community.

During 2001, each institute appointed Fellows, supported several research proposals, engaged students and postdoctoral investigators in institute activities, and began to formulate plans for gathering the best minds from within and outside the Institution to consider oceanographic research issues that have significant bearing on society. This productive first year promises to be a springboard for a new era of research, education, and communication at the Woods Hole Oceanographic Institution.

—**James Luyten**, Senior Associate Director & Director of Research

The Applied Ocean Physics and Engineering Department (AOPE) maintains the cutting edge of ocean engineering research and technology. The Department is renown for its technological contributions to ocean exploration, including the pioneering development of the human-occupied submersible *Alvin*. More recently, tethered Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs, see photo) are extending our observational reach into the abyssal depths, as well as into the shallow but much more turbulent coastal ocean environment. The Department also develops advanced moored and bottom-mounted observation systems for short- and long-term measurements. The Martha's Vineyard Coastal Observatory integrates atmospheric and oceanographic measurements into a high-bandwidth, real-time data feed to WHOI and the Worldwide Web, providing a continuous source of interdisciplinary data for coastal researchers.

Another major element of AOPE's research is in ocean acoustics and underwater communication. Two recent awards recognize our expertise in this area. The British Institute of Acoustics presented the 2001 A.B. Wood Medal to Associate Scientist John Colosi for his contributions to acoustical oceanography. Lee Freitag received WHOI's Skip Marquet Senior Technical Staff Award, recognizing his leadership in the development of underwater acoustic communications for oceanographic data transmission.

Tom Kleindinst

Hanu Singh, right, and Joint Program student Oscar Pizarro test an autonomous vehicle on the WHOI pier. The vehicle is designed for imaging benthic and Arctic environments.

A growing component of AOPE is the Coastal and Ocean Fluid Dynamics Lab, comprising scientists, engineers, technicians, postdocs, and students who pursue research in a broad range of environmental transport processes. These include turbulence studies in the surf zone, coastal boundary layers, and the deep ocean; air-sea interaction at local and global scales; sediment transport in the surf zone, estuaries, and continental shelf area; wave dynamics from the deep ocean to the beach; and physical-biological coupling in plankton dynamics.

Assistant Scientist Peter Traykovski was awarded the Office of Naval Research Young Investigator Award for innovative use of acoustic instruments to study boundary-layer sediment transport. Gene Terray was the 2001 recipient of the Institution's Allyn C. Vine Technical Achievement Award for his accomplishments in upper ocean velocity measurement technology.

John Trowbridge, a boundary layer dynamics specialist, was promoted to Senior Scientist in 2001. Hanu Singh, an expert in underwater imaging systems, and Jim Preisig, signal processing and underwater communication specialist, were promoted to Associate Scientist positions during 2001. Mike Purcell and Ben Allen were promoted to Senior Engineer, Janet Fredericks to Information Systems Associate III, Bob Elder to Research Engineer, Griff Outlaw to Engineer II, and Valery Kosnyrev to Research Associate III. John Reilly was appointed our new Department Administrator.

—**Wayne R. Geyer**, Department Chair

The ASIAEX South China Sea Experiment

James F. Lynch, Senior Scientist,
and the ASIAEX Group

Seven years ago, the Office of Naval Research took a strong and unprecedented stance favoring the development of Sino-American cooperation in the field of ocean acoustics, a subject that has a strong connection to naval applications, even though its basic scientific foundations rest on the open literature and unclassified research. A number of developments quickly followed. In 1995, Chinese and American researchers held their first workshop at the Naval Postgraduate School in Monterey, CA, and agreed to institute a joint program in shallow-water acoustics, an area of considerable expertise for both China and the US.

Shallow water acoustics, the study of how sound propagates and scatters in coastal waters from the edge of the beach to the continental shelfbreak, emphasizes the interaction of sound with the bottom and surface boundaries, as well as with the very complex water column thermal structures typical of coastal oceanography. It is important for naval purposes, marine mammal studies, environmental monitoring, and as a remote sensing tool for physical oceanography, biology, and geology.

The Monterey workshop spawned a 1996 acoustics experiment in the Yellow Sea that resulted in both scientific success and increased good will among the scientists involved. The next immediate step was a large, international meeting dubbed "Shallow Water Acoustics '97," held in Beijing to showcase results from Yellow Sea '96 and numerous other recent experiments in shallow-water acoustics.

Keith von der Heydt

An acoustic array is laid out ready to deploy on the deck of R/V *Fisheries Researcher I* (Taiwan). The hydrophone array forms a figure 8 at right with its rectangular deployment controller at the top of the picture. A blue tarp covers the data acquisition system, and the round yellow subsurface float is at upper left near an anchor recovery system festooned with yellow floats.

Based on the first two years' success, both scientists and sponsors were encouraged to proceed with a much larger scale experiment, and so ASIAEX (the Asian Seas International Acoustics Experiment) was born. Discussions among the researchers identified two appealing sites—one in the East China Sea, where the flat bottom was ideal for reverberation (acoustic echo) studies, and one in the South China Sea, where the shelfbreak region (the transition zone between the continental shelf and the deep ocean) displayed interesting characteristics that would strongly affect acoustic propagation at low frequencies (50 to 600 hertz). Moreover, the success of the initial US–China collaboration attracted the

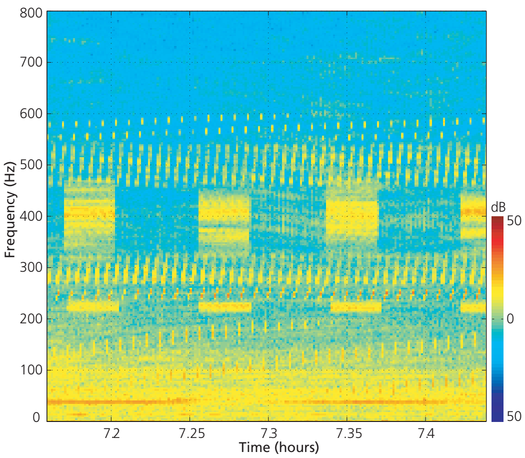
Tim Duda

Will Ostrom, right, and ship technicians aboard a Taiwanese research vessel handle a LOCOMoor float during ASIAEX operations.

Republic of Korea, Japan, Taiwan, and Singapore to join the effort.

The East China Sea and South China Sea experiments extended from April through June 2001, involving 6 ships, 38 principal investigators, 18 major institutions, and 108 total days at sea.

WHOI's involvement was principally with the South China Sea study, whose goal was to understand acoustic



A "spectrogram" picture of acoustic emissions heard by the WHOI/NPS receiving array in the ASIAEX South China Sea experiment. The vertical line traces are FM sweep or "chirp" signals, while the more solid blocks are the signatures of "pseudorandom noise sequences." Both types of signals have very useful signal processing properties that will be exploited during data analysis.

propagation through shallow water in areas exhibiting strong oceanic and geological variability. Measuring the acoustic field requires both sound sources and receivers. Supported by the Office of Naval Research, WHOI, the Naval Postgraduate School (NPS), and the Naval Research Laboratory (NRL) joined forces to deploy a number of moored and towed sources.

The spectrogram on page 7 displays their signatures. For the receiver, WHOI and NPS created a combination vertical and horizontal hydrophone array that could look in any direction with high resolution, much like an optical telescope does. This autonomous array, designed and deployed by Keith von der Heydt and John Kemp of WHOI, collected close to a terabyte of data over three weeks, giving the ASIAEX investigators the longest duration and highest-quality, shallow-water acoustics data set yet collected.

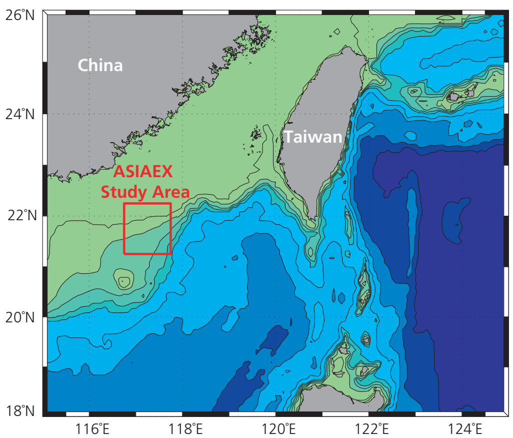
Of particular interest to WHOI acousticians are the "coherence properties" of signals received on the horizontal portion of the array. They determine how much processing capability is available. Scattering of the acoustic signal by the ocean and its boundaries results in a wavering acoustic signal that is very much like the twinkling of stars due to scattering of light by the atmosphere. Underwater acousticians are trying to understand this wavering and correct for it, much as astronomers do, in order to improve the power of our instruments.

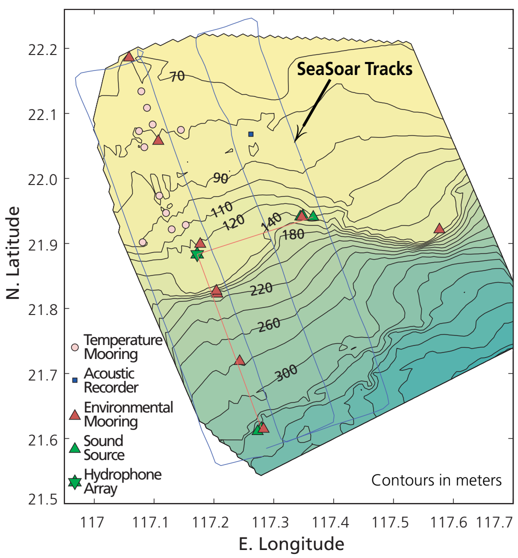
Acoustic data is most valuable when supported by first-rate, simultaneous measurements of the area's geology and physical oceanography. For ASIAEX, leading researchers in both physical oceanography and marine geology collaborated with the acousticians and conducted their own specific studies. WHOI physical oceanographer Glen Gawarkiewicz teamed with Taiwanese researchers to provide a continuous, three-dimensional look at the water column with the SeaSoar towed conductivity/temperature/depth system. WHOI acoustician Tim Duda deployed a number of temperature-sensing, low-cost moorings (dubbed LOCOMoors) to examine the very strong internal tides in the region. In addition, a number of standard oceanographic moored instruments contributed a well-sampled view of ocean processes both along- and across-shelf, particularly along the moored-source, acoustic-transmission lines. Satellite images provided a view from above, and marine geology investigators from the Florida Atlantic University, the University of North Carolina, and the National Sun Yat Sen University in Taiwan performed chirp sonar, bathymetry, and coring studies.

The five-year experimental phase of ASIAEX concluded in June 2001. However, the next phase, analysis of the vast data set collected, promises to be every bit as exciting. ASIAEX investigators gathered in Hawaii and Seattle for analysis meetings in November 2001 and January 2002, and there will be an all-hands meeting in October 2002 in Chengdu, near Tibet. Smaller gatherings in Taiwan, Korea, and Japan are also keeping the channels between scientists open, and, in a sense, this might be one of ASIAEX's best accomplishments. Relations between nations depend in large part upon individual relations, and, in ASIAEX, the ocean science community proved once again that the exploration of nature can be a unifying force among individuals from different countries and cultures. (The photo above shows an unusual example of "cultural relations!")


Arther Newhall

WHOI mooring engineer John Kemp holds his newly adopted Taiwanese "pier puppy" Tai at the vet's office. In one of the more interesting "cultural exchanges," several people adopted local stray puppies that inhabited the ASIAEX pier and warehouse staging areas in Kaohsiung, Taiwan.





Plan views of the general location of the ASIAEX South China Sea experiment (top) and the location of the various experimental measurements made (bottom).

Wave Phenomena Beneath the Surface

John Colosi, Associate Scientist

Wave forms are common in everyday life and across scientific disciplines—optical, acoustical, and water wave phenomena are familiar to most of us, and quantum mechanical waves describe the dynamics of atomic and subatomic particles. In the social sciences, we hear about cycles or "waves" of behavior and economic activity. Yet, in many wave problems there is underlying statistical uncertainty, and there are questions concerning what wave patterns scientists are most likely to observe. The study of statistical wave phenomena forms the basis of a general branch of science called "wave propagation through random media" (WPRM). The photo above shows a beautiful example: Light propagating through a wavy air/water interface produces a complex web of bright bands and broad dark spots.

Disciplines awash in uncertainty like economics have had to come to grips with this problem a long time ago, and natural scientists have worked on it in many different areas. The first reference to WPRM may be that of Sir Isaac Newton, who pointed out that even were the most powerful telescope designed, "yet there would be certain bounds beyond which telescopes could not perform. For the air through which we look upon the stars is in a perpetual tremor; as may be seen by the tremulous motions of shadows cast from high towers, and the twinkling of the fixed stars."

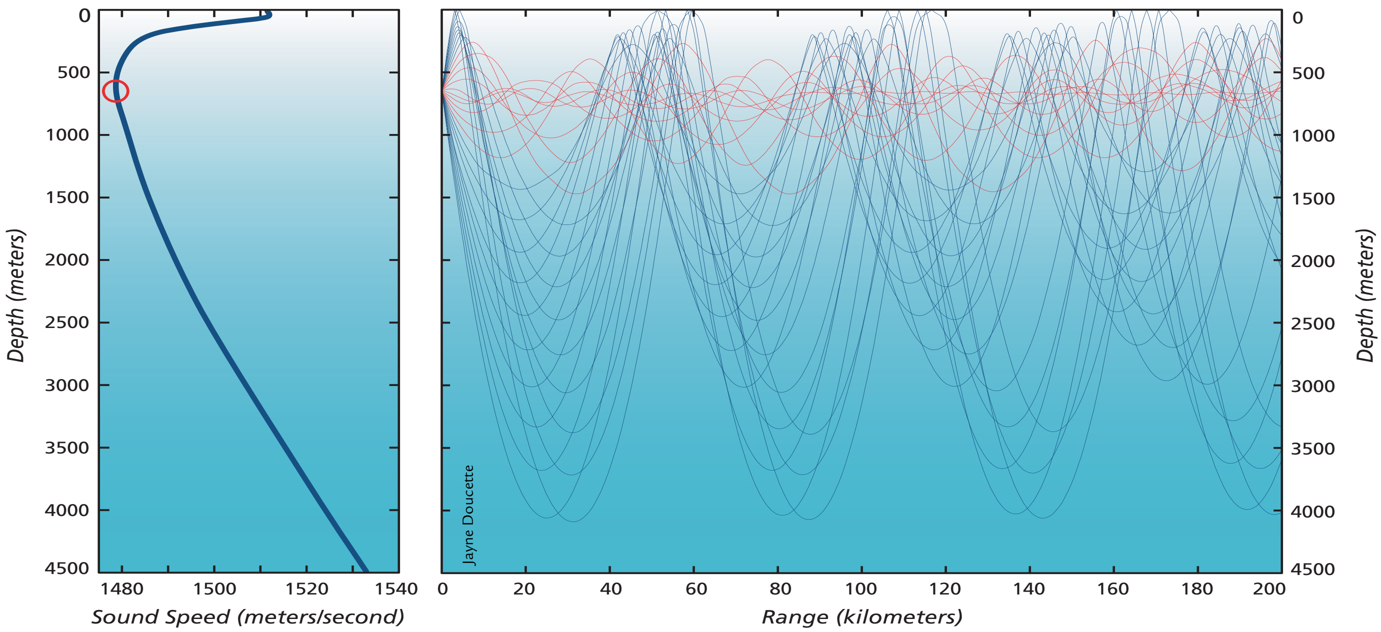
Bright, narrow bands of light and broad, low-intensity regions reflect off Tahitian sand. The interesting network of bright bands is a phenomenon called caustics, which form when sunlight passes through the rippled air/sea interface. Another commonly observed—but not random—caustic is the rainbow.

WPRM phenomena are ubiquitous in geophysics and oceanography: They include seismic wave propagation through the variable earth; optical and acoustical propagation through seawater with varying temperature, salinity, particulates, and biological matter; and hydrodynamic wave propagation across variable bathymetry or through thermal structures.

My own research, with support from the Office of Naval Research, has focused on the problem of very long-range acoustic propagation in the ocean. The ocean is relatively transparent to low frequency sound and opaque to electromagnetic radiation, and therefore it is no surprise that marine life has evolved remarkable auditory systems. Oceanographers have also learned to utilize the ocean's sound transmission ability to measure ocean temperatures in much the same way doctors use sound waves to analyze the human body. We use the technique called "ocean acoustic tomography" to estimate average temperature by precisely measuring the time it takes for a signal to travel from source to receiver. A warmer ocean has a faster sound speed and thus a shorter travel time. Further sound transmission occurs in the SOFAR (SOund Fixing And Ranging) channel, which ducts the sound along different "paths" that sample temperature at a variety of ocean depths. By "resolving" these different SOFAR paths, we can measure average temperature at several depths (see figure at top of page 10).

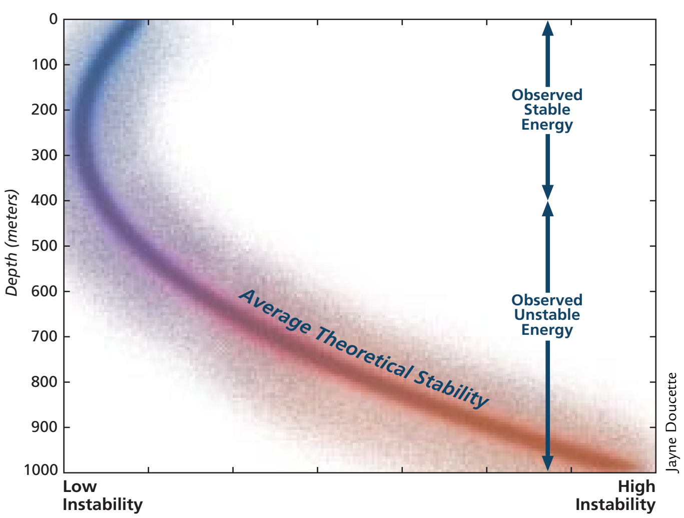
Ocean acoustic tomography is well suited to measure ocean climate change since the estimated temperature is an average over the distance from source to receiver; the spatial averaging allows suppression of local temperature variations from waves and eddies so that large-scale temperature variations stand out. In fact, the technique can measure average temperature changes as small as a few millidegrees over a 1,000-kilometer range. However, WPRM effects limit ocean acoustic tomography by reducing the vertical resolution of temperature changes, much as atmospheric turbulence limits ground-based telescopes, as Newton astutely observed.

The primary source of random



An example of the ocean SOFAR (SOund Fixing And Ranging) channel in the North Pacific Ocean (left), and a source of sound (red circle) located near the sound speed minimum. Ray path propagation through the SOFAR channel (right). Steeply cycling stable rays (blue) sample nearly the whole ocean depth, while low angle unstable rays (red) are trapped near the sound-speed minimum.

sound-speed changes in the ocean is internal gravity waves that undulate along boundaries of layers of seawater whose densities differ. They are like the familiar ocean surface waves that occur at the air/sea interface, but they fill the entire ocean volume at all times and in almost every geographical location. My colleagues and I have focused on the theory of sound propagation through internal waves, which, to date, has primarily been based on a mathematical technique developed by physicist Richard Feynman and called path integrals. Examining data from several experiments that transmitted sound over the entire North Pacific Ocean, we were able to demonstrate several severe shortcomings to the path integral theory—namely, the theory predicts strong instability for all the acoustic energy, while the observations show a mixture of stable and unstable components. Abandoning the path integral, we adopted a geometrical ray theory/nonlinear dynamics approach to estimate the stability of assorted sound paths that agrees very well with the observations (solid curve in figure at left). Further, we were able to identify, both theoretically and numerically, probability functions associated with the stability parameters, which describe the variations about the smooth curve in this figure. In addition, we found that the stability of the sound field is not only a function of the depth region that the sound samples, but also that it is a strong function of the background sound channel (SOFAR channel). The sound channel in the North Atlantic is very different from that in the North Pacific, and the North Atlantic channel is much more stable overall. Therefore our work contributes to the refinement of the tomographic technique so that improved vertical resolution can be obtained when experiments are conducted in favorable sound channels. Further, our work to explain and predict the stability characteristics of the ocean sound channel may help in the design of an underwater Global Positioning System (GPS) for navigation and communication—a technology that could significantly advance many other observational capabilities in oceanography and geophysics.



Observed and theoretical acoustic field stability.

Research in the Biology Department is wide ranging, in themes and subject material as well as geographically. The broad themes continue to involve nearly all aspects of life in the sea. Areas of special strength include microbiology (bacteria and protozoa), invertebrate zoology, toxicology, population studies, and the biology of phytoplankton, marine larvae, and marine mammals.

While broadly similar to themes of previous years, we are addressing these areas with new approaches and ever-more-sophisticated and powerful field and laboratory instruments. Molecular biology and genome studies are showing us how populations and families of organisms are related and evolve. Similar studies address relationships and evolution of gene families, and the roles they play in marine life. Mathematical analyses and computer modeling of population dynamics are more sophisticated and effective. Optical approaches for studies of phytoplankton and zooplankton are yielding new insights into the ecology at these foundations of the food web. A state-of-the-art CT scanner acquired this year is yielding new understanding of the effects of sound on whales, and a new mass-spectrometer system is disclosing otherwise unobtainable information about fish populations over time. Development of new instrumentation for remotely gathering data on biota and the marine chemistry relevant to life continues apace.

During 2001, WHOI biologists carried out extensive field work, both locally and globally, in most oceans. The waters of New England continue to yield new fundamental information in some theme areas. There were studies of deep-sea biota including vent animals and microbes in the Pacific and Indian Oceans. Several Department members worked in the Artic, and others spent weeks to months on demanding cruises in the Southern Ocean (during the austral winter), studying zooplankton important to Antarctic ecology.

A broad array of federal agencies provide support for our research, along with the increasingly important local, state, and private sources of funding. In 2001, the Biology Scientific Staff submitted 144 proposals to agencies, foundations, and individuals and were successful in receiving full or partial funding for 62 percent of them, totaling a little over $9 million for sponsored research. In addition to their individual research programs, staff members continue to participate and provide leadership in large national and international programs, including Global Ocean Ecosystems Dynamics (GLOBEC) Atlantic and Southern Ocean programs and national and international Ridge Interdisciplinary Global Experiments (RIDGE) programs for hydrothermal vents. Headquarters for the Ecology of Harmful Algal Blooms (ECOHAB) Gulf of Maine program and the US GLOBEC Northwest Atlantic program on Georges Bank are based in the Department. During 2001, Scientific Staff members made presentations to Congress and served on National Research Council committees and as editors or editorial board members for 16 journals.


Heidi Sosik

Rob Olson aligns a flow cytometer during a June 2001 cruise aboard R/V *Endeavor* (University of Rhode Island) to measure photosynthetic characteristics of single-celled organisms.

As 2001 drew to a close, Department personnel numbered 27 Scientific Staff, along with 5 Scientists Emeritus, 4 Oceanographers Emeritus, 21 Postdoctoral Scholars, Fellows, and Investigators, 34 Joint Program students, 19 Technical Staff, and 36 other support staff. During the year, our scientists pursued studies on nearly 200 separate grants, published 70 scientific papers and books and 14 reports, and had 110 papers either submitted or in press. Lauren Mullineaux was promoted to Senior Scientist, Scott Gallager was awarded tenure, and Rebecca Gast was promoted to Associate Scientist. Postdoctoral Scholars Tim Shank and Eric Webb were appointed Assistant Scientists, and Assistant Scientist Sönke Johnsen took a position at Duke University. On the technical staff, Mary Ann Daher was promoted to Research Associate II.

Senior Scientist Hal Caswell was honored in a Boston photo exhibit of leading intellectuals in New England.

—**John J. Stegeman**, Department Chair

Southern Ocean GLOBEC researchers and *Nathaniel B. Palmer* crew launch the BIo-Optical Multi-frequency Acoustical and Physical Environmental Recorder (BIOMAPER-II), a newly developed, towed system designed for quantitative surveys of the spatial distribution of coastal and oceanic plankton. The system consists of multi-frequency up-looking and down-looking sonar, a video plankton recorder system, an environmental sensor system (conductivity/temperature/depth sensors plus fluorometer and transmissometer), and several other bio-optical sensors. Special handling equipment travels with the 1,500-pound BIOMAPER II. The vehicle operates to a depth of 300 meters (990 feet) at 4 to 6 knots, while near the surface it may be towed at speeds up to 10 knots.

Dynamics of Overwintering Antarctic Krill Populations

Peter Wiebe, Senior Scientist

Vast, isolated, dark, and very cold during the winter portion of the year, the waters surrounding the Antarctic continent have rarely been studied. Yet, what transpires ecologically during overwintering has great bearing on the dynamics of the Antarctic marine community, known for very high primary production and large populations of top predators (seals, whales, penguins, and sea birds) during well-lit seasons. Central in the food chain that links phytoplankton (primary producers) and microzooplankton (secondary producers) to the top predators are the krill, principally *Euphausia superba*. Adult krill constitute a large fraction of the zooplankton biomass in key areas and often occur in very large numbers, massed in intense patches and swarms ranging in size from a few tens of square meters to tens of square kilometers. While a great deal has been learned over the past three decades about the distribution, abundance, and population biology of krill during the warmer, ice-free periods of the year, little is known about how the different life stages of krill survive the long, cold, ice-covered winter period.

Four members of the Biology Department Scientific Staff—Carin Ashjian, Cabell Davis, Scott Gallager, and I—traveled to the Antarctic twice during 2001 to map the distribution and abundance of krill and other zooplankton. We were among 35 US investigators from some 20 institutions participating in the first field year of the Southern Ocean Global Ocean Ecosystems Dynamics (SO GLOBEC) Program. It was designed to examine continental shelf circulation processes and their effect on sea-ice formation, Antarctic krill distribution, and the factors that govern krill survival and availability to higher trophic levels. The study area is the central Western Antarctic Peninsula continental shelf, in particular, Marguerite Bay. This region exhibits unusually high krill production thought to result from a unique combination of physical and biological factors that contribute to enhanced krill growth, reproduction, recruitment, and survival throughout the year. The program is especially focusing on physical factors deemed favorable for winter survival of larval and adult krill, including: 1) shelf circulation that retains the krill population in a favorable environment on the shelf for extended periods of time, 2) a persistent winter ice cover that provides dependable food and protection for larval krill to grow and survive over the winter, and 3) on-shelf intrusions of Upper Circumpolar Deep Water that supply heat, salt, and nutrients that affect ice properties and enhance biological production.

The SO GLOBEC program, like its GLOBEC predecessors on Georges Bank and off the northwest US coast, has four basic components:

1) Periodic broad-scale surveys to quantify the distribution and abundance of the target species (krill) as well as its prey and predators and to profile environmental features (temperature, salinity, meteorology, currents, etc.).

2) Process studies of the feeding, growth, development, and behavior of the krill and their prey and predators. Because sea ice is thought to be important in the overwintering survival of larval krill, this program also emphasizes understanding of sea-ice formation and processes.

3) Use of long-term moorings and automated weather stations to collect data between cruises.

4) Integration and synthesis of results using physical/biological coupled models.

We deployed the moorings early in the calendar year (late austral summer). In mid to late austral fall, scientists aboard two National Science Foundation research vessels, *Nathaniel B. Palmer* (with icebreaking capability) and *Lawrence M. Gould*, conducted broad-scale and process work in the study area while it was largely ice-free. A second pair of cruises took place in the winter period (July to September) when the area is covered with pack ice. Each voyage was 40 to 50 days long.

During the relatively ice-free fall cruise, krill adults and larvae were distributed principally in the upper 200 meters (660 feet) of the water column. Through extensive towing of the multi-sensored BIOMAPER-II, we

Peter Wiebe

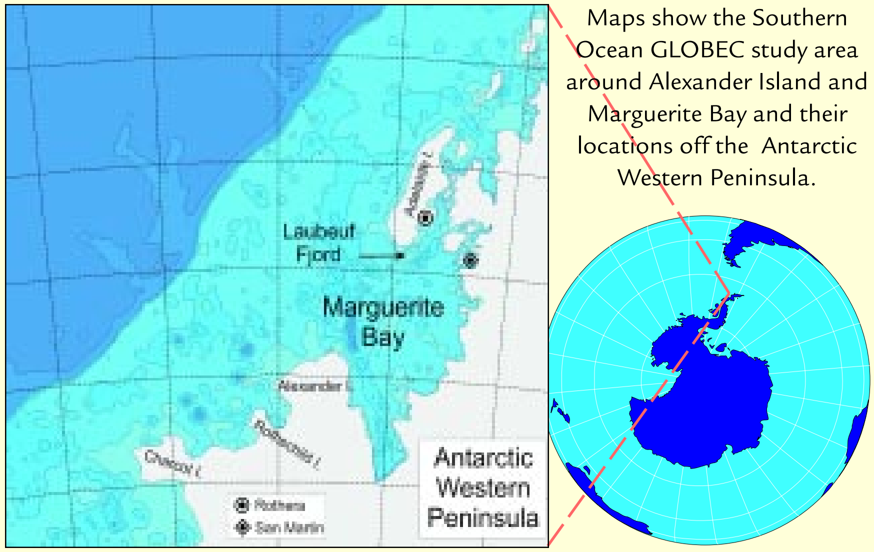
Southern Ocean GLOBEC investigators experimented with using strobe lights mounted on some of their collecting nets to surprise the krill and reduce their net avoidance capability. They found that, though the catch of smaller krill was not affected, use of the lights nearly doubled the catch volume for larger, adult krill, indicating that further work in this area may improve sampling techniques.

Peter Wiebe

Euphausia superba, the focus of Southern Ocean GLOBEC, is central to the Antarctic water food chain. Shown in a collection tray, they ranges in size from 5 to 15 millimeters for the small larval forms to 30 to 60 millimeter adults.

acquired high-resolution acoustic and video data that provided new insights about "krill hotspots," places in Marguerite Bay and off Alexander Island where adult krill occurred in large patches and very high numbers. Large numbers of whales, crabeater seals, and sea birds were also observed here. An unexpected finding was that krill larvae were distributed across the entire shelf survey area. During the winter cruise when ice pack covered the study site, we surveyed the ice undersurface with a remotely operated vehicle equipped with a pair of high-resolution video cameras. As predicted, krill larvae had moved up to the sea surface near the ice pack. Large numbers of larval krill, however, were observed only in regions where the ice undersurface was highly irregular as a result of the ridging and down thrusting caused by ice sheet collision and compaction during violent winter storms.

We are scheduled to repeat these extensive observations in 2002 toward further understanding of Southern Ocean dynamics and GLOBEC's broader goal of determining what makes a marine ecosystem productive.



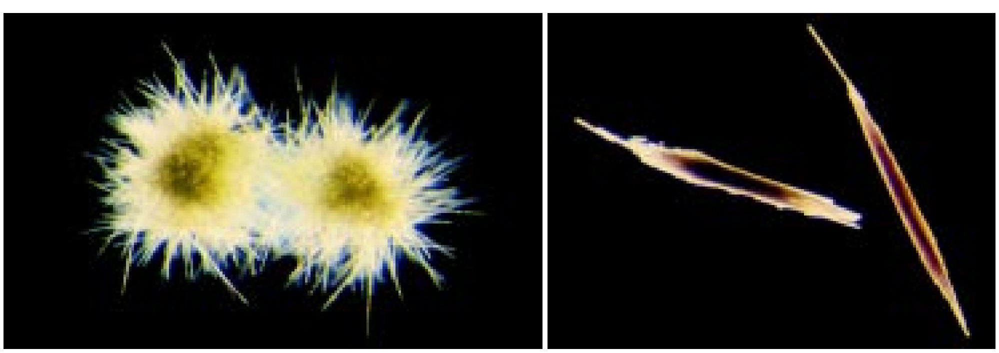
Maps show the Southern Ocean GLOBEC study area around Alexander Island and Marguerite Bay and their locations off the Antarctic Western Peninsula.

New Tools Help Reveal Role of Cyanobacteria

John Waterbury, Associate Scientist,
Eric Webb, Assistant Scientist,
Sonya T. Dyhrman, Postdoctoral Scholar

Ocean life accounts for approximately half of global primary production (conversion of atmospheric carbon dioxide to cell carbon through the process of photosynthesis). Traditional thought attributed most of this production to eukaryotic algae (whose cells have distinct nuclei) such as diatoms and dinoflagellates. However, studies done in the last 20 years show that a group of bacteria (prokaryotes, with no distinct nucleus) called cyanobacteria are prominent at the base of the marine food web where they contribute significantly to the oceanic carbon cycle through photosynthetic fixation of carbon dioxide.

They include the unicellular species *Synechococcus*, *Prochlorococcus,* and *Crocosphaera* and filamentous species of *Trichodesmium*. The factors that control their growth directly impact not only their contribution to the carbon cycle but, in the case of *Crocosphaera* and *Trichodesmium*, also their contribution to the nitrogen cycle through nitrogen fixation. (Some groups of bacteria can fix nitrogen by enzymatically reducing atmospheric nitrogen to ammonia, which they use to make amino acids and ultimately cell proteins. No higher organisms can fix nitrogen except those that live in symbiosis with nitrogen-fixing bacteria.)



John Waterbury

Photos show two cultured species of Trichodesmium, *T. thiebautii* at left (about 2 millimeters in diameter) and *T. erythraeum* (about 2 millimeters long). In calm weather in the tropics, *T. erythraeum* colonies float to the surface where they can form large windrows that sailors used to refer to it as "sea sawdust" for the tan color its colonies impart to water.

Mariners have known *Trichodesmium* for centuries. Members of this group form aggregates that sailors called "sea sawdust." During calm weather in the tropics, colonies of *Tri-*

chodesmium gather at the sea surface to form blooms that can cover thousands of square kilometers. *Trichodesmium* has fascinated biological oceanographers since the 1960s when research determined that members of this group fix nitrogen. Since then, progress in studying them has been slow because they are difficult to isolate and culture. As a result, much of what we do know about them is based on studies at sea.

Following limited success by several groups in culturing one of the species, *T. erythraeum*, we developed techniques that permitted us to culture five of the six species and to obtain pure cultures of two (*T. erythraeum* and *T. thiebautii*). In hindsight, the necessary procedures seem almost trivial: Because this group lives in the pristine, nutrient-depleted waters of the central oceanic gyres, they are extremely sensitive to contamination, by heavy metals, for example. Using rigorous clean techniques and ultra pure chemicals, it is now possible to grow *Trichodesmium* rapidly, at high cell densities and in large volumes. Similar techniques also allowed us to isolate a new genus of unicellular, nitrogen-fixing cyanobacterium, *Crocosphaera*, from the tropical Atlantic and Pacific Oceans. This cyanobacterium is unusual because it has a minimum growth temperature of about 26 °C (78.8 °F), which effectively restricts it to equatorial regions.

With the ability to isolate these oceanic cyanobacteria in pure culture and to grow them in the laboratory, microbiologists developed new approaches to assess their roles in nature. One of the most exciting is the field of microbial genomics, sequencing of the entire genomes of microorganisms. Since these studies began in the mid 1990s, more than 100 bacterial genomes have been or are currently being sequenced. We collaborated with colleagues at several institutions and at the Department of Energy's Joint Genome Institute to complete entire sequences of marine *Synechococcus* and *Prochlorococcus*. *T. erythraeum* is currently being sequenced, and we have proposed that *Crocosphaera watsonii* be sequenced in the near future. The next steps will be detailed comparative studies of genomic composition and gene organization and functional analyses of gene regulation to gain new insights into the factors controlling the growth of these cyanobacteria and their species succession under varying environmental conditions.

In another new approach we use molecular diagnostics to measure phosphorus and iron stress in oceanic cyanobacteria, particularly *Trichodesmium*. Recent advances in measuring the very low concentrations of iron and phosphorus in the nutrient-limited central oceanic gyres have led to hypotheses that one or both of these elements may limit *Trichodesmium* growth and nitrogen fixation. However, demonstrating phosphorus or iron limitation of phytoplankton is not trivial because of these two elements' complex geochemistry. Methods currently available are generally unable to resolve how nutrient limitation impacts specific phytoplankton species.

Over the past two years, with funding from the National Science Foundation and WHOI, we have developed two new techniques to assess phosphorus and iron stress at the cellular level in natural populations of *Trichodesmium*. Using pure cultures manipulated to induce stress, we learned that *Trichodesmium* cells produce the enzyme alkaline phosphatase when there is little or no phosphorus available to them. Addition of a substance called ELF-97 to a phosphorus-stressed culture produces an insoluble fluorescent precipitate that tags the phosphorus-stressed cells, which we can then view using light microscopy and record as digital images. Iron-stressed *Trichodesmium* cells produce a specific protein known as IdiA that can be identified using immunological techniques. In the first field test of these two new diagnostics conducted during 2000 in the subtropical western north Atlantic, we determined that populations of *Trichodesmium* experienced iron stress in August and phosphorus stress in November. We believe that iron and phosphorus availability are both important factors controlling *Trichodesmium* productivity and that there may be a dynamic interplay between these two essential elements that depends on location and seasonal changes. Further work on this hypothesis begins with a research voyage in early 2002.

Endeavor Science Party

John Waterbury (foreground) and Eric Webb use a hose and pump to collect seawater for culturing algae during an R/V *Endeavor* (University of Rhode Island) cruise in June 2001.

The Department of Geology and Geophysics (G&G) conducts research into the oceans' role in past climate change, the geologic structure and tectonics of the ocean basins and their margins, and the composition and dynamics of Earth's mantle. There were 235 active awards in the Department during 2001 totaling $11.6 million in funding.

We added one new member to the Department's resident Scientific Staff in 2001. Olivier Marchal, who completed his Ph.D. thesis in 1996 at the Centre des Faibles Radioactivities in Gif-Sur-Yvette, France, joined the Department's strong climate research group. His thesis work involved developing a model simulation of the seasonal cycle of carbon dioxide in the upper layer of the Sargasso Sea, including effects of gas exchange with the atmosphere and plankton activity. Olivier spent four years as a postdoctoral fellow at the University of Bern, where he incorporated biochemical components into the Bern paleoclimate model. At WHOI, Olivier's research is aimed at understanding the mechanisms responsible for rapid climate changes in the recent geological past by combining paleoclimate data with paleoclimate models. Associate Scientist Neal Driscoll left WHOI for a faculty appointment at Scripps early in 2001.

With these changes, the size of the Department's resident Scientific Staff remained constant at 34 at the end of 2001. We currently also have 28 Technical Staff members, 22 MIT/WHOI Joint Program Ph.D. students, 11 Postdoctoral Fellows, Scholars, and Investigators, 15 graded staff, and 10 administrative staff working in the Department. Three new adjunct appointments were made in 2001—Maureen Raymo (Boston University), Chris German (University of Southampton), and Wayne Crawford (Institut de Physique du Globe, University of Paris)— bringing the total number of Adjunct Scientists in G&G to 11.

In 2001 Deborah Smith was promoted to Senior Scientist, and Associate Scientist Greg Hirth was awarded tenure. Rindy Ostermann was promoted to Research Specialist, and Dana Stuart-Gerlach and Sean Sylva, both members of the National Ocean Sciences Accelerator Mass Spectrometer group, were promoted to the Technical Staff as Research Associate IIs.


Tom Kleindinst

Working on the WHOI pier, Assistant Scientist Rob Sohn, left, and Guest Investigator Peter Hall conduct dynamic control tests on a vehicle designed to map unexplored regions of the Arctic seafloor under the ice cap.

Several Department members received recognition for their scientific accomplishments in 2001. The W. Van Alan Clark, Sr., Chair was awarded to Senior Scientist Dan Fornari, recognizing his contributions to our understanding of submarine volcanism, mid-ocean ridge processes, and the use of deep submergence technology for exploration of the deep sea. John Hayes and Lloyd Keigwin were both named Fellows of the American Geophysical Union (AGU), bringing the total number of AGU Fellows in G&G to six. Finally, G&G Joint Program Student Carolyn Gramling received an AGU Outstanding Student Paper Award in the Hydrology section for her poster titled "Reactive Transport: A Comparison of Experimental and Model Results."

—**Robert S. Detrick**, Department Chair

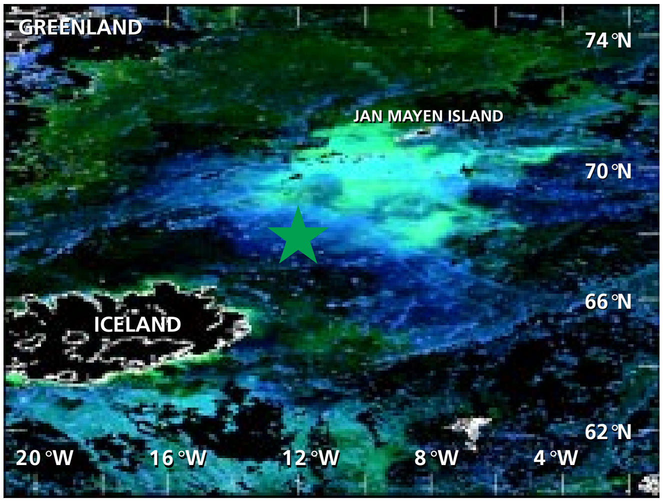
Iceland Sea Carbonate Flux Increases Dramatically

Dorinda Ostermann, Research Specialist

Records from sediment traps deployed worldwide since the 1970s quantify the amounts, composition, and timing of particle deposition to the ocean floor. The most revealing particles we collect in sediment traps are the skeletons of surface-water plankton that die and settle to the seafloor. Changing the flow of cold polar and warm Atlantic waters into the Greenland/Iceland/Norwegian Sea gyre influence both atmospheric and oceanographic conditions, which impact the type of particles collected. As research underscores the importance of the Arctic to global climate, it is imperative that we understand oceanographic processes in this area. Since 1986, colleagues at the Marine Research Institute in Reykjavík, Iceland, and I have continuously deployed a time-series sediment trap that allows us to monitor the effects of changes in polar and Atlantic flows in the Iceland Sea, and the effect these changes have on the amount and types of particles.

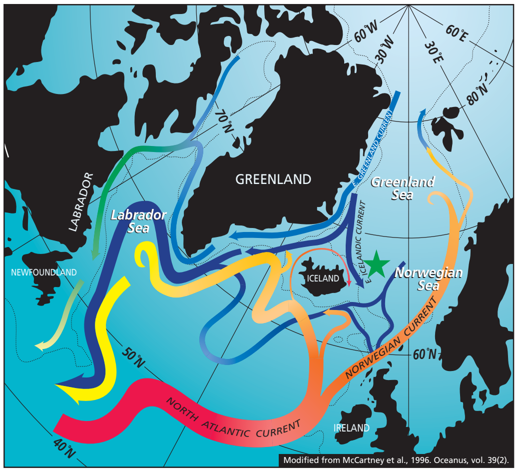
Prior to 1997, the majority of the particles we collected were siliceous plankters (diatoms, dinoflagellates, and radiolarians). But after monitoring the particle flux in the Iceland Sea for 15 years, a remarkable event was captured both in our samples and by Sea-viewing Wide Field-of-view Sensor (SeaWiFS) satellite imagery (see figure below). In the summer of 1999, we collected as much calcium carbonate in one two-week interval as in the previous 15 years of collection combined! All but one percent of the material we collected was composed of the coccolithiphore *Coccolithus pelagicus.* To put this in perspective, satellite imagery showed the Iceland Sea *C. pelagicus* bloom covered 29,220 square kilometers (11,688 square miles), a land mass equivalent to the country of Belgium or the state of Maryland. A bloom of this size and extent produced a carbonate flux equal to that of the monsoonal upwelling in the Western Arabian Sea, one of the most productive regions of the world's oceans.

Why did a carbonate and not a silicate plankter, as normal, bloom in the Iceland Sea in 1999? We believe that a number of hydrographic and atmospheric conditions coincided to allow for the *C. pelagicus* bloom. Starting in winter 1996, nutrient data show that dissolved silica was totally depleted while important nutrients such as phosphate and nitrate remained available for increased production of nonsiliceous plankters such as coccolithiphores. Surface waters of the Iceland Sea then freshened and cooled dramatically, causing a water column instability that we believe is the trigger for maximum growth of this species. Sediment trap data from the Sea of Okhotsk supports this hypothesis with indications that spring surface waters in the Sea of Okhotsk freshen due to input from the Amur River and melting sea ice, leading to increased carbonate production and flux.



Christopher Brown, SeaWiFS project, NASA/Goddard Space Flight Center

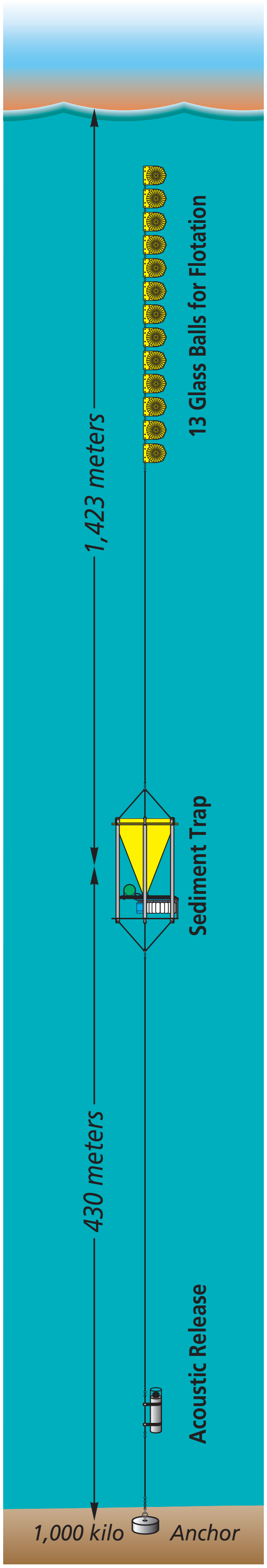
SeaWiFS satellite composite image for June 18, 1999, to July 31, 1999. The areal extent of the *Coccolithus pelagicus* bloom (lighter colors) was about 29,220 square kilometers (11,688 square miles). The bloom is centered at 70.23°N, 9.75°W, a full 120 nautical miles from the mooring location (green star).



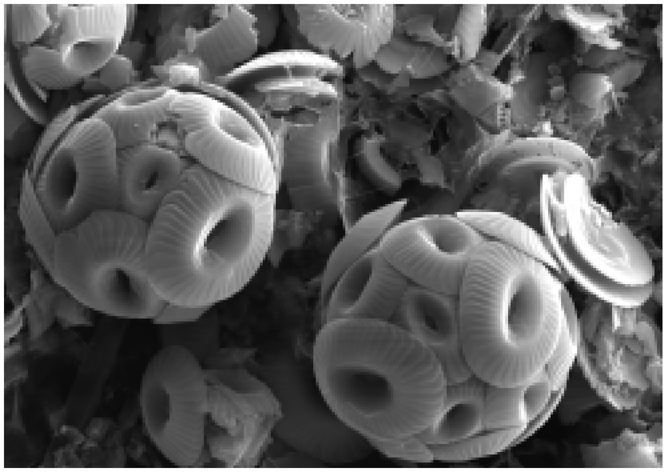
Jack Cook

Representative surface circulation scheme for the North Atlantic with a green star marking the Iceland Sea mooring location. The mooring is located in 1,853 meters (6,115 feet) of water, 1,420 meters (4,686 feet) below the surface at 68°N, 12.6°W. It is ideally situated to monitor interactions between the cold (drawn in blue) and warm (drawn in red) currents crossing the Nordic Seas today.

The freshening of the water mass at the Iceland Sea mooring location may be a result of Arctic Sea ice thinning and/or Greenland glacial wasting. Arctic sea ice has thinned from an average of 3.1 meters (about 10 feet) in the 1950s to 1.8 meters (6 feet) in the 1990s, resulting in 15 percent less total coverage than in 1978. NASA's Program for Arctic Regional Climate Assessment has shown that high elevation (more than 2,000 meters) glacial Greenland appears to be in overall balance while glaciers along coastal regions thinned be-

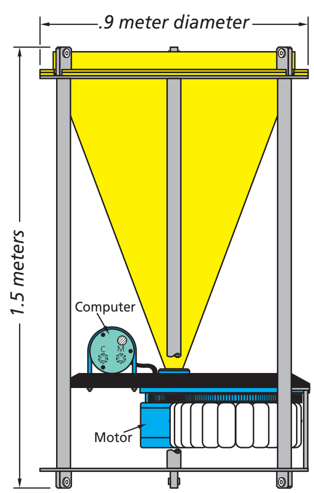


Jayne Doucette



Louie Kerr, Marine Biological Laboratory

Coccolithiphores such as *Coccolithus pelagicus* are one of some 5,000 species of single-celled phytoplankton that drift freely and photosynthesize in the upper layers of the world's ocean. These microscopic plants grow armored platelets made of carbonate. The white cliffs of Dover are an example of the accumulation of eons of coccoliths, the fossilized remains of the platelets. *Coccolithus pelagicus* is one of the largest (8 to16 microns) and most robust of the coccolithophore species found in the water column today.



A sediment trap is basically a large funnel anchored to the seafloor (see illustrations right and left). It catches material on its way down through the water column to become part of the geological record. A motor moves an empty sample cup under the collection funnel at predetermined intervals of a few weeks to a month. For the first 15 years of the Iceland mooring, the sample interval was around 27 days. In 1999, the interval was changed to two weeks during the spring and summer and two months during the winter. To the researchers delight, this turned out to align the production and eventual deposition of *C. pelagicus* perfectly with satellite imagery of the bloom. Large, heavy particles such as foraminifera and clumps of coccoliths may settle from the surface to the trap at rates of 100 meters per day or around 14 days. Cup #4 (above) shows the early July 1999 sample of *C. pelagicus*. Each cup can hold 250 milliliters of material (about 8 oz).

tween 1 meter (3.3 feet) per year in the north to 10 meters (33 feet) per year in the southeast. The fresh water resulting from Arctic and Greenland glacial thinning flows into the East Greenland Current, which feeds into the waters of the mooring location.

The remarkable Iceland Sea carbonate flux is not an isolated condition but part of a larger pattern of increased carbonate production in high latitude regional seas connected to the Arctic. SeaWiFS data compilations show that the Bering, Norwegian, and Barents Seas each experienced major coccolith blooms in 1998, followed in 1999 by the large bloom of *C. pelagicus* in the Iceland Sea. The carbonate blooms of the Greenland, Iceland, Norwegian, and Barents Seas were not repeated in 2000 or 2001.

Dramatic changes in the Iceland Sea carbonate flux will certainly affect the amount and kind of material preserved in the sedimentary record during unique production events such as the 1999 pulse our trap recorded. Conditions altering the relative amounts of polar and Atlantic waters not only influence the atmosphere and the surface ocean but also the deposition of particles to the deep ocean. For instance, because the North Atlantic is an important sink for atmospheric carbon dioxide, coccolithiphore blooms can significantly affect the drawdown of greenhouse gases such as carbon dioxide, possibly altering the air-sea fluxes of climate controlling chemical constituents. These kinds of linked observations are critical to our ability to interpret paleoclimate variability of sedimentary records from deep-sea cores collected in the Greenland, Iceland, and Norwegian Seas.

This project was funded initially by the National Science Foundation as a one-year deployment. However, we have been able to used limited funds from associated projects to keep this project going for 17 years. The Iceland Sea sediment trap is now the second longest such time-series data set in the world.

Icebreaker Voyage to North Pole Brings New World in View

Jeff Standish, Joint Program Student,
and **Henry Dick**, Senior Scientist

Of all the world's oceans, the most inaccessible is the Arctic. Covered by ice and shrouded in darkness for six months of the year, it represents the last great frontier for ocean sciences. The few reliable maps available at the turn of the century were made by nuclear submarine only in the last few years. To those of us studying ocean ridges and the evolution of Earth's deep interior, it was the last unexplored ocean ridge—a key gap in our global collection of rock from the ocean basins.

Some three-fifths of Earth's crust forms at ocean ridges, and the Gakkel Ridge occupies a unique and important place within the global ridge system. It runs over the top of the world, extending 1,080 miles from off the northeastern corner of Greenland, across the Eurasian Basin, to the continental margin in the Laptev Sea. It is the deepest ocean ridge, and it has the slowest spreading rate, decreasing rapidly west to east from one inch per year near Greenland to a half an inch per year at its eastern end. Because fast and slow spreading ridges exhibit great differences in the composition and structure of the ocean crust, theory predicted that as seafloor spreading slows along the Gakkel Ridge, a major change would occur. Namely, volcanism would wither as seafloor spreading decreased, and the ridge would become essentially a crack in the planet where solid mantle rock from depth would be pulled up by the spreading plates to form new seafloor.

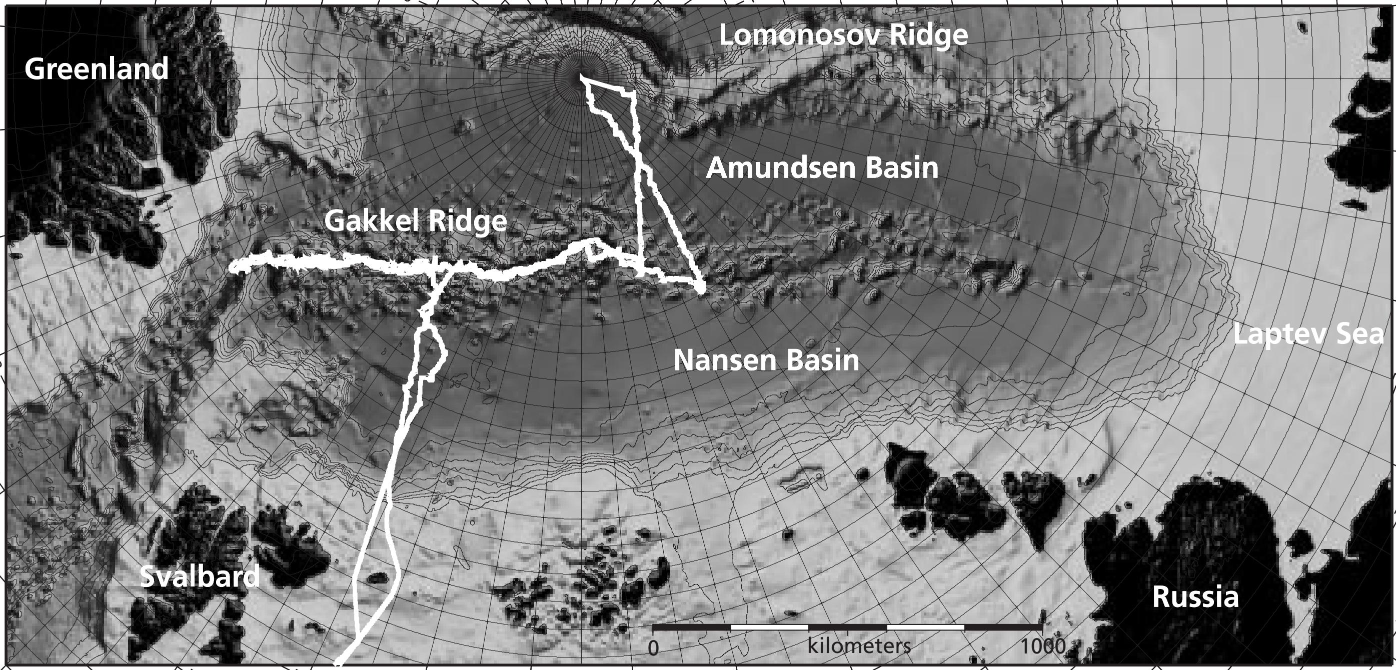
Henry Dick

Jeff Standish hugs the North Pole.

Lavas erupting from deep within the earth at mid-ocean ridges provide the principle means for inferring the composition of the mantle and its global variation. The Gakkel Ridge has long tantalized geochemists because sampling rocks along its length promised a view into the interior of the earth beneath the pole of planetary rotation. It also presented, however, the possibility of sampling mantle peridotite over a large region and directly observing lateral varia-

Henry Dick

Two icebreakers equipped for oceanographic research traveled together on the 2001 Gakkel Ridge/North Pole expedition. The US Coast Guard's *Healy*, foreground, was on its first research cruise, while the German *Polarstern* has made nearly 30 Arctic and Antarctic voyages since its commissioning in 1982.



Greg Kurras, University of Hawaii and International Bathymetric Chart of the Arctic Ocean

Healy cruise track shows extensive exploration of the Gakkel Ridge and an excursion to the pole.

tions in mantle composition—a unique opportunity simply not available anywhere else. In July 2001, US oceanographers not only got their first detailed look at the Gakkel Ridge but also gained a new ocean to explore when the US Coast Guard's icebreaker *Healy* made its first research voyage. Along with WHOI Research Specialist Jim Broda and Postdoctoral Investigator Deborah Hassler, we were fortunate to be among 21 US scientists embarking from Tromso, Norway, for an epic two-ship expedition to the Arctic Ice Cap. Among the scientific party were Joint Program graduates David Graham (Oregon State University) and Hedy Edmonds (University of Texas at Austin) and a former Summer Student Fellow, Peter Michael (University of Tulsa), the lead scientist aboard *Healy*. We were accompanied by German scientists aboard R/V *Polarstern*, including another Joint Program graduate, Jon Snow (Max Planck Institute for Chemistry, Mainz, Germany). Our objective was to do detailed rock sampling along a 1,000-kilometer (690-mile) section of

Henry Dick

Joint Program graduate Hedy Edmonds, now at the University of Texas at Austin, marks potential dredge sites on a SWATH bathymetry map created during the Gakkel Ridge cruise.

actively spreading ridge and to monitor for hydrothermal plume activity within the rift valley.

A great deal of logistical and scientific planning preceded this expedition, yet the largest unknown remained: How would *Healy* perform on its first scientific voyage? One old Arctic hand predicted we wouldn't be able to do "dredge 1." No one even contemplated collecting high quality SWATH bathymetery data while pounding through the ice. It did not take long for *Healy* to impress us, both with its ice breaking and its technological strength. Any doubts about *Healy's* capabilities were quickly put to rest, as we, along with the *Polarstern* scientific party, proceeded to conduct 200 successful dredges and to produce a high resolution bathymetry map.

The character of the Gakkel Ridge turned out to be a bit different than predicted. As we moved from west to east, instead of gradually dying away, the volcanoes abruptly stopped at 3°E. From there, for nearly 100 kilometers (60 miles), we found mantle rock from deep within the earth rising up in great solid slabs to form new seafloor. Then, surprisingly, a new volcano appeared. Further east, there was more mantle rock, then another volcano, and so on as far as we surveyed (figure below right). This showed for the first time that ocean ridge volcanism isn't simply a primary function of spreading rate. The generation of magmas deep within the earth's interior is more complicated than ever imagined!

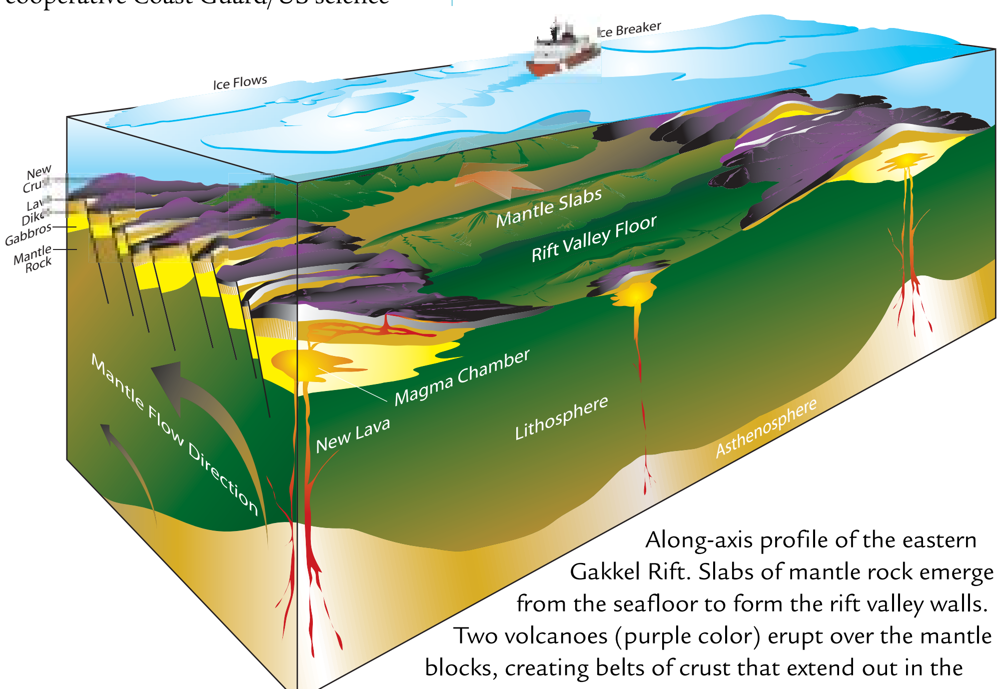
Based on the ultra-slow spreading rate, current dogma also predicted near absence of hydrothermal vent activity—as spreading rate slows, less volcanism should also mean that hydrothermal vents disappear. However, on a *Knorr* cruise in 2000 to the slow-spreading Southwest Indian Ridge, we sampled six new hydrothermal deposits in a relatively small area of ridge. Did this mean that hydrothermal venting was more frequent than predicted for ultra-slow spreading ridges? This was dramatically confirmed when we dredged several hydrothermal deposits on the Gakkel Ridge and our sensors registered hydrothermal plume anomalies at 12 separate sites. Nearly as many hydrothermal plumes were discovered in this one cruise as in the last 20 years of Mid-Atlantic Ridge exploration. Along with vent sulfides dredged from an active black smoker, we recovered a variety of biological fauna—a discovery of great potential importance. Like the Mediterreanean Sea, the Arctic Ocean is unusual because of its limited connections to other major oceans—with the extraordinary feature of being covered by ice. The abundant biology we found, then, was a great surprise.

In addition to the unexpected scientific discoveries and the overall success of the cruise, we all became "polar explorers." On September 6, 2001, *Healy* reached 90°N latitude. None of us will ever forget the exhilaration of stepping off *Healy* to stand at the point where all Earth's lines of latitude converge and having the entire world directly below our feet!

In addition to the many scientific discoveries of this cruise, to many, its most important aspect was the remarkable capabilities of the ship. With the advent of *Healy*, carefully planned by a cooperative Coast Guard/US science community effort, the US has gone in a single season from a minor presence in the Arctic Ocean to perhaps the principle player.

Henry Dick

A Gakkel Ridge dredge sample comes aboard *Healy*. Inset shows hydrothermal sulfide dredged from Gakkel Ridge rift valley.



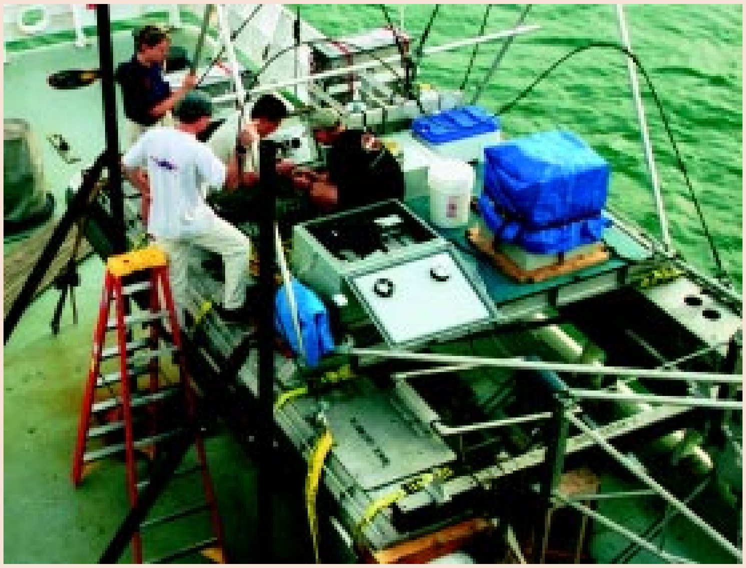
E. Paul Oberlander

Along-axis profile of the eastern Gakkel Rift. Slabs of mantle rock emerge from the seafloor to form the rift valley walls. Two volcanoes (purple color) erupt over the mantle blocks, creating belts of crust that extend out in the direction of seafloor spreading, while a single small isolated volcano erupts in the rift valley between them. The asthenosphere/lithosphere boundary occurs where rising hot mantle cools to form the rigid lithosphere.

Research in the Department of Marine Chemistry and Geochemistry (MCG) involves all aspects of chemical fluxes to and from the oceans. MCG researchers use laboratory and field-based tools to understand the many processes that control the chemistry of the oceans and its variations with time. The research projects often focus on the mechanisms and rates of chemical transport at ocean boundaries, ranging from the groundwater fluxes in coastal areas to the importance of hydrothermal activity in the deep ocean. Many of these studies involve the use of ships: MCG researchers participated in cruises in most of the major oceans, from the Galápagos Islands near the equator to the Ross Sea off Antarctica.

Ongoing research projects also include upper ocean biogeochemical cycles, organic geochemical transformations, seafloor hydrothermal circulation, photochemistry, atmospheric chemistry, marine aerosols, the sediment-ocean interface, mantle geochemistry, extraterrestrial fluxes to the oceans and atmosphere, anthropogenic contaminants, and remote sensing of the oceans. These projects often involved international collaborations. In 2001, a delegation from MCG, including Bill Martin, Jim Moffett, Chris Reddy, and Fred Sayles, traveled to Chile to teach a marine chemistry course at the University of Concepción.

At the end of 2001, there were 22 Scientific Staff members, 5 Scientists Emeritus, 20 Technical Staff members, 10 graded staff, 6 administrative support staff, 4 Adjunct Scientists, and 1 Adjunct Oceanographer. In addition, there were 18 MIT/WHOI Joint Program Ph.D. students, 14 postdoctoral researchers, and 5 summer fellows. MCG staff taught four graduate courses as part of the MIT/WHOI Joint Program. Department members submitted 89 proposals and participated in 134 actively funded projects, a significant number of which were initiated and augmented with internal WHOI funds. The main source of research funding for the department is the National Science Foundation, but outside support also came from the Office of Naval Research, Department of Energy, National Aeronautics and Space Administration, Environmental Protection Agency, and National Oceanic and Atmospheric Administration.



Bob Nelson

Nelson Frew, foreground, and Nick Witzell, right, work with colleagues to prepare the sampling/sensor package called LADAS for air-sea interaction investigations aboard R/V *Ron Brown* (National Oceanic & Atmospheric Administration) during a January-to-March 2001 research voyage in the Pacific Ocean.

There were a number of important personnel changes in 2001. Jim Moffett was promoted to Senior Scientist and Jeff Seewald to Associate Scientist with tenure. Kathleen Ruttenberg received the Woman Scholar Award from Michigan Technological University, but also announced that she is leaving MCG to take a position at the University of Hawaii. Two new Scientific Staff appointments were announced in 2001: Bill Jenkins, who recently received the A.G. Huntsman Foundation's Award for Excellence in Marine Science, will return to MCG following four years at the University of Southampton. Scott Doney, a 1991 MIT/WHOI Joint Program graduate who received the American Geophysical Union's 2001 MacElwane Medal, recognizing significant contributions to the geophysical sciences by a young scientist of outstanding ability, will join the department from the National Center for Atmospheric Research in Boulder, Colorado. We are pleased to welcome these two outstanding scientists to WHOI; they will enhance the departmental research programs through studies of air/sea gas exchange and global biogeochemical models.

—**Mark D. Kurz**, Department Chair

Submarine Groundwater Discharge Creates "Iron Curtain"

Matthew A. Charette, Assistant Scientist

Nearly 97 percent of Earth's freshwater reservoir exists as groundwater, yet groundwater is often neglected in calculations of freshwater and associated dissolved substance input to the coastal zone. Groundwater movement into salt-water bodies, called submarine groundwater discharge, occurs wherever the water table is above sea level and hydraulically connected to the ocean. Until recently, however, submarine groundwater discharge has received little attention, mainly because it is difficult to quantify. New applications of geochemical tracers have led to great advances in this emerging topic over the past several years.

Recent estimates put global submarine groundwater discharge at 2,200 square kilometers per year, roughly equivalent to five percent of total river input. Though this may not represent a significant component of freshwater flux to the oceans, some dissolved substances carried by groundwater may be orders of magnitude higher than they are in rivers or receiving water bodies and thus account for a significant component of the geochemical budget of certain elements.

On Cape Cod, the key biogeochemical problem associated with coastal groundwater flow is the introduction of "new" nitrogen entrained by groundwater plumes passing through septic tank fields located along the coastline. It is not unusual for Cape Cod groundwater to contain dissolved inorganic nitrogen concentrations ranging from 100 to1,000 times greater than receiving water concentration. This has caused eutrophication of coastal embayments where much of the nitrogen is stored as particulate nitrogen (for example, as macroalgae).

A number of investigations have considered the impact of submarine groundwater discharge on a wide range of spatial scales from global fluxes to processes occurring at the groundwater/ocean interface. This zone was recently termed the "subterranean estuary" by 1999 WHOI Ketchum Award winner Willard Moore (University of South Carolina). He describes parallels with the surface estuary, including that both are mixing interfaces for freshwater and seawater bodies and both are significantly impacted by human activities.

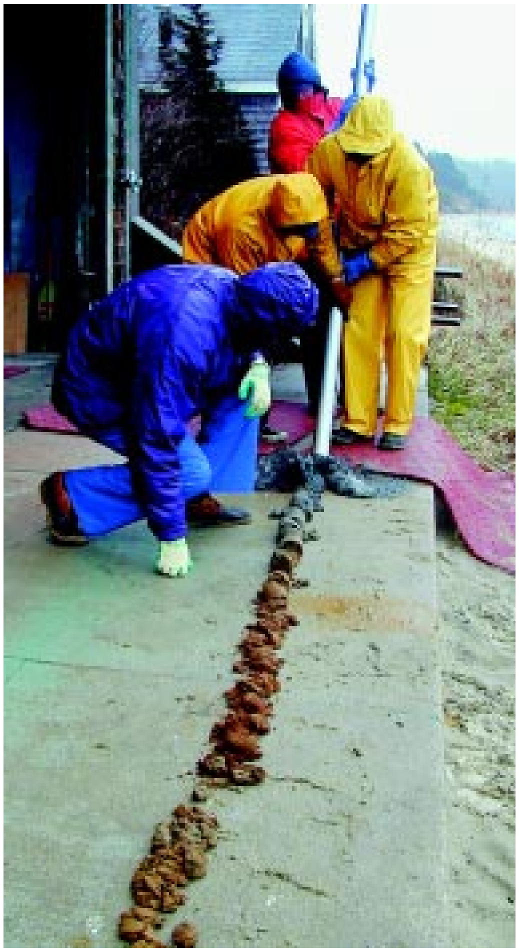
Since early 2000, with support from the National Science Foundation, Ed Sholkovitz and I have been studying the subterranean estuary of Waquoit Bay, a large semi-enclosed surface estuary located about 15 kilometers (9 miles) east of WHOI. On a routine sampling trip, we observed relatively high concentrations of dissolved iron in the groundwater at the head of the bay. From prior studies, we knew that approximately 30,000 cubic meters of submarine groundwater discharge per day were flowing into the bay. Given the iron content of the groundwater, this meant that nearly 30 tons of iron was being carried toward the bay each year. But where was it going? There was some surficial evidence of iron-stained sands in the northeastern portion of the bay, but not nearly enough to balance the calculated input rate.

This led us to hypothesize that an "Iron Curtain" was forming in the subterranean estuary beneath the head of the bay. Sediment cores we collected from the intertidal zone on a cold and rainy day in April 2001 validated our hypothesis. They exhibited iron oxide-rich sands colored dark red, yellow, and orange and formed by the oxidation of iron-rich groundwater near the groundwater-seawater interface. The iron oxide content of these "Iron Curtain" sediments was four to six times greater than that of surface sands and 10 to15 times higher than that of sands collected from an off-site location.

Many elements readily attach to the surface of iron oxides in the presence of oxygen. Because of this immense binding capacity, the Iron Curtain sediments created a geochemical barrier by retaining and accumulating certain dissolved chemical species along with the iron. Indeed, phosphorus con-

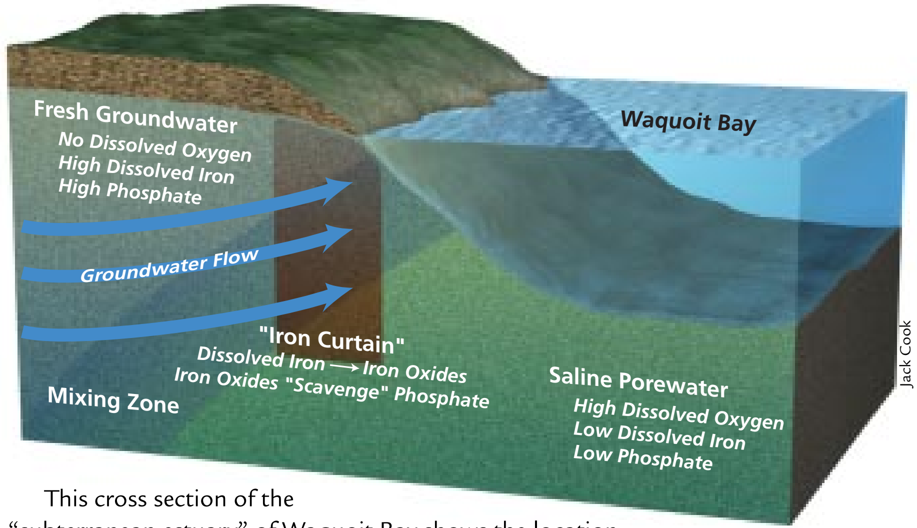
Chris Weidman, Waquoit Bay National Estuarine Research Reserve

Matt Charette and colleagues operate a coring rig in Waquoit Bay to collect sediments.



Chris Weidman, Waquoit Bay National Estuarine Research Reserve

Rusty color of extracted sediment core indicates iron-rich sediments influenced by groundwater discharging offshore.



Jack Cook

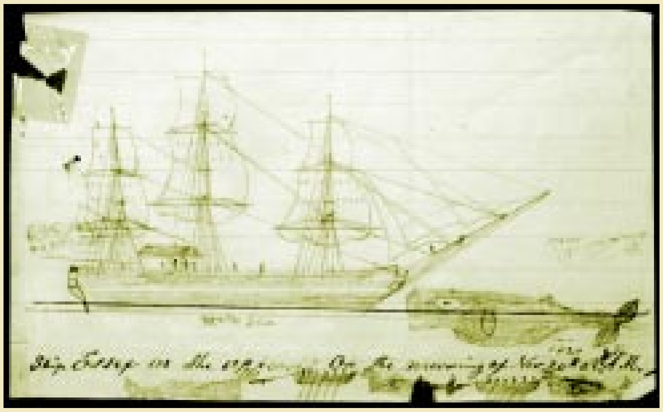
This cross section of the "subterranean estuary" of Waquoit Bay shows the location of the "Iron Curtain." Dissolved iron oxidizes rapidly in the presence of oxygen. The process of iron-rich groundwater upwelling at the shoreline and encountering oxygenated sediments forms the "Iron Curtain." Because phosphate (as well as other dissolved chemicals in the groundwater) has a strong affinity for iron oxide surfaces, it is essentially filtered out by the Iron Curtain before it can enter the estuary.

centrations in the iron oxide-rich sands of Waquoit Bay were five to seven times greater than in overlying surface sands.

The formation of an Iron Curtain requires an aquifer that is rich in dissolved iron and flowing into oxygenated coastal sediments. Iron Curtains may be common in coastal regions: Conditions favorable to their formation have been described for a sandy German beach on the North Sea, New York coastal areas, a freshwater flood plain in Ontario, Canada, and in wetlands of New Zealand's North Island. As we work toward a better understanding of the geochemistry of subterranean estuaries, we expect to find more Iron Curtain type conditions. The next step will be to examine their implications for the health of coastal waters.

A life-saving example of submarine groundwater discharge is described by Nathaniel Philbrick in his account of the whale ship *Essex* tragedy titled "In the Heart of the Sea" (Penguin paperback, 2001). In 1822, about one month at sea after the sinking of their ship, the sailors happened upon a small uplifted coral atoll. Having nearly exhausted their supply of fresh water, they began to search the island for any sign of the precious liquid. After nearly two days of searching, they got lucky in a most unlikely location:

"Up in the cliffs, Nickerson had noticed the...display of 'extraordinary spirit and activity' and soon became part of a general rush for the beach. The men had, in fact, found a spring bubbling up from a hole in a large flat rock...once everyone had been given a chance to drink, they began to marvel at their good fortune. The spring was so far below the tide line that it was exposed for just a half-hour at dead low; at high tide it was as much as six feet underwater. They had time to fill only two small kegs before the rock once again disappeared below the surf."



Courtesy of the Nantucket Historical Association

Thomas Nickerson, the 15-year-old cabin boy aboard *Essex*, was the first to spot the huge whale and was at the helm when it struck. Nickerson's sketch of the whale attacking the ship shows members of the crew already beginning to untie the spare whaleboat from the rack above the quarterdeck.

Ocean Drilling Program Explores the Making of Ore Deposits

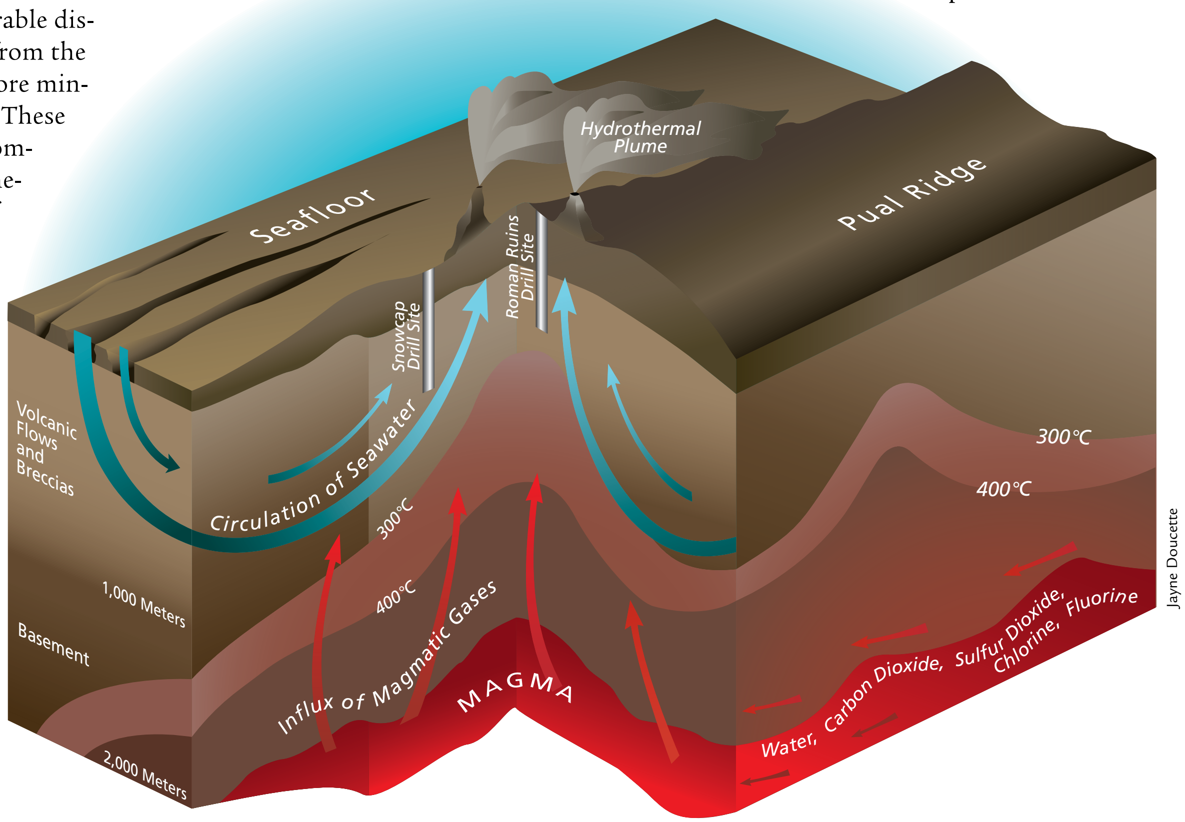
Wolfgang Bach, Assistant Scientist

In volcanically active areas of the seafloor, seawater circulating through subseafloor rock can reach temperatures over 400 °C (750 °F). After leaching large amounts of metals from Earth's oceanic crust, the heated water rises to the seafloor-seawater interface. Dissolved in the hot fluid, the metals may be transported considerable distances before precipitating from the cooled water in the form of ore minerals at or near the seafloor. These hydrothermal systems are common along the 60,000-kilometer (36,000-mile) network of submarine volcanoes that form the global mid-ocean ridge system. Marine scientists have long recognized their important role in our planet's energy and chemical budgets. They also know that some of the world's largest copper and gold deposits were created by submarine volcanic and hydrothermal activity.

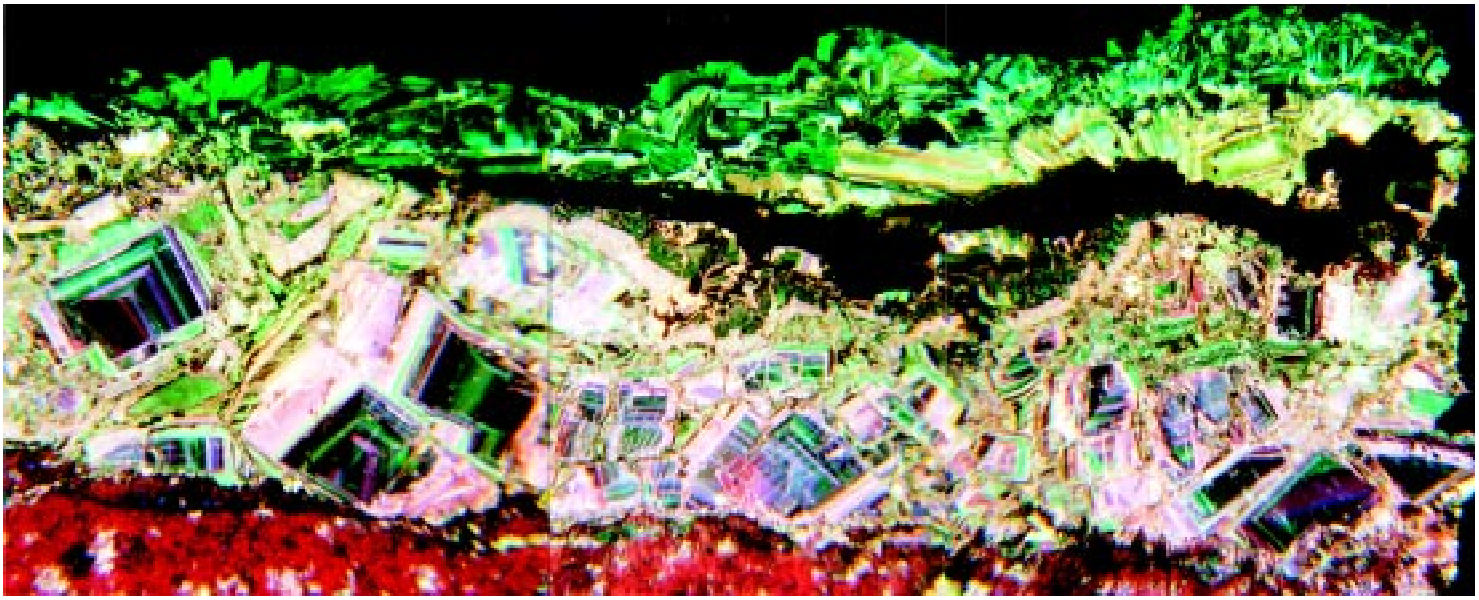
More than a decade ago, economic geologists Steve Scott (University of Toronto) and Ray Binns (Commonwealth Scientific & Industrial Research Organisation, Australia) set out to explore large areas of southwest Pacific Ocean seafloor in search of modern sulfide ore deposits, with the idea that studying modern deposits would bring insight into the historic formation of ores. In 1991, they discovered numerous active hydrothermal sites in the eastern Manus Basin on the crest of the 35-kilometer- (21-mile-) long Pual Ridge and named the area the PACMANUS Hydrothermal Field. Ten years later, the Ocean Drilling Program's *JOIDES Resolution* began to recover samples from the basement underlying PACMANUS to examine ore formation in this environment.

Clouds of ash erupting from Rabaul, one of many volcanoes that occur in chains around the Manus Basin, reminded drill ship scientists that they were working in one of the Earth's most magmatically and plate tectonically active areas. We were drilling into a submarine volcano in water nearly a mile deep. The eastern Manus Basin offered us the unique opportunity to study the birth of a new sea: Crust pushed above sea level long ago is being ripped apart by plate-tectonic forces and replaced by magmatic rocks that become new seafloor. Just south of the Manus Basin, in the New Britain Trench, the same forces are subducting ocean crust back down into the earth's mantle. Water squeezed from the downgoing crust triggers mantle melting that feeds volcanism in the Manus Basin and adjacent volcanic arcs. Cycling of elements through the subduction zone and specifics of melting reactions in the presence of water result in volcanic rock whose composition differs drastically from the rock formed at mid-ocean ridges. Manus Basin rocks exhibit higher contents of silica and metals such as copper, zinc, silver, and gold. These magmas are also very gas-rich, due to release of water and carbon dioxide from the subducting ocean crust.

The *JOIDES Resolution* team drilled holes as deep as 386 meters (1,274 feet), with significant penetration of



Schematic model of the PACMANUS hydrothermal system. Magma reservoirs at depth provide heat to drive hydrothermal circulation of seawater and feed gases and metals into the hydrothermal system.



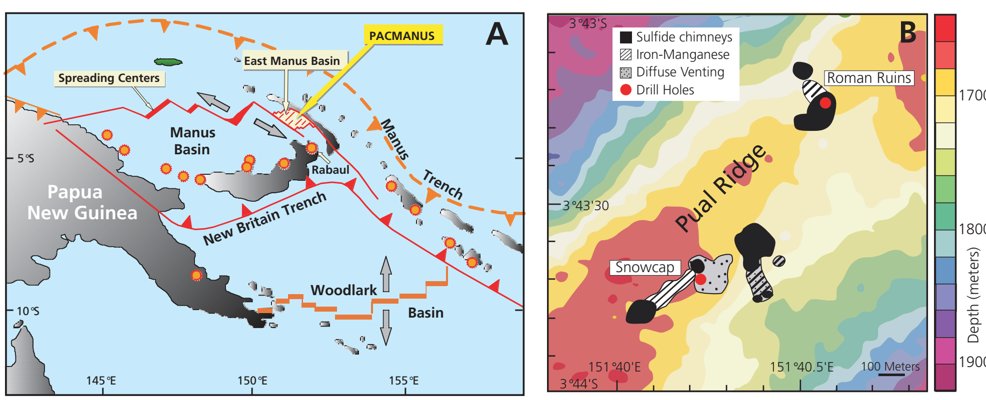
David Vanko, Towson University

Cathodoluminescence microscopy image of an anhydrite vein recovered from ODP Site 1188. Color variations indicate different levels of manganese and rare earth element incorporation in the crystal lattice. Width of image is 5 millimeters.

the subseafloor in the Snowcap field (an area of diffuse discharge of cooled hydrothermal fluids mixed with large fractions of seawater) and the Roman Ruins field (focused fluid flow that results in the formation of sulfide chimney structures). Analysis of rocks and minerals recovered from these drill holes will help me to elucidate chemical reactions occurring between heated seawater and basement rock. I will study the role of magmatic vapor released from the gas-rich magmas upon cooling and solidification and examine the distinct mineral assemblages that form when sulfur dioxide released from the crystallizing magmas reacts with hydrothermal fluid. It will also be of interest to decipher fluid pathways and the extent to which fluids are cooled, heated, and mixed with one another in different parts of the systems.

Curiously, PACMANUS drilling recovered only a small amount of ore. However, data from sensors lowered into the bore holes to measure rock density and electrical conductivity indicate the presence of massive amounts of ore in some areas. The mineral anhydrite, common in submarine hydrothermal systems, is an excellent recorder of subseafloor hydrothermal processes. It is a salt composed of calcium, sulfur, and oxygen, but, unlike most salts, it dissolves better in cold water than in hot. Study of active systems therefore allows scientists to gain insights into ore deposit formation that is not available from work on ancient deposits found on land, because anhydrite dissolves in groundwater.

Analysis of anhydrite will help to unravel the spatial and temporal development of the PACMANUS hydrothermal system and further our understanding of hydrothermal ore formation. I plan to examine the ratios of different sulfur, oxygen, and strontium isotopes, which, like fingerprints, allow reconstruction of fluid sources and formation temperatures. This research will further our understanding of hydrothermal ore formation and will allow estimation of consequences for element fluxes into the ocean.



Sequence of maps showing the regional tectonic setting of the PACMANUS vent field in the eastern Manus Basin. (A) The Manus basin is a rapidly opening marginal sea, forming in response to a major reorganization of plate boundaries in the Southwest Pacific. The Eastern Manus Rift zone is a pull-apart structure between two of the major transform faults. Dots represent active volcanoes. (B) Distribution of hydrothermal deposits and drill sites within the PACMANUS field along the crest of Pual Ridge.

The Physical Oceanography Department includes scientists who study broad-scale, general ocean circulation on time scales from seasonal to decadal and longer, the role of the ocean in climate variability, and processes affecting water mass formation such as mixing and air-sea interaction. Department investigators make fundamental observations of the ocean, spanning the globe from the Arctic to the Antarctic, from the coastal ocean to the deep sea, and from the surface layer to the ocean bottom.

Over the last year, two new Assistant Scientists joined the Department. Steve Jayne, an MIT/WHOI Joint Program graduate, returned to WHOI after a postdoctoral term at the National Center for Atmospheric Research/University of Colorado. Steve plans to concentrate on studies begun during his Ph.D. thesis on problems related to eddy dynamics, and he is an active participant in a new National Aeronautics and Space Administration Gravity Recovery And Climate Experiment (GRACE) mission. It is scheduled for launch in 2002 to make precise measurements of Earth's shifting water masses and to map their effects on our planet's gravity field. The important ocean signal measured by this new satellite will be time-varying pressure at the bottom of the ocean. Bernadette Sloyan came to WHOI following a postdoctoral appointment at the National Oceanic and Atmospheric Administration's Pacific Marine Environmental Laboratory in Seattle. She completed a Ph.D. at the University of Tasmania, Australia, and her area of expertise is the use of inverse models to study ocean dynamics. Her main focus thus far has been on the Southern Ocean, and she plans to initiate new measurements there in collaboration with others in the Department.

During 2001, we made two adjunct appointments, Greg Holloway (University of British Columbia Institute of Ocean Sciences) and Changsheng Chen (University of Massachusetts Dartmouth). Greg is interested in Arctic processes and eddy dynamics while Changsheng will collaborate with our coastal group. Sonya Legg was promoted to Associate Scientist, and Dick Payne, a long-term member of our Technical Staff, retired and was appointed Oceanographer Emeritus.

Tom Bolmer

Dave Wellwood, left, John Toole, and Ellyn Montgomery prepare the high-resolution profiler for a plunge through the water column. The instrument made its 1,000th data collection profile in fall 2001.

Several department members have recently received honors. Nelson Hogg accepted the Henry Stommel Award from the American Meteorological Society, and Rui Xin Huang was awarded WHOI's W. Van Alan Clark, Jr., Chair. Ken Brink was appointed a fellow of both the American Geophysical Union and the American Meteorological Society, and Karl Helfrich was elected a Fellow of the American Physical Society.

Amy Bower undertook perhaps the most perilous research in 2001. As Chief Scientist aboard R/V *Maurice Ewing* (Lamont-Doherty Earth Observatory) in the Gulf of Aden, she had to alter the cruise plan due to a piracy incident when *Ewing* was fired upon (without injuries or damage to the ship) off the Somali coast. The scientists completed their work, avoiding coastal waters, and debarked in Djibouti, where they were escorted to the airport for a flight to Paris—and were stranded in Paris for several days in the aftermath of the September 11 terrorist attack on the United States.

—**Terrence M. Joyce**, Department Chair

Arctic Climate Variability in the 20th Century

Andrey Proshutinsky, Associate Scientist and Arctic Coordinator

Significant variations are evident in the last century's records of the Arctic, which is considered the "canary" of climate change. They include a dramatic decrease in sea-ice area, a general increase in precipitation and river discharge, rising sea level, and alternating cyclonic (counterclockwise) and anticyclonic (clockwise) wind patterns.

Assembling these observations is not easy: Before 1943, most of the existing data do not cover the central Arctic area. Relatively good-quality but scarce observations from high latitudes are available following 1942, and there are large numbers of data points after 1978 when satellites and surface buoys began to provide information from the central Arctic. Despite the paucity of information, it is important to understand past Arctic conditions as we work toward prediction of climate change. Therefore, with support from the Wadati Fund of the Geophysical Institute at the University of Alaska Fairbanks and WHOI funding for Arctic coordination, we integrated data from many sources to construct a picture of 20th century Arctic conditions.

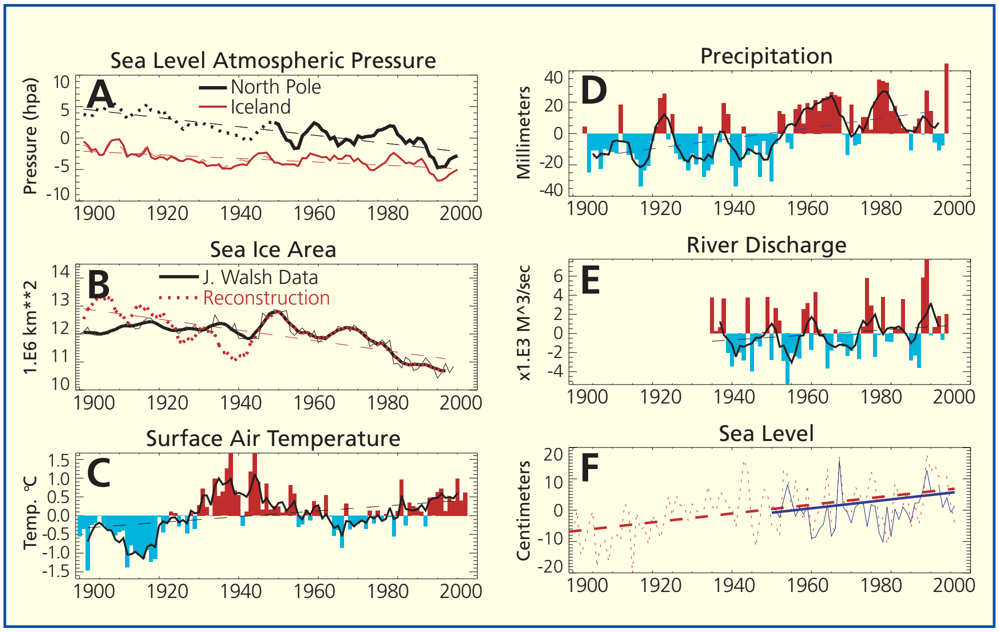
Andrey Proshutinsky

In 1978, the author joined colleagues in the Russian Arctic Program for a research expedition to the North Pole region. Using three AN-2 airplanes (two planes carried scientists and equipment and a third worked as a shuttle, providing fuel for the long distance legs between oceanographic stations), the team measured meteorological and oceanographic phenomena.

Monthly mean atmospheric sea level pressure data is available from the National Center for Atmospheric Research for the entire century. Though there are no data for the *central* Arctic until 1943, we reconstructed data for the earlier period and used it as a basis for determining other central Arctic characteristics for the early 20th century. Our methods included both a mathematical technique for determining principal modes of variability and use of data from later periods to create analogs for earlier periods with no data available. The figures show some of our results for the North Pole and for Iceland. Sea level atmospheric pressure at the North Pole and over the ocean (not shown) decreases from the beginning of the century, with the maximum decrease at the North Pole. Variability on a decadal scale is also evident.

The plot marked C at left shows surface temperature. It exhibits two cold and two warm climate states during the 20th century, with a positive trend of about 0.8°C (1.44°F). Note the significant warming event from the 1920s to the 1940s.

The plot labeled B, annual mean sea-ice area, shows a dramatic decrease since approximately 1950. After 1950, sea-ice area correlates very well with surface air temperature; that is, there were colder air temperatures and increased sea ice in the 1960s and 1970s, and warmer temperatures in the 1980s and 1990s correlate with a significant decrease in sea-ice area. We reconstructed pre-1950s sea-ice conditions based on our sea level pressure reconstruction by assuming that each



Andrey Proshutinsky

Observed and reconstructed anomalies of Arctic climate parameters. Solid lines show 5-year running mean and bars depict annual mean anomalies from observations. Dotted lines depict 5-year running mean reconstructed anomalies. Dashed lines show trends.

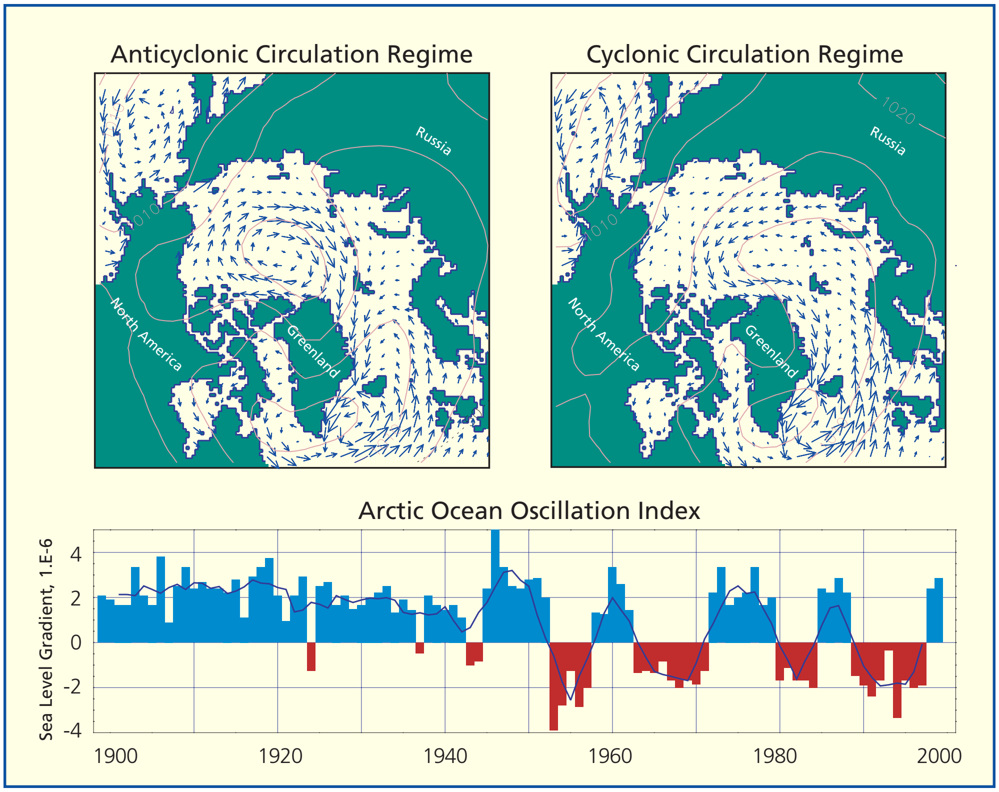
monthly sea-level pressure field has its own sea-ice distribution pattern. The dotted line shows the results: There is much greater decadal variability for 1899 to 1943 than in the original data set, and its variability is consistent with air temperature variations. There is a sea-ice area maximum at the beginning of the century when air temperature anomalies were negative. From the 1920s to the 1940s, when the Arctic air temperature anomalies were positive, sea ice area was significantly lower than normal. Based on the reconstructed data, we conclude that sea ice area decreased by 1 million square kilometers during the 20^{th} century.

Plot D shows an increase in precipitation during the century at an overall rate of 3 millimeters per 100 years, and river discharge (Plot E) is consistent with increased precipitation, though the positive trend is not as evident.

About 60 tide-gauge stations in the Siberian seas recorded sea-level changes from the 1950s through the 1990s. Most of these stations show significant sea-level rise. The dotted line in Plot F depicts annual mean sea level from a numerical simulation based on the reconstructed sea level pressure record. The observed and simulated sea surface heights are in good agreement, and the simulated positive sea level trend of 10 centimeters per 100 years corresponds very well with the observed trend.

Changes in the thermohaline and wind-driven circulation of the Arctic along with decreasing sea-level pressure explain the sea-level changes. To examine the wind-driven Arctic Ocean circulation, we constructed a set of numerical coupled ice-ocean models and found that wind-driven motion in the central Arctic alternates between cyclonic and anticyclonic, with each regime persisting for five to seven years. Anticylonic wind-driven motion in the central Arctic predominates during five periods (1946 to 1952, 1958 to 1963, 1972 to 1979, 1984 to 1988, and 1998 to the present) and cyclonic motion during four periods (1953 to 1957, 1964 to 1971, 1980 to 1983, and 1989 to 1997). Changes in the location and intensity of the Icelandic low and the Siberian high result in shifts from one regime to another. These transformations occur quite rapidly and can be defined as climate shifts. The top part of the figure above shows a typical distribution of sea-level pressure, ice circulation, and surface wind-driven currents for the anticyclonic and cyclonic circulation regimes. In order to reconstruct the ice and ocean circulation, we simulated ice drift and ocean circulation for 1899 to 1999 using the reconstructed monthly sea level pressure data.

The lower panel above shows a time series of simulated sea level gradients. A positive gradient means that sea level in the center of the Arctic Basin is higher than along the coastline and that the circulation is anticylonic. A negative sea level gradient indicates lower sea level in the central Arctic and increased sea level along the coastline. Before 1942, the strong anticyclonic circulation regime dominated over the Arctic Ocean, and the alternating regimes described above are evident after that. Detailed analysis of available observational data and the results of numerical modeling reveal significant differences in the Arctic atmosphere, ice cover, and ocean during these two climate states: The anticyclonic “winter” circulation regime brings a cold and dry atmosphere, increased ice thickness and concentration, and a saltier, colder upper ocean. During the cyclonic “summer” regime, the atmosphere is relatively warm and wet, ice decreases, and the ocean is fresher and warmer. We expect that the 1998 shift from cyclonic to anticyclonic will bring some cooling in the Arctic with increased ice thickness, ice concentration, and ice extent during the period from 2000 to 2005.

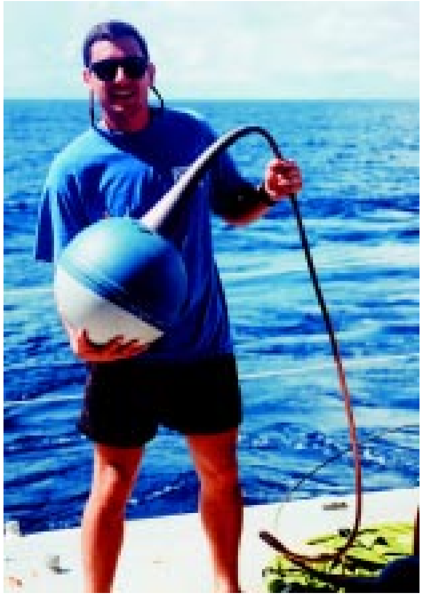


Upper panels: Typical annual wind-driven sea-ice and surface water circulation and atmospheric pressure distribution during anticyclonic (left) and cyclonic (right) circulation regimes. Bottom panel shows time series of the Arctic Ocean Oscillation index or sea level gradient (see details in the text) simulated using a 2-D model and reconstructed sea level pressure data.

North Brazil Current Rings Engulf the Windward Islands

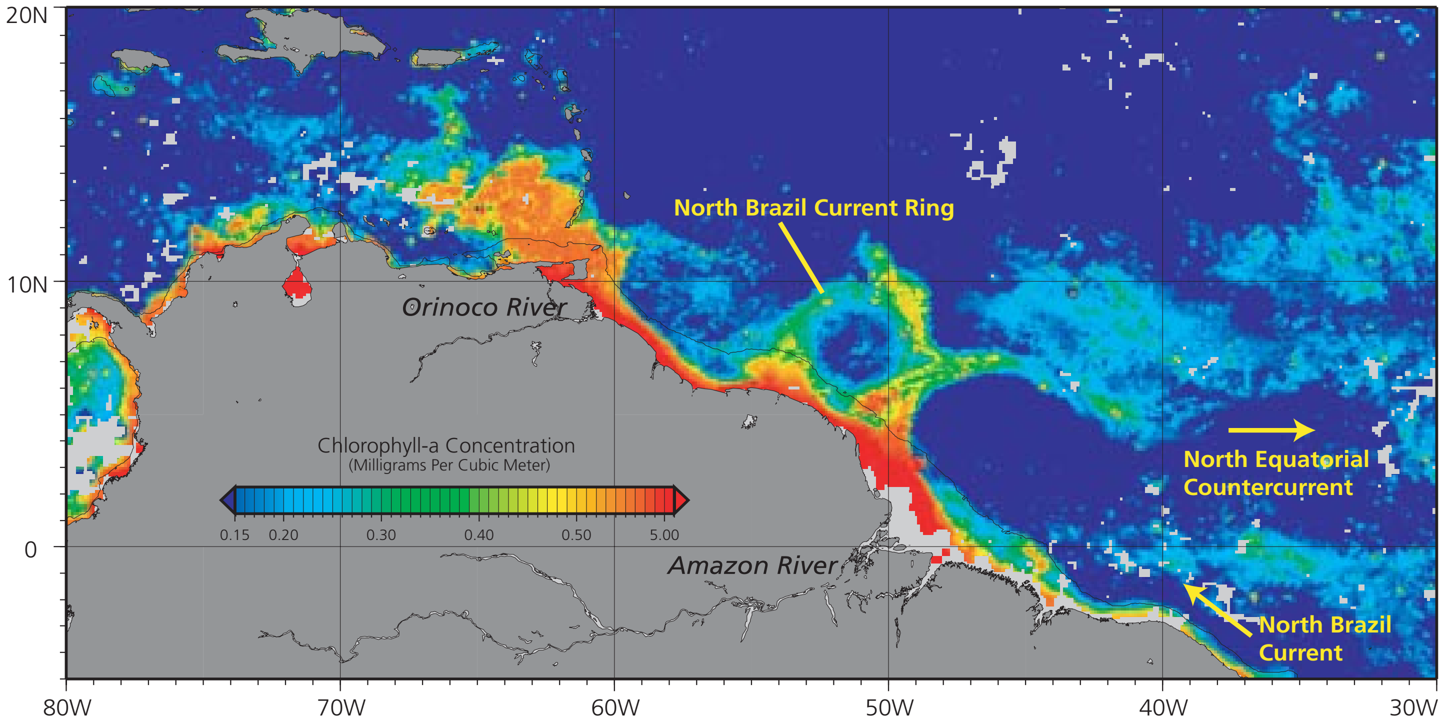
David M. Fratantoni, Assistant Scientist

Swift western boundary currents, including the Gulf Stream and the Gulf of Mexico Loop current, generate energetic, swirling rings. The largest ocean rings spin off the North Brazil Current (NBC) near 8°N in the western tropical Atlantic offshore of Suriname and French Guinea. NBC rings, which can exceed 450 kilometers (270 miles) in diameter and 2,000 meters (6,600 feet) in vertical extent, move northwestward parallel to the South American coastline until they collide with the Windward Islands in the southeastern Caribbean Sea. These energetic rings and their remains, including filaments of nutrient- and sediment-rich Amazon and Orinoco River discharge, disrupt regional ocean circulation patterns, impact the distribution of fish larvae from island coral reefs, and pose a physical threat to expanding offshore oil and gas exploration near Trinidad and Tobago. In a global context, the six NBC rings generated annually are responsible for up to one-third of the equatorial-to-subtropical mass and heat transport associated with the Atlantic meridional overturning circulation, a fundamental component of Earth's climate system.



Dave Fratantoni displays a drifter ready for launch from a ship.

Recently, with Scientist Emeritus Phil Richardson and colleagues at the University of Miami, Lamont-Doherty Earth Observatory, and the National Oceanic and Atmospheric Administration's Atlantic Oceanographic and Meteorological Laboratory, we completed the first comprehensive investigation of NBC ring

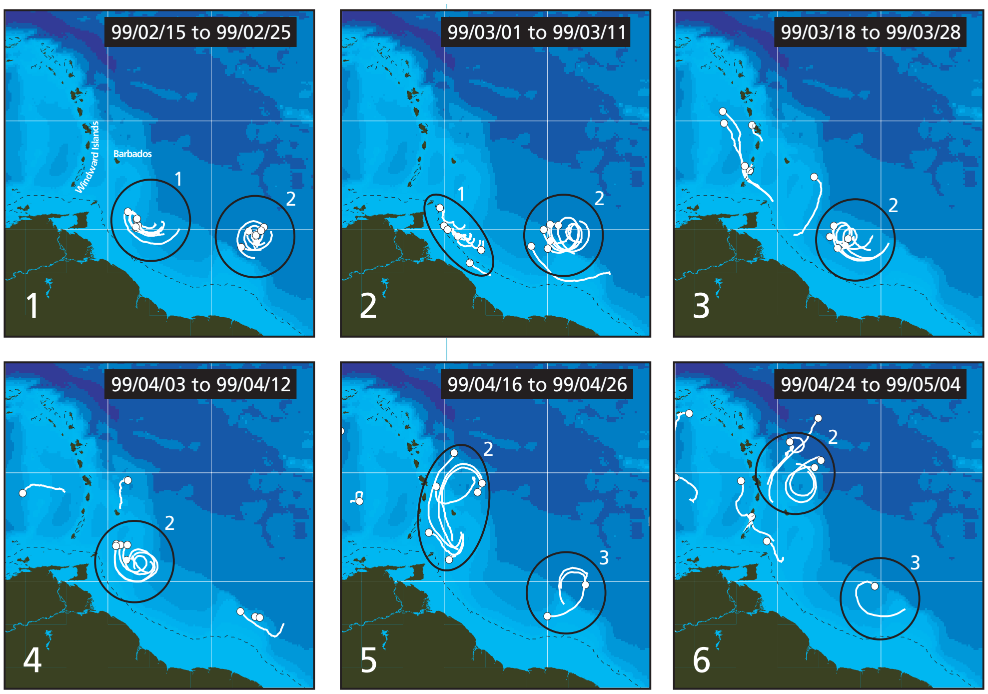


The Amazon River discharges onto the continental shelf of equatorial Brazil, resulting in elevated nutrient concentrations and enhanced biological productivity. A plume of phytoplankton-rich, high-chlorophyll water is swept northwestward along the nearshore edge of the North Brazil Current (NBC) and into the interior as the current turns offshore into the North Equatorial Countercurrent. Surface chlorophyll fields derived from satellite-based, ocean-color observations reveal filaments of highly productive, Amazon-influenced water adjacent to and surrounding relatively lifeless mid-ocean water. This contrast permits visualization of the cyclic advance and retreat of the NBC retroflection and the accompanying formation of pinched-off NBC rings.

generation, structure, and evolution. From 1998 to 2001 we conducted four research cruises, each lasting a month, aboard R/V *Seward Johnson* (Harbor Branch Oceanographic Institution) as part of the National Science Foundation (NSF)-supported North Brazil Current Rings Experiment. On each cruise we identified and surveyed one or two NBC rings with an acoustic Doppler current profiler and collected vertical profiles of temperature, salinity, and dissolved oxygen within the swirling ring core. These velocity and water property measurements were the first ever collected within an NBC ring and revealed much about the origin of water trapped within the rings and the efficiency of NBC rings as a transport mechanism. As each ring is comparable in area to the state of Pennsylvania, a single ring survey took more than a week.

Once we determined the ring's basic geometry and located its center, we launched several acoustically tracked subsurface floats and satellite-tracked surface drifters into the ring core. The floats were ballasted to drift at one of three depths (250, 550, and 900 meters). We were interested in how the rings respond to abrupt topographic features such as ridges, seamounts, and the Lesser Antilles island chain. We deployed floats and drifters in a total of five different rings during the course of the experiment. Individual instruments swirled around the ring core for periods as short as several days and as long as several months. The final collection of trajectories provides a unique depiction of the horizontal and vertical velocity structure, downstream evolution, and eventual catastrophic demise of NBC rings.

We found the float and drifter measurements particularly valuable and revealing during the final phases of the NBC ring life cycle. Ring structure and intensity are radically modified when rings collide with the Windward Islands and break into filaments and smaller scale vortices, some of which penetrate the narrow island passages of

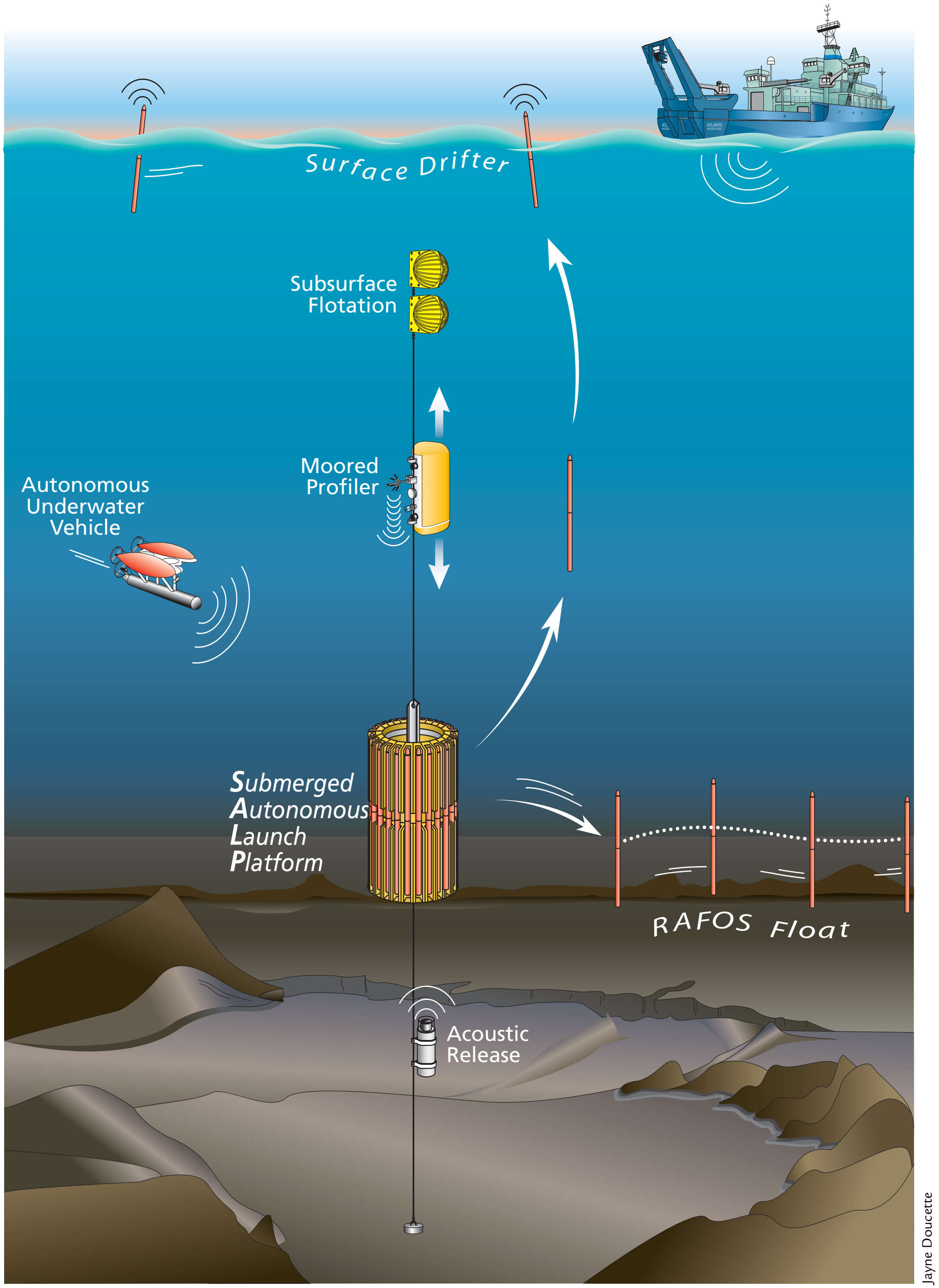


Time-series of drifter trajectories deployed in successive North Brazil Current rings during a February 1999 cruise. As the first ring crashes into the Windward Islands the drifters that were in its core disperse through several shallow island passages. In contrast, the second ring turns northward and passes over the island of Barbados while retaining a relatively intact core. Drifters looping around a third ring are visible in panels 5 and 6.

the southeastern Caribbean Sea. Unlike simulations performed with numerical ocean models, our results suggest that the much of the water contained within the core of NBC rings does not enter the eastern Caribbean but is instead dispersed east of the islands as the rings are sheared apart. Interestingly, the surface drifter observations revealed that at least two NBC rings completely engulfed the island of Barbados while maintaining their swirling structure. These close encounters between a ring and a reef-fringed island are consistent with the belief of University of Miami biologists that NBC rings may contribute significantly to the dispersal of fish larvae throughout the eastern Caribbean.

The drifter trajectories indicated

The Slocum glider is a two-meter-long torpedo-shaped winged vehicle conceived by Henry Stommel and Doug Webb and built by Webb Research Corporation of East Falmouth, MA. It maneuvers through the ocean at a forward speed of one knot in a sawtooth-shaped gliding trajectory for as long as 45 days while making measurements of temperature, salinity, and bio-optical water properties.



The Submerged Autonomous Launch Platform (SALP), currently in late-design stage, to be deployed at depths as great as 2,000 meters (6,600 feet) on a standard oceanographic mooring, will allow scientists to launch floats and drifters by time according to a user-defined schedule, by real-time, acoustic, remote control from a ship or autonomous underwater vehicle, or adaptively on the basis of local environmental conditions. SALP will facilitate intensive and cost-effective studies of ocean circulation in rapidly changing, geographically remote, or environmentally hostile regions, and will enable investigators to address difficult research problems that are presently financially or logistically untenable. As a component of an autonomous ocean observing system, SALP will allow investigators to project and maintain an interactive presence at sea while promoting the efficient use of community seagoing resources.

that neighboring rings exert substantial influence on each other, affecting the time and location at which ring core water escapes into the tropical/subtropical gyre circulation. Also, deformation of the generally elliptical rings occurs rapidly, indicating that prediction of high-velocity events at a particular location (such as an island or oil rig) depends on knowledge of both the ring's travel speed and deformation history. Because NBC rings interact continually with neighboring rings and topographic features, existing simple models of ring translation and evolution provide insufficient predictive capabilities. Improved simulation and/or prediction of the intense velocity fluctuations requires more thorough understanding of a ring's evolution from genesis to demise, with particular emphasis on the mechanisms of ring interaction with the underlying bottom topography.

Over the next two years we will reduce and analyze the results of our recent field expeditions and make plans for a new and larger experiment focused specifically on the collision of NBC rings with the Windward Islands. With NSF support, we are developing a new autonomous moored launch platform with engineers Dan Frye (Applied Ocean Physics and Engineering Department) and Jim Valdes. This Submerged Autonomous Launch Platform (SALP) will allow us to deploy large numbers of floats and drifters automatically or by remote control without the expense of multiple research cruises. In addition to the passive floats and drifters used previously, we plan to use a new class of long-range, high-endurance, autonomous gliding vehicle called Slocum developed by Webb Research Corporation to conduct continuous, three-dimensional surveys of NBC rings as they translate and evolve. These new technologies will be of immense value as we attempt to further elucidate the physics and societal implications of NBC ring collisions with the Windward Islands.

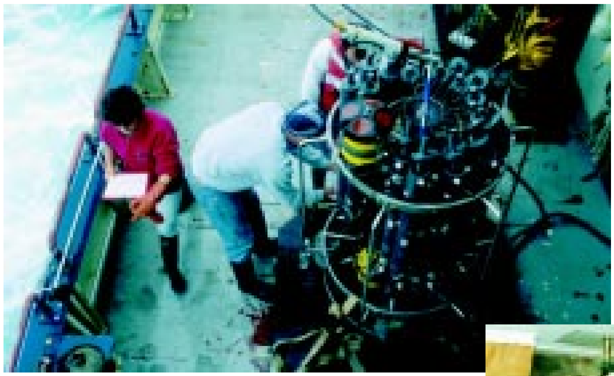
Cooperative Institute for Climate and Ocean Research

The Cooperative Institute for Climate and Ocean Research (CICOR), initiated in 1998, provides the framework at WHOI for facilitating research activities funded by the National Oceanic and Atmospheric Administration (NOAA). CICOR's objectives include building ties between WHOI investigators and colleagues at NOAA laboratories and developing cooperative NOAA-funded research at academic institutions in the northeastern United States. A new five-year Cooperative Agreement was signed by WHOI and NOAA in July 2001.

CICOR research revolves around three themes: the coastal ocean and near-shore processes, the ocean's role in climate and climate variability, and marine ecosystem processes. The amount of NOAA-funded research at WHOI is growing, with WHOI scientists taking lead roles in many projects.

Participation in CICOR's activities extends across the full range of WHOI's scientific staff, from graduate students to senior scientists. An important goal of the Cooperative Institute is to bring students and postdoctoral investigators into NOAA research programs. Toward this end, CICOR commits to the support of graduate students and Postdoctoral Scholars. MIT/WHOI Joint Program students Rob Jennings (Biology Department) and Steve Fries (Applied Ocean Physics and Engineering Department) were CICOR Graduate Research Assistants during 2001. In September, Fries became the first CICOR Joint Program student to defend his Ph.D. thesis, titled "Enhancement of Fine Particle Deposition to Permeable Sediments."

This year's report highlights the work of the first three CICOR Postdoctoral Scholars. Fiamma Straneo's research follows the climate and climate variability theme and James Lerczak's the coastal oceanography and near-shore processes theme. Both are based in the Physical Oceanography Department. CICOR's third Postdoctoral Scholar, Liviu Giosan, who joined the Marine Chemistry and Geochemistry Department in the fall, is also working under the coastal oceanography and near-shore processes theme.



Chris Linder

David Fisichella

Above, CICOR Postdoctoral Scholar Fiamma Straneo heads for the R/V *Oceanus* lab with a water sample log while Bob Pickart and Summer Student Fellow Jimmy Mistler of Susquehanna University draw water samples collected near Iceland. Right, on an Indian Ocean cruise, Straneo learns about ship control from *Knorr* Third Mate Kent Sheasley.

Collaborating with Robert Pickart, Fiamma Straneo investigated the interannual variability of Labrador Sea deep convection, a mechanism that removes heat from the mid to deep ocean and releases it to the atmosphere. This results in the formation of Labrador Sea Water, a water mass found throughout the entire North Atlantic and a component of the meridional overturning circulation. Observations reveal that deep convection in the Labrador Sea is a highly time-dependent process, and modeling studies show that such variability has a potentially large impact on the North Atlantic's thermohaline circulation, and thus on our climate system. To improve understanding of this heat- and salinity-driven system, Straneo coupled a model for the spreading of Labrador Sea Water through the Atlantic basin and an idealized convective model. Her work shows that, rather than passively mimicking atmospheric variability, as was hypothesized, the ocean can modify the atmospheric signal. The time series Straneo derived for the amplitude of convection in the Labrador Sea using realistic atmospheric fluxes from 1950 to the present constitutes a substantial improvement in the prediction of observed Labrador Sea Water variability.

Working with Rocky Geyer of the Applied Ocean Physics and Engineering Department, Jim Lerczak studies cross-channel flows in estuaries using both field observations in the Hudson River and numerical modeling. While currents mainly flow along estuary channels, the comparatively weak cross-channel flows influence how salty water from the ocean mixes with fresh water from rivers. These flows are important to the dispersion of tracers, such as pollutants, within estuaries. The cross-channel flows are driven by cross-channel density differences, by the influence of Earth's rotation, and by meanders in the estuary channel. In May 2001, with Bob Chant of Rutgers University and Bob Houghton of the Lamont-Doherty Earth Observatory, they injected a fluorescein dye patch into the Hudson River Estuary to directly measure the influence of cross-channel flows on mixing and dispersion. They also collected current and density profiles to measure the mechanisms driving the cross-channel flows over a tidal cycle. Lerczak and Geyer developed numerical simulations to study the driving forces for cross-channel flows in idealized estuaries under different tidal conditions, varying river flows, and channel meandering. Lerczak also works with Cabell Davis and Carin Ashjian of the Biology Department and Bob Beardsley of the Physical Oceanography Department to analyze data collected in Cape Cod Bay in 1999 and 2000 for studies of how copepods use convergences in tidal currents to help them aggregate. Dense aggregations enhance reproductive success for the copepods and provide a critical food source for North Atlantic right whales. The scientists used detailed measurements of copepod behavior and density as well as current and water property data to determine the dynamics of the tidal convergences and how the copepods responded to the currents.

Liviu Giosan, who came to WHOI following completion of his Ph.D. at the State University of New York at Stony Brook, is contining his work on samples from the Blake Ridge sediment drift to recover climatic information over the Pliocene/Pleistocene periods (2 to 5 million years ago). He will be participating in Ocean Drilling Program Leg 202, planned to extract sediment cores from the southeast Pacific in 2002, to study the same time interval using sediment physical properties and geochemical techniques. Giosan also studies wave-influenced deltas to determine causes for asymmetric delta evolution.

—**Robert Weller**, CICOR Director

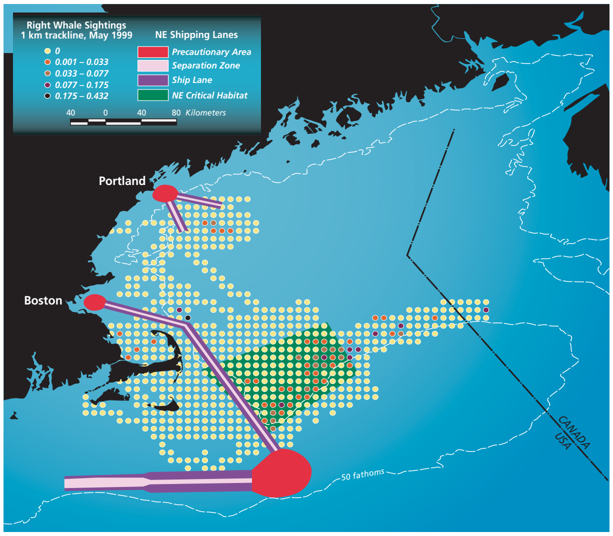
Marine Policy Center

The Marine Policy Center (MPC) conducts social scientific research to advance the conservation and management of marine and coastal resources. A new focus of MPC research in 2001 is the assessment of proposed management measures to reduce mortalities of the northern right whale, *Eubalaena glacialis*.

The northern right whale is a highly endangered species, currently numbering only about 300 animals, so losses of any individuals are taken seriously. Small numbers of losses are known to have resulted from collisions with large ships along the US eastern seaboard. The National Marine Fisheries Service is currently considering ship traffic management measures to reduce the incidence of ship strikes, and MPC researchers are contributing estimates of the costs and effectiveness of alternative management measures.

The primary form of regulation under consideration is the designation of ship traffic management areas where traffic overlaps whale habitat or migration routes. During specified periods or "seasons," ships would be required either to reduce speed when transiting a management area or to reroute around it. The requirement could be static (continuously in effect) or dynamic (activated by the observed or inferred presence of whales).

The first phase of the MPC research focused on producing a rough, upper-bound estimate of the total economic cost to vessel operators of a set of base case management measures affecting all traffic headed into or out of US ports from Portland, Maine, to Port Canaveral, Florida. Two main types of costs—expected and unexpected—have been estimated for all vessels, based on their normal operating speeds, daily costs, and other relevant factors such as tide windows.



Jayne Doucette

Estimated seasonal densities of northern right whales (based on sightings per unit survey effort in May 1999) in relation to established shipping lanes and critical whale habitat in the New England region. This information will be combined with data on vessel traffic densities to estimate the effectiveness of alternative vessel traffic management measures in reducing the incidence of ship-whale encounters and fatal strikes.

Expected costs are those associated with anticipated additional transit time when either a static measure is in force, or when the measure is dynamic and a vessel operator takes a low-risk response of planning transit times for the entire management season as if the measure in force were a static speed restriction. Unexpected costs apply only to inbound transits and arise only in cases where the management measure is dynamic, the vessel operator makes a high-risk assumption that the restriction will not be triggered during transit, but the restriction is triggered and causes the vessel to miss a tide or daylight window for entering port. For cruise ships and container ships that incur unexpected costs, additional penalties for missing a scheduled arrival or berth assignment are included in the estimated cost as well.

Using the US Army Corps of Engineers' port-level vessel traffic data for 1999–2000, the first phase of the research project produced annual cost estimates at the port level for 18 categories of vessels. Estimated costs range from a high of about $4.8 million for the Port of New York & New Jersey to a low of about $300,000 for Wilmington, DE, and Portland, ME. Container ships account for the most significant costs ($780,000/per port/per year), followed by cruise ships ($460,000/per port/per year). Dry bulk ships, tankers, LNG ships, car carriers, and roll-on/roll-off cargo vessels are each estimated to account for an average of $120,000 to $160,000/per port/per year. The total estimated annual cost of the base case management measures along the US east coast is about $17 million.

The objectives of the current phase of the project are twofold: to refine the estimates already developed to capture more information about vessel traffic patterns and the regional economic impacts of increases in vessel costs, and to develop a model for evaluating the effectiveness of the proposed management measures in reducing the incidence of ship strikes.

The first task is to develop data sets of recent historical and expected future vessel traffic densities along additional areas of the east coast, with particular emphasis on critical whale habitat or migration areas. Using these data and right whale distribution estimates from aerial and ship-based whale surveys, MPC researchers will develop a model of recent historical exposure of right whales to ship strike as a function of geographic area and season. Two components of baseline risk will be estimated: the expected number of ship-whale encounters (potential collisons) and the expected number of fatal strikes given the number of encounters.

These estimates will serve as the starting point in developing a framework to estimate the reduction in ship strike risk that may be expected from alternative traffic management measures. Broadly speaking, vessel diversions can be expected to lower the number of encounters, while speed reductions can reduce the risk of collision given an encounter. The effectiveness of speed reductions is modeled as a function primarily of well-understood whale behaviors (feeding, mating, transiting, calving) and how they affect an animal's awareness of and responsiveness to approaching vessels.

Finally, the research team will integrate its model of vessel costs with an economic "input-output" model that captures how the increases in costs to individual shippers will ripple through affected economic sectors and down to the level of households in the coastal counties of the New England, mid-Atlantic, and South Atlantic regions.

—**Andrew Solow,** Marine Policy Center Director

Coastal Ocean Institute and Rinehart Coastal Research Center

The Coastal Ocean Institute and Rinehart Coastal Research Center (RCRC) is dedicated to promoting coastal ocean research within the Woods Hole Oceanographic Institution. A "center without walls," it supports new technologies, innovative scientific directions, and interdisciplinary research. These activities often include "proof of concept" projects that provide a basis for federal funding.

2001 has been a year of major transitions for the Center, beginning with a change in leadership. Rocky Geyer served very capably as Director for five years, including the critical scaling-up period following the generous Montgomery bequest. His leadership was insightful, decisive, and extremely effective. A second major change is reflected in the Center's new title: RCRC has evolved to become one of the Institution's four new Ocean Institutes, a change that offers a wonderful range of new challenges and opportunities.

Diverse Center activities include administering the Coastal Research Laboratory (which provides valuable space for large equipment such as flumes) and maintaining a fleet of small boats available for working in local waters. Providing small grants that initiate new lines of research is central to the Center's mission. Three such innovative projects are described below.

Eutrophication (high nutrient loading) is a common ecological problem in estuaries located near populated areas. Nitrogenous wastes can leak into the watershed, with profound effects on the ecology and species composition of estuarine ecosystems, including populations of economically important fish and shellfish. Little work has been done on how eutrophication affects the ability of predators to visually locate their prey, despite the fact that the associated phytoplankton blooms can dramatically decrease underwater light levels and visibility (especially in the ultraviolet range). Larry Madin and Sönke Johnsen were funded to measure the optical effects of eutrophication in three estuaries with differing nitrogen loads within nearby Waquoit Bay. They also measured the optical characteristics of common prey and, using established models, estimated the effects of eutrophication on visual predation. Because recent research suggests that the mummichog *Fundulus heteroclitus*—a very small fish that is a key predator in Waquoit Bay—can see ultraviolet light, they examined the effects on ultraviolet visual predation particularly closely.

During late summer, nutrient overloading combined with otherwise favorable conditions led to a dramatic bloom of microscopic plants in Waquoit Bay, especially those branches that are most heavily developed. The mummichog's sighting distance for its prey dropped by a factor of about five. While it is clear that this is strongly detrimental for the mummichog, it is actually difficult to evaluate this loss of feeding ability since there are so many other negative effects, such as toxicity, associated with the eutrophication-driven bloom.

Another research area concerns the discharge of terrestrially derived fresh water onto the continental shelf. Though this phenomenon provides an important flux of nutrients onto the seafloor, few geophysical techniques are sensitive to the presence of fresh pore water in sediments on the continental shelf. Consequently, our ability to estimate the volume and distribution of sub-bottom fresh water remains weak. Rob Evans surmised that the difference in electrical conductivity between fresh water and salt water might be a key since salt enhances the conductivity of seawater. He tested the ability of a range of commercially available electromagnetic tools to detect electrical resistivity features both offshore and beneath the beach at Wrightsville Beach, North Carolina. The most successful tool was an inductive system that probes 20 to 30 meters beneath the beach. Data from 6-kilometer-long profiles show reduced electrical resistivities in the mid-part of the beach at a depth consistent with the location of the regional Castle Hayne aquifer. Since offshore data show that this aquifer is a continuous feature throughout the region, Evans interpreted the reduced resistivities to mean that salt water is intruding into the aquifer as a result of pumping. In this project, Center funding allowed for evaluating instruments, refining future sampling plans, and finding evidence for a previously undetected saltwater intrusion.

Katrina Edwards

Postdoctoral Investigator Ann Pearson works with shallow cores of marsh mud near Wood Neck Beach in Falmouth for studies on microbial biodegradation of petroleum hydrocarbons.

Petroleum spills represent a significant environmental threat to coastal regions. Although physical processes like wind and wave action disperse much of the spilled oil, true remediation ultimately is achieved by microbial biodegradation. It is difficult to verify the in situ consumption of petroleum hydrocarbons, however. Traditional laboratory methods in microbiology (such as growth of enrichment cultures on oil inoculant) may yield results that are not representative of processes occurring within a complex, natural bacterial consortium. Employing molecular techniques and geochemical isotopic measurement methods in a pioneering approach, Postdoctoral Investigator Ann Pearson, in cooperation with Katrina Edwards, John Hayes, and Andreas Teske, utilized the difference between the natural radiocarbon concentration of oil (which exhibits no carbon 14 because it has all decayed away while the oil was forming underground) and fresh organic matter (exhibiting carbon 14 at modern atmospheric levels) to monitor metabolism of this oil by salt marsh bacteria. In the end, using sensitive accelerator/mass spectrometer assays of carbon isotopes, the group found that the stable, naturally occurring carbon isotope carbon 13 was actually a much better tool for tracking the effects of environmental petroleum. This finding provides an efficient, well-targeted new method that will open new doors for studying how oil spills can affect specific organisms in the coastal ocean.

—**Kenneth H. Brink**, Coastal Ocean Institute and Rinehart Coastal Research Center Director

Sea Grant Program

The WHOI Sea Grant Program supports research, education, and advisory projects to promote the wise use and understanding of ocean and coastal resources for the public benefit. It is part of the National Sea Grant College Program of the National Oceanic and Atmospheric Administration, a network of 29 individual programs located in each of the coastal and Great Lakes states. The goal of the program is to foster cooperation among government, academia, and industry. WHOI Sea Grant-supported projects provide linkages between basic and applied aspects of research and promote communication among the scientific community and groups that utilize information on the marine environment and its resources.

During 2001 the WHOI Sea Grant

Program supported 15 concurrent research projects and six new initiative awards. These projects are included in three theme areas: Estuarine and Coastal Processes, Fisheries and Aquaculture, and Environmental Technologies. Many of the projects address local and regional needs; some have national or even global implications. Investigators from the Woods Hole scientific community, universities throughout Massachusetts, and scientists from industry and other states all participate in WHOI Sea Grant's competitive funding process.

In 2001, WHOI Sea Grant provided 18 months of support for graduate students and five months of support for undergraduate students through research awards. WHOI Sea Grant also supported Christopher Grogan, a doctoral candidate in the wildlife and fisheries graduate program at the University of Massachusetts Amherst, as part of a National Sea Grant College Program/National Marine Fisheries Service Joint Graduate Fellowship Program in Population Dynamics.

In terms of informal education, WHOI Sea Grant maintains close working relationships with the Massachusetts Marine Educators, the National Marine Educators Association, and the Woods Hole Science and Technology Education Partnership. At the local level, Sea Grant is an active participant in science fairs, with staff serving as project advisors and judges. Each year, top science fair winners are guest speakers at the opening night of the spring "Oceans Alive" lecture series. For the ninth consecutive year, WHOI Sea Grant sponsored "Sea Urchins," a summer program for children ages five to seven. Perhaps Sea Grant's most important contribution to education in our region is the provision of educational materials to numerous programs, including Children's School of Science, Cape Cod Children's Museum, Cape Cod Museum of Natural History, Association for the Preservation of Cape Cod, Cape Cod National Seashore, Wellfleet Audubon Sanctuary, New England Aquarium, Thornton W. Burgess Society, and school districts throughout Southeastern Massachusetts and the world.

Transferring the results of research and providing general marine-related information are important components of the WHOI Sea Grant Marine Extension and Communications Programs. Both facilitate communication among users and managers of marine resources, including members of the fishing community, aquaculturists, local officials, environmental regulatory agency managers, educators, and the general public. Two areas of particular interest in the marine extension program are coastal processes and fisheries and aquaculture. Workshops, training programs, and informational meetings sponsored by Sea Grant emphasize better management of resources at the local and regional levels.


Tom Kleindinst

WHOI geochemist Matt Charette (left) and Research Assistant Craig Herbold measure nitrate concentration in a Cape Cod estuary using a nitrate analyzer. They can track groundwater-derived nutrients and identify their sources by analyzing chemical tracer data from this instrument.

WHOI Sea Grant provides information to a broad audience through a variety of means, including Worldwide Web sites. The WHOI Sea Grant Web site (www.whoi.edu/seagrant) provides access to information on current research and outreach projects and funding opportunities. With support from the National Sea Grant office, the WHOI and New Hampshire Sea Grant programs offer a Web site devoted to careers in the marine sciences (www.marinecareers.net) as a companion to the publication *Marine Science Careers: A Sea Grant Guide to Ocean Opportunities*.

Publications are another outreach vehicle for WHOI Sea Grant. Along with MIT Sea Grant, we publish the *Two if by Sea* newsletter three times each year. Our educational fact sheets series, "Focal Points," is geared for legislators and coastal decision makers. Another series, "Marine Extension Bulletins," is designed for a more technical audience.

Beginning in 2001, WHOI Sea Grant collaborated with the WHOI Information and Education Offices to organize teacher workshops based at the Exhibit Center. The workshops, offered in the spring and fall for middle- and high-school teachers as well as informal educators, consider various topics in oceanography. Interaction with WHOI scientists and engineers, the opportunity to network with peers from other schools, and the take-home resources and classroom activities are some of the workshop aspects praised by participants in follow-up evaluations.

—**Judith E. McDowell**, Sea Grant Coordinator

We are proud to announce that Woods Hole Oceanographic Institution was accredited in 2001 by the New England Association of Schools and Colleges, Inc. through its Commission on Institutions of Higher Educations. (See box below for the official statement.) Prior to the 1990s, no need was seen for the Institution to seek accreditation for several reasons: MIT's accreditation encompassed MIT/WHOI Joint Program graduate degrees, the Institution had a Commonwealth of Massachusetts charter to grant graduate degrees, and periodic reviews by external committees of distinguished colleagues attested to the excellence of WHOI's education programs.

In the early 1990s, discussions with the Educational Council and Education Assembly, and with the WHOI Trustees' Education Committee led us to seek accreditation for the following reasons:

1) During the 1980s and into the 1990s, an increasingly significant portion of the MIT/WHOI Joint Program teaching and advising effort was centered at WHOI.

2) Accreditation would verify the quality of the Institution's education efforts within the broader community of higher education programs and not just within the ocean sciences and ocean engineering communities.

3) The accreditation process provides a useful framework for self study and evaluation.

4) Accreditation would remove the necessity for seeking special exemptions for the Institution and Institution Scientific Staff when applying for funding grants reserved for accredited organizations, or for eligibility for certain matching gifts.

The self study report was submitted in early 2001. The review team visited in April and submitted their report in July. In early October, the Institution received official notice of accreditation, and on December 6th I had the honor and pleasure of officially accepting the Accreditation Certificate at a meeting of the Commission on Institutions of Higher Education, New England Association of Schools and Colleges, Inc.

The Institution's Education programs are described on the WHOI Web site at www.whoi.edu, and current students and postdocs are listed later in this report. We continue the practice established in the 2000 *Annual Report* of highlighting individual stories as exemplars of the many students and postdocs involved in our Education Programs.


Peter Cleary, Brown University

Jeff Donnelly climbs out of a pit excavated in a Pawcatuck, CT, salt marsh, where samples yielded a 1,300-year record of sea-level change.

Jeff Donnelly grew up in Massachusetts and thought he was headed west when he began a master's program at Yale following completion of a B.S. in Earth Science at the University of Massachusetts Boston. However, the next step was a U-turn to Brown, where part of his Ph.D. thesis work was funded by WHOI Sea Grant.

This research chronicled changes in salt marsh vegetation over time, driven by an acceleration in the rate of sea-level rise, through analysis of peat samples. In addition Jeff pioneered methods aimed at reconstructing the history of past hurricane activity from coastal sediments. Storm surges related to the intense onshore winds of major hurricanes overtop barrier islands and result in the deposition of overwash fans behind the beach. Sand layers in cores extracted from such areas provide a record of these past storms. This work was supported by the reinsurance industry based in Bermuda, whose interest in long records of intense hurricane strikes was sparked by major losses associated with Hurricane Andrew in 1992.

Jeff's work drew the attention of WHOI staff concerned with coastal geological processes, and he was encouraged to apply for a postdoctoral position here. He received an appointment as a US Geological Survey (USGS)/WHOI Postdoctoral Scholar and arrived in September 2000. An hour later he was on the McKee Ball Field engaged in a pickup softball game for postdocs and their advisors. Jeff hit a line drive into the forehead of

Accreditation Statement: The Woods Hole Oceanographic Institution is accredited by the New England Association of Schools and Colleges, Inc. through its Commission on Institutions of Higher Education. Inquires regarding the accreditation status by the New England Association should be directed to the administrative staff of the institution. Individuals may also contact: Commission on Institutions of Higher Education, New England Association of Schools and Colleges, 209 Burlington Road, Bedford, MA 01730-1433. Phone: (781) 271-0022. E-mail: cihe@neasc.org.

Senior Scientist Joe Pedlosky, breaking his glasses and sending him to the emergency room. (Joe forgave Jeff, returned to the game, and hit a triple.) Jeff went on to spend 18 months continuing his work on sedimentary records of coastal environmental change. In late 2001 he was appointed Assistant Scientist beginning in Febuary 2002.

In one interesting project, he is collaborating with USGS colleagues to examine evidence of catastrophic drainage of inland lakes created by glacial scraping and melting. One such lake was Glacial Lake Iroquois in what is now the Lake Ontario Basin located in the upstate New York area. Sedimentary evidence suggests that the northern retreat of glacial ice that was damming the lake allowed the lake water to rush down the Hudson River valley and out into the Atlantic, where the large, rapid surge of fresh water may have been a trigger for an abrupt climate change episode.

The pathway to Woods Hole probably began for MIT/WHOI Joint Program student Anna Cruse during a voyage aboard the University of Texas research vessel *Longhorn*. Though she was working on land-based geology problems in a master's program at the University of Missouri–Columbia, her advisor studied both rocks and oceanic sediments and invited her to join the cruise. "I was hooked on oceanography," she says.

Anna found the independence promised by the Joint Program curriculum attractive as a follow-on to the more structured academic setting of her master's work. "In the Joint Program, students are treated as colleagues," she observes.

With master's course work on her record, Anna needed just one year, rather than the usual two years, of classes when she arrived in summer 1997. She is in her fifth Joint Program year, scheduled to complete her Ph.D. in fall 2002, having taken some time off for the birth of her daughter Maia, who turned three in January. In a bit of tricky (although completely unplanned) timing, Anna defended her thesis proposal on January 8, 1999, and Maia arrived (two weeks early) on January 10. "Having supportive advisors in Jeff Seewald and my thesis committee members has made combining family and student life work well for me," Anna says.

Anna's research focuses on identifying and quantifying the concentrations and stable carbon isotopic composition of organic molecules in hydrothermal vent fluids from two sites on the Juan de Fuca Ridge (abut 35 miles off the coast of Vancouver) that have different geological characteristics. It will contribute knowledge about reactions between inorganic and organic substances in mid-ocean ridge systems, leading to a better understanding of water-sediment and water-basalt interaction in subseafloor environments. This information can then be applied to better understand the subsurface flow paths and chemical regimes in mid-ocean ridge systems. Anna participated in a summer 2000 *Atlantis* research voyage and made two dives in *Alvin* to collect samples for her thesis research.

She will be attending an invitation-only, government-agency-sponsored dissertation symposium for new Ph.D.s in May 2002, and she is looking at a variety of next-step possibilities. These include academic postdoctoral and junior faculty positions as well as industrial research. "At least we're not facing the challenge of finding two research positions," says Anna. "That's a real issue for many graduating Ph.D.s. Fortunately, my husband's sales career is very portable."

John Billings, McLane Research Laboratory

MIT/WHOI Joint Program student Anna Cruse, left, and Assistant Scientist Katrina Edwards wait to board *Alvin* on July 25, 2000, for dive 3597 to collect fluid samples from the Juan de Fuca Middle Valley hydrothermal vent field.

The success of the Institution's education programs depends on the efforts of many individuals working in concert over the years. It is with sadness that we note the passing on February 28, 2001, of Arnold Arons, a member of the Trustees' Committee whose work with Director Paul Fye led to establishment of a formal degree program at WHOI in 1967 and the MIT/WHOI Joint Program in 1968. Arnold's guidance for the Joint Program has been a significant factor in its success. To honor his contributions to Institution education programs, the Arnold B. Arons Award for Excellence in Teaching, Advising, and Mentoring will be conferred periodically to recognize the educational efforts of a WHOI Scientific or Senior Technical Staff member.

On a personal note, I miss Arnold and his thoughtful advice. I am comforted by the knowledge that his legacy lives on with the experience of each participant in WHOI's education programs, and especially with the graduates of the MIT/WHOI Joint Program.

–**John W. Farrington**, Associate Director for Education and Dean of Graduate Studies

One of WHOI's core values is declared forthrightly in our mission statement: "It is the goal of the Institution to be a world leader in advancing and communicating a basic understanding of the oceans and their decisive role in addressing global questions."

For decades, we've strived to achieve that—by means ranging from face-to-face conversations and publications to broadcasts over the Internet, for audiences ranging from congressional representatives on the Hill to kindergartners strolling in off the ferry with their grandparents. It is testimony to our success that so many and such varied audiences regularly come to us seeking knowledge of the oceans.

But in recent years, our message has become more urgent. Communications avenues have become far more numerous and complex, and our audiences are overwhelmed with competing information. To fulfill our mission, we have redoubled our outreach efforts, launching initiatives to harness an exploding assortment of media and venues. Here are some recent examples:

Logo for prize-winning Web site.

© Photo-Op, Inc.

Bob Weller, Director of the Cooperative Institute for Climate and Ocean Research, left, and Fred Grassle of Rutgers University testified on global ocean observing systems before a joint hearing of the House Science and Resources Committees.

Increasingly, the Internet has become the portal and public face of most organizations. Our new Web Communications team has implemented a thorough redesign of WHOI's Web site that makes www.whoi.edu more attractive, user-friendly, and rich in content. Behind the splash pages, the team is also setting up the necessary technological foundation to support rapidly expanding future Web communications efforts.

Cover of "ocean impact" publication.

To build new bridges with the media, WHOI established the Ocean Science Journalism Fellowship Program for professional science writers and editors. Journalists in a variety of media spend a week at WHOI, visiting labs, observing fieldwork, and participating in seminars with scientists who introduce them to a broad range of current and future oceanographic research and engineering. Fellows in 2000 and 2001 included journalists from *The New York Times*, *USA Today*, National Public Radio, the Associated Press, and *U.S. News & World Report.*

Extending efforts to Washington, an intensive, three-day symposium brought 15 key congressional staff to Woods Hole. The program highlighted important ocean issues where science and policy have strong connections, such as fisheries, climate change, coastal problems, and technology needs. The two-way exchange was lively with pointed questions and discussions.

WHOI scientists were called to give congressional testimony an impressive five times in 2001—on toxic waste dumping, harmful algal blooms, climate change, possible effects of sonar on marine mammals, and a global ocean observing system.

A facet of that system, the ARGO float program, received congressional funding with the help of information supplied in an ARGO brochure designed by WHOI at the request of the National Oceanic and Atmospheric Administration. WHOI Graphic Designer Jim Canavan received a Society for Technical Communication 2001–2002 Award of Excellence for the work.

WHOI Director and President Bob Gagosian also helped galvanize attention for a global ocean observing system and the societal imperative for ocean research in a *New York Times* op-ed piece in August 2001, headlined "What the Seas Can Offer." He also took that message to influential audiences, giving multimedia presentations to world leaders at the World Economic Forum and to world energy industry leaders at the Cambridge Energy Research Associates annual meeting.

We increased proactive outreach efforts in 2001 by publishing "Perhaps our planet should be called Ocean," a provocative, eye-catching brochure designed to stimulate awareness of the oceans' impact on our lives and WHOI's important work. Our Information, Education, and Sea Grant offices organized pilot Teacher Training Workshops, providing ocean-science-related information and teaching materials to teachers who, in turn, spread the message to students, their students' parents, other educators, and community leaders and legislators.

WHOI also joined 13 other premier

research institutions providing Web-based information and seminars for fathom.com, the online education venture launched by Columbia University. Other fathom.com member institutions include the British Museum, Cambridge University Press, the New York Public Library, and the RAND Corporation.

In 2001, WHOI also formalized a decades-long relationship with the National Geographic Society (NGS) to provide scientific stories and images for NGS's new cable channel and Web site, as well as its traditional magazine and television production group. WHOI and NGS together produced public service announcements promoting WHOI and ocean research for airing on the NGS channel.

Another partnership with BBH Exhibits, Inc. (now part of Clear Channel Entertainment) resulted in "Extreme Deep—Mission to the Abyss," a traveling museum exhibit highlighting WHOI research. With 2001 venues in North Carolina, Oklahoma, and Mexico, the number of Extreme Deep visitors taking the opportunity to learn about deep-ocean exploration totals well over a million. And back at Woods Hole, we have made improvements to our Exhibit Center, which receives 25,000 to 30,000 visitors each year.

One of 2001's highlights, the Dive and Discover Web site, demonstrates the team effort required to create and execute successful, broad-based outreach campaigns. Our Web, Publications, and Graphics staff worked with scientists to create a rich body of accessible information on deep-sea research for broad and diverse audiences. Our Information and Sea Grant staff enlisted teacher participation in Dive and Discover, and more than 10,000 students in 22 US states, Canada, Great Britain, Guam, and the Seychelles followed Expedition 4 in their classrooms. We partnered with COSI Toledo (Ohio's Center of Science and Industry) to develop and distribute a free "educators' companion," explaining the science and technology behind the cruise and providing classroom activities to help students create their own experiments. We also partnered with NASA to orchestrate a joint Webcast, leveraging NASA's large (1 million hits/month) audience.


Tom Kleindinst

Oceanographer Emeritus Graham Giese, holding tube, and Senior Scientist Stan Hart, third from left, led a coastal processes discussion during a lunchtime walk with congressional staff attending a June symposium in Woods Hole.

Dive and Discover reached a large audience, peaking March 26 during Expedition 4 with 170,000 hits! *Yahoo.com*, *The Wall Street Journal*, and *Scientific American* all identified it as a top site for earth and environmental science information. Dive and Discover—as well as WHOI's Web site—*each* received nominations for 2001 Webby Awards (considered the "Oscar" of the Web). A "Web Source" review in the American Geophysical Union's *Eos* called it a "virtual treasure chest of deep sea science and classroom resources."

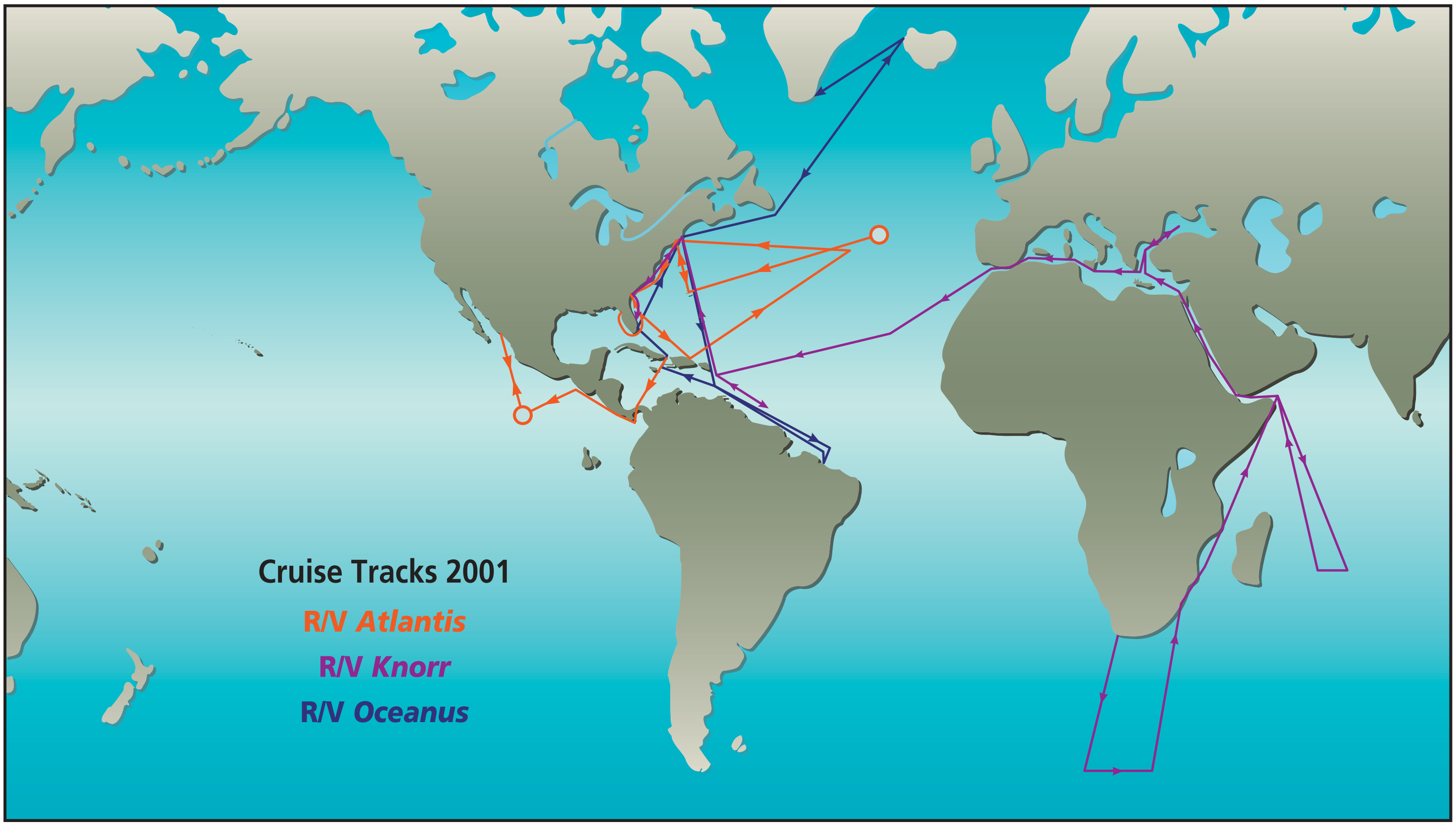
As we look ahead, we are conceiving and launching a variety of innovative communications initiatives with our newly established Ocean Institutes, whose mission includes a concerted effort to convey the results of oceanographic research to policy makers and the public.

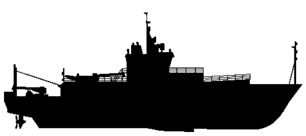
We feel strongly that our future depends on understanding our oceans. Therefore, it also depends on getting that message out to the widest possible audience.

—**Jacqueline M. Hollister**, Associate Director for Communications, Development, and Media Relations


Shelley Lauzon

Atlantis was part of a fall public outreach and education event sponsored by the National Oceanic and Atmospheric Administration Office of Ocean Exploration in Charleston, South Carolina. *Alvin* Group members Brian Leach, left, and Jason Stephens introduce a school group to the submersible.





R/V *Atlantis* & DSV *Alvin*

Total Nautical Miles in 2001—23,751 • Total *Alvin* Dives in 2001—91 • Total Days at Sea—218

Voyage	*Cruise Period*	*Cruise Objective/Area of Operation*	*Ports of Call*	*Chief Scientist*
4-I	27 Dec'00–2 Jan'01	Transit	Tampa	
4-II	11 Feb–18 Feb	Supporting Littoral Warfare Advanced Development (LWAD) systems testing with deployment of the Navy's TB-16 array, acoustic Doppler current profiles (ADCPs), CTDs and XBTs. 32°45′N, 78°10′W.	Charleston	E. Thiel, Naval *Air Warfare Center*
4-III	26 Feb–2 Mar	Transit	San Juan, P.R.	
4-IV	6 Mar–31 Mar	Recover and redeploy six hydrophone moorings along the Mid-Atlantic Ridge; deploy towed camera system and make SeaBeam survey. 15°30′N, 24°50′W.	Woods Hole	D. Smith
5-I	14 Jun–17 Jun	Over-the-side testing of *DSL-120* during transit.	St. George's Bermuda	B. Walden
5-II–5-IID	19 Jun–24 Jun	Test Certification and engineering dives for *Alvin*. At dock, 1 dive. Leg 5-IIA, 6 dives. Leg IIB, 1 dive. Leg IIC, 1 dive. Leg IID, 1 dive	St. George's Bermuda	B. Walden
5-III	26 Jun–Jul 29	Sampling at vent sites along the Mid-Atlantic Ridge for mussel bed biodiversity studies and recovery of data at ODP Borehole site #395A. CTDs and SeaBeam surveys. 17 *Alvin* dives.	Ponta Delgada, Azores	C. Van Dover *William and Mary*
5-IV	4 Aug–30 Aug	Collect images of hydrothermal vent and environments with IMAX and HDTV camera systems at TAG (26°08′N, 44°49′W) and Lost City (30°00′N, 42°00′W) vent sites and at a site near Bermuda Islands. 18 *Alvin* dives.	St. George's, Bermuda	R. Lutz *Rutgers U*
5-V–5VI	1 Sep–3 Sep	Sample deep escarpments for living and fossil deep-sea corals northeast of St. George's harbor entrance. 2 *Alvin* dives on 1 Sep, 1 *Alvin* dive on 2 Sep.	St. George's, Bermuda	B. Walden

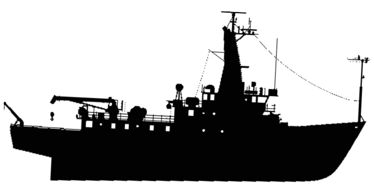
5-VII	3 Sep–5 Sep	Transit	Woods Hole	B. Walden
6-IA	9 Sep–15 Sep	Study diversity of coral communities in Oceanographer, Lydonia, and Hydrographer Canyons and Bear and Physalia Seamounts focusing on their reproductive, class size distribution, habitat, and genetic characteristics. 2 *Alvin* dives.	Woods Hole	L. Watling *U Maine*
6-IB	16 Sep–21 Sep	Explore deep-sea diversity in Hudson Canyon and the effects of past dumping activities at Deep Water Dumpsite 106. 5 *Alvin* dives.	Woods Hole	F. Grassle *Rutgers U*
7-I	22 Sep–30 Sep	Study mussel bed diversity and chemosynthetic bacterial mats and collect multibeam bathymetry data on Inner Blake Ridge. 32˚30′N and 76˚11′W. 4 *Alvin* dives.	Charleston	C. Van Dover *William and Mary*
7-II	2 Oct–10 Oct	Transit	Puntarenas, Costa Rica	D. Sims
7-III	15 Oct–1 Nov	Collect filamentous epibiotic bacteria for gene characterization and phenotypic analyses; deploy PLASMA Plankton Pump. East Pacific Rise near 9˚N, 105˚W. 12 *Alvin* dives.	Manzanillo Mexico	C. Cary *U Delaware*
7-IV	5 Nov–3 Dec	Near-bottom mapping of the Central Axial Magnetic High on the East Pacific Rise. Eight days of *DSL-120* surveying and *ABE* deployment; rock dreding and gravity coring. East Pacific Rise near 9˚N, 104˚W.	Manzanillo, Mexico	H. Schouten
7-V	9 Dec–1 Jan '02	Conduct biological studies of vent communities and collect biological samples for laboratory studies. East Pacific Rise near 9˚N, 104˚W. 20 *Alvin* dives.	Manzanillo, Mexico	C. Fisher *Penn State*

R/V *Knorr*

Total Nautical Miles in 2001—35,888 • Total Days at Sea—250

Voyage	*Cruise Period*	*Cruise Objective/Area of Operation*	*Ports of Call*	*Chief Scientist*
162-VII	8 Dec'00-5 Jan'01	Swath mapping of the Southwest Indian Ridge to acquire multi-beam, gravity, and magnetic data; rock dredging. 51˚54′S, 9˚22′E.	Cape Town, S. Africa	H. Dick
162-VIII	7 Jan–10 Jan	Second Southwest Indian Ridge cruise.	Cape Town, S. Africa	H. Dick
162-IX	11 Jan–30 Jan	Third Southwest Indian Ridge cruise.	Durban, S. Africa	H. Dick
162-X	4 Feb–11 Feb	Transit	Mombasa, Kenya	R. Laird
162-XI	11 Feb–15 Mar	Study pathways, structure, and variability of Red Sea outflow water as it leaves the Red Sea through the Bab-al-Mandab Strait and spreads into the Gulf of Aden and Indian Ocean using CTD casts, acoustic Doppler current profilers (ADCPs), RAFOS float deployments, and short-term moorings. Western Gulf of Aden.	Victoria, Seychelles	W. Johns *U Miami*
162-XII	24 Mar–27 Mar	Transit to Port Louis to mobilize Deep Submergence Operations Group container vans.	Port Louis, Mauritius	C. Van Dover *William and Mary*
162-XIII	30 Mar–1 May	Extensive surveys of Central Indian Ridge hydrothermal vent communities including mapping and biological sampling of vent fluids and plumes using WHOI vehicles *Jason, DSL-120,* and *Argo II*; CTD casts, rock dredging, coring; SeaBeam and magnetometer and gravimeter data collection. 18˚25′S, 65˚70′E.	Port Louis, Mauritius	C. Van Dover *William and Mary*
162-XIV	2 May–5 May	Transit	Victoria, Seychelles	C. Van Dover, *W&M*
162-XV	7 May–20 May	Transit with collection of XBT profiles and SeaBeam and acoustic Doppler current profiler data.	Istanbul, Turkey	B. Walden
162-XVI	23 May–1 Jun	Study water column geochemistry in the suboxic zone located at 100 meters and complete water column geochemistry from surface to 2100 meters; collect water and net samples for characterization of biological food web; obtain sediment cores for geochemical analyses. Black Sea/Western Basin.	Istanbul Turkey	J. Murray *U Washington (UW)*

162-XVII	1 Jun–10 Jun	Second geochemistry cruise.	Istanbul, Turkey	J. Murray, *UW*
162-XVIII	13 Jun–22 Jun	Transit and collect surface plankton samples.	Las Palmas, Grand Canary Island	E. Goetz *Scripps*
162-XIX A, B, C	25 Jun–24 Jul	Studies of nitrogen and carbon cycling in upper water column; CTD casts, MOCNESS tows, OPTIC cage deployments, recover/redeploy sediment trap moorings. 30˚N, 45˚W to 10˚N, 45˚W.	Bridgetown, Barbados	D. Capone *U Southern California*
162-XX	25 Jul–17 Aug	Second nitrogen/carbon cycling cruise. 15˚N to 5˚N and 38˚W to 60˚W.	Bridgetown, Barbados	E. Carpenter *San Francisco State U* A. Subramaniam *U Maryland*
162-XXI	21 Aug–27 Aug	Transit	Woods Hole	R. Laird
163	24 Sep–27 Sep	Mechanical trials of the Lightweight Broadband Variable Depth (LBVDS) ODIM winches, and overboarding system. 39˚20'N, 70˚50'W.	Woods Hole	M. Simard, *Naval Undersea Warfare Center (NUWC)*
164-I	5 Oct–8 Oct	LBVDS trials.	Charleston	M. Simard, *NUWC*
164-II	9 Oct–23 Oct	Demonstration sea test of the LBVDS; tow sonar fish and acoustic array. 32˚30'N, 78˚30'W.	Charleston	M. Simard, *NUWC*
164-III	23 Oct–26 Oct	Hydrocasts along transit track to Woods Hole.	Woods Hole	M. Simard, *NUWC*
165	6 Nov–10 Nov	Sea trial for GLAD-800 drill apparatus. 40˚N, 70.5˚W.	Woods Hole	G. Mountain, *LDEO*
166-I	30 Dec–3 Jan 2002	Acoustic Doppler current profiler tests during transit.	Fort Lauderdale	F. Bahr



R/V *Oceanus*

Total Nautical Miles in 2001—35,633 • Total Days at Sea—239 days

Voyage	*Cruise Period*	*Cruise Objective/Area of Operation*	*Ports of Call*	*Chief Scientist*
365-I	5 Jan–12 Jan	Transit from Woods Hole to Bridgetown, Barbados	Bridgetown, Barbados	L. Goepfert
365-II	15 Jan–12 Feb	Salt Finger Tracer Release Experiment survey of sub-surface mixed layers; CTD high resolution profiler and RAFOS float deployments; XBTs. 12˚N, 54˚W.	Bridgetown, Barbados	R. Schmitt
365-III	16 Feb–1 Mar	Study variability of Antarctic bottom water as it flows into the North Atlantic using CTDs, moored instruments, and drifting floats. 15˚N, 55˚W and 1˚N, 36˚W to 1˚S, 36˚W.	Fortaleza Brazil	R. Limeburner
365-IV	5 Mar–25 Mar	Study interaction between off-equatorial currents and the Equatorial Undercurrent using CTDs, ADCP surveys, deployment of 10 PALACE floats and 6 surface drifters. Western Tropical Atlantic from 5˚S to 12˚N and 36˚W to 62˚W.	Bridgetown, Barbados	R. Molinari C. Schmid *NOAA/AOML*
365-V	28 Mar–8 Apr	Detemine in-situ air-sea fluxes of heat, moisture, and memomentum in the Northwest Tropical Atlantic for comparison with operational models; measure structures of eastward flow of bottom and deep waters through Vema Fracture Zone for VEX project; CTDs, ADCP surveys, and mooring deployments. Tropical Atlantic east of Barbados near 11˚N, 43˚W to 15˚N, 51˚W.	Bridgetown, Barbados	A. Plueddemann M. McCartney
365-VI	10 Apr–17 Apr	Measure the transport and water mass properties of the upper ocean flow between the Atlantic Ocean and the Caribbean Sea. CTD survey and diving operations along an inter-island cruise track through the Caribbean.	St. Thomas, Virgin Is.	W.D. Wilson *NOAA/AOML*
365-VII	18 Apr–19 Apr	Second transport and water mass property cruise.	St. Thomas, Virgin Is.	R. Watlington *U Virgin Is.*
365-VIII	20 Apr–23 Apr	Transit	Miami	S. Eykelhoff

365-IX	26 Apr–7 May	Time series observations to measure the current transport and water mass properties east of Abaco, Bahamas, in support of the CLIVAR -Atlantic climate variability studies; CTD and ADCP survey in the Florida Straits and Northwest Providence Channel near Abaco Island.	Miami	M. Baringer *NOAA/AOML*
365-X	10 May–30 May	Examine high levels of nitrate in subsurface waters in the Caribbean and Sargasso Seas to improve understanding of cycling of major elements in the ocean. CTDs to 1,000 meters.	Woods Hole	D. Hansell *U Miami*
366	5 Jun–14 Jun	Repeat earlier large-scale survey to compare evolution of plankton bloom distribution, vertical migration behavior, and frontal dynamics of the toxic dinoflagellate, *Alexandrium*; perform fluorescent dye release to observe fate and dynamics of *Alexandrium* cell patch over 2–3 day period; CTD casts ADCP survey, and tow sled through dye patch. Western Gulf of Maine.	Woods Hole	J. Churchill
367	18 Jun–29 Jun	Sea surface micro-layer chemical study along biological productivity gradient; deploy semi-autonomous SCIMS catamaran for chemical mapping of surface films; CTD casts, ADCP survey; Zodiac operations to collect uncontaminated seawater. US Continental Shelf southeast of Woods Hole.	Woods Hole	N. Frew
368	3 Jul –16 Jul	Map extent of salp populations and collect animals for shipboard experiments; open-water scuba diving for biological sampling, CTDs, tucker trawls, and plankton net tows. US continental shelf and slope waters southeast of Woods Hole.	Woods Hole	L. Madin
369-I	20 Jul–29 Jul	Deploy two moorings. 59˚N, 40˚W.	Reykjavik, Iceland	S. Worrilow
369-II	1 Aug–27 Aug	Conduct CTD/ACDP survey and other operations in the Irminger Sea to observe deep convection and quantify basinwide circulation. Irminger Sea, East Coast of Greenland and Denmark Straits.	Reykjavik, Iceland	R. Pickart
369-III	31 Aug –9 Sep	Transit	Woods Hole	
370	14 Sep–26 Sep	Map salp populations and collect animals for shipboard experiments; open water scuba diving for biological samples plus CTDs, tucker trawls, and plankton net tows. U.S. continental shelf and slope waters southeast of Woods Hole.	Woods Hole	L. Madin
371	4 Oct–6 Oct	Initiate "Station W"—a long-term ocean time series station on the continental slope south of Woods Hole; deploy moored profiler and conduct CTD section from the 4,000 meter isobath offshore to onshore of the shelf break. 30˚N and 69˚W.	Woods Hole	J. Toole
372-I	11 Oct–15 Oct	Transit to Atlantic Drydock	Jacksonville	
372-II	2 Dec–5 Dec	Transit	Woods Hole	

David Fischella

R/V *Knorr* spent several months in the Indian Ocean early in 2001.

Trustees & Corporation Members

Tom Kleindinst

Clockwise from left, Peter McCormick, Coley Burke, Arthur Allen, Frank Snyder, and Tom Devine enjoy a lunchtime discussion during the October 2001 Trustee and Corporation meetings.

Tom Kleindinst

Dana Yoerger talks with Corporation partner Bob Ducommun following the May 2001 annual meetings of the Trustees and Corporation.

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Ship's crew, *Alvin* group members, and others in the scientific party line the rail as *Atlantis* leaves Woods Hole June 13, 2001, for *Alvin* sea trials near Bermuda following the sub's regular overhaul period.

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Tom Kleindinst

John Toole, right, describes the moored profiler to Vice Admiral Conrad Lautenbacher Jr., USN (Ret.), who visited WHOI in August 2001 during his term as president of the Consortium for Oceanographic Research and Education.

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Bruce R. Woodin
Research Associate III

David Fisichella

Amy Bower, shown here aboard R/V *Knorr*, with the Seychelles shoreline in the background, had two cruises to the Indian Ocean during 2001 for REDSOX (Red Sea Outflow Experiment).

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David G. Aubrey
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Tim Duda, foreground, and Clayton Jones of Webb Research Corporation unload shear meter floats aboard *Oceanus* at the WHOI pier in preparation for work in the Guiana Basin.

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Ocean and Climate Change Institute Director Bill Curry, left, explains the use of sediment cores in paleoceanography to visiting professional staff member Chris Miller of the US Senate Committee on Environment and Public Works.

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Jayne Doucette

Carpenters Sonny Cummings, left, and Craig Henderson and machinist John Fetterman, right, watched *Atlantis*'s June 13 departure from the Iselin Facility south mezzanine.

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Matt Gould, left, Andy Girard, and Amy Kukulya run tests on Scott Gallager's Autonomous Vertically Profiling Plankton Observatory.

Tom Kleindinst

Tom Kleindinst

Carol Hampton, Management Information Services, was honored for 40 years' service to WHOI at the fall Employee Recognition Ceremony. She is flanked at the lectern by Director and President Bob Gagosian and Human Resources Manager Kathy LaBernz.

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Illustrator Paul Oberlander works on an ocean life mural in the Exhibit Center courtyard as visitors approach the lower-floor entrance.



Photos by Tom Kleindinst

Senior Plant Mechanic Charlie Olson, at left with wife Brenda, received the 2001 Vetlesen Award for a variety of exceptional contributions to the WHOI community over a long period of time. Members of the R/V *Knorr* crew, represented in the center photo by Chief Engineer Steve Walsh, were named winners of the Penzance Award for overall exceptional performance, WHOI spirit, and contributions to the personal and professional lives of Institution staff. Associate Director for Marine Operations Dick Pittenger is at the lectern. The Linda Morse-Porteous Award for leadership, mentoring, dedication to work, and involvement in the WHOI community went to Information Systems Associate Debbie Shafer, shown at right receiving congratulations from Annda Flynn.

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John J. Cartner
Charles Clemishaw
Thomas N. Colon
Marc A. Costa
John A. Crobar
Robert M. Crowley
William B. Cruwys
Rowland N. Cummings
Judith O. Cushman
Elizabeth S. Delaney
Peter P. Delorey
Kirk Dirubio
Geoffrey K. Ekblaw
John Fetterman
Michael J. Field
Jason E. Gaudet
Damon E. Gayer
Edward S. Good
Billy Guest
David S. Hamblin

Tom Kleindinst

Captain A.D. Colburn, left, consults with Steve Page on *Knorr*'s bridge.

Patrick J. Harrington
Craig T. Henderson
Robert W. Hendricks
J. Kevin Kay
Fred W. Keller
Troy Kelley
Raymond G. Kimball
Remmert H. Kokmeyer
Donald C. LeBlanc
Paul E. LeBlanc
Wendy W. Liberatore
Pamela A. Lopez
Keith A. Mann
Robert A. McCabe
Napoleon McCall Jr.
Carlos A. Medeiros
Norman E. Morrison
Jose S. Mota
Jay R. Murphy
John R. Murphy
Charles A. Olson
Sheila T. Payne
David C. Peterson
Vasco Pires
Dennis J. Reardon
Jeremy T. Roache
John P. Romiza
Lewis J. Saffron
Michael J. Sawyer
Robert W. Schreiter
Daniel L. Slevin
Steven P. Solbo
William F. Sparks
Robert G. Spenle
Mark L. St. Pierre
Anne Marie Taylor
Kevin D. Thompson
Robert Wichterman
Bonnie L. Woodward

David Fisichella

Medic Janet Costello left, and Shipboard Scientific Services Technician Amy Simoneau enjoy a break during a *Knorr* port call in the Indian Ocean.

Alvin and Marine Operations Staff

Jonathan C. Alberts
Marine Operations Coordinator

Courtenay Barber III
Chief Mate, R/V Oceanus

Richard C. Bean
Third Mate, R/V Atlantis

Lawrence T. Bearse
Master, R/V Oceanus

Michael P. Brennan
Marine Personnel Coordinator

Richard S. Chandler
Submersible Operations Coordinator

Richard P. Chase II
Second Mate, R/V Oceanus

Gary B. Chiljean
Master, R/V Atlantis

Carl H. Christensen
Chief Mate, R/V Atlantis

Joseph L. Coburn Jr.
Ship Operations Manager

Arthur D. Colburn III
Master, R/V Knorr

Margaret M. Crane
Chief Mate, R/V Atlantis

Sallye A. Davis
Third Mate, R/V Atlantis

Craig D. Dickson
Second Mate, R/V Atlantis

Richard S. Edwards
Port Captain

Deidra L. Emrich
Third Mate, R/V Knorr

Kevin C. Fisk
Chief Engineer, R/V Atlantis

Larry D. Flick
Marine Operations Administrator

Philip E. Forte
Deep Submergence Vehicle Pilot

Lynn Griffin
Administrative Associate I

Christopher L. Haines
First Assistant Engineer, R/V Atlantis

K.I. Faith Hampshire
Center Administrator I

J. Patrick Hickey
Deep Submergence Vehicle Expedition Leader

Jeffrey Little
First Assistant Engineer, R/V Atlantis

Timothy P. Logan
Communications Officer, R/V Atlantis

J. Douglas Mayer
Second Mate, R/V Knorr

Anthony D. Mello
Second Mate, R/V Oceanus

Patrick S. Mone
First Assistant Engineer, R/V Knorr

Theophilus Moniz III
Marine Engineer

Christopher D. Morgan
First Assistant Engineer, R/V Knorr

Richard F. Morris
Chief Engineer, R/V Oceanus

David I. Olmsted
Boat Operator

Terrence M. Rioux
Diving Safety Officer

James A. Schubert
Second Assistant Engineer, R/V Atlantis

Adam B. Seamans
Third Mate, R/V Knorr

Kent D. Sheasley
Third Mate, R/V Knorr

George P. Silva
Chief Mate, R/V Atlantis

Wallace C. Stark
Fleet Planning Officer

William B. Strickrott
Deep Submergence Vehicle Pilot

Wayne A. Sylvia
Second Assistant Engineer, R/V Knorr

Barrie B. Walden
Manager, Operational Science Services

Tom Kleindinst

Ed Popowitz aboard *Knorr* hands a line off to Larry Costello as the ship ties up in Woods Hole in August 2001.

Stephen A. Walsh
Chief Engineer, R/V Knorr

Ernest C. Wegman
Port Engineer

William R. White
Third Mate, R/V Knorr

Robert L. Williams
Chief Deep Submergence Vehicle Pilot

Alvin and Marine Operations Support Staff

Wayne A. Bailey
Linda J. Bartholomee
Matthew L. Bartlett
Harold A. Bean
Brett S. Bluestein
Nelson L. Botsford
Leonard Boutin
Kevin D. Butler
Leonidas Byckovas
Sherry H. Carton
John A. Cawley
Michael J. Conda
Alden Cook
Barbara L. Costello
Christina Courcier
Michael R. Doherty
William J. Dunn Jr.
Gavin Eppard
Edwin A. Estaniel
Steven J. Eykelhoff
Laura Goepfert
Allan G. Gordon
Jerry M. Graham
Edward F. Graham Jr.
Jay Grant
Patrick J. Hennessy
Marjorie M. Holland
Alan J. Hopkins
Orville B. Kenerson
Robbie Laird
Brian Leach
Peter T. Leonard
Charles R. Lewis
Manuel P. Lopes
Timothy P. Logan
Piotr Marczak
Eduwiges L. Martinez
Noel Masias
James M. McGill
Todd D. Meeker
Mirth N. Miller
Christopher Moody
Igor V. Myachin
Brian M. O'Nuallain
Stephen G. Page
Edward S. Popowitz
Kenneth W. Rand
Victoria R. Simms
Amy Simoneau
David Sims
Jeffrey M. Stolp
Keith L. Strand
Linwood J. Swett
Anthony Tarantino
Philip M. Treadwell
Paul A. Vinitsky
Colin L. Walcott
Carl O. Wood

2001 Retirees

Richard E. Payne
Hélène J.H. Longyear
Norman E. Morrison
Barbara Gaffron
Judith O. Cushman
John Porteous
Herman Wagner
Alden H. Cook
Margaret M. Walden

Degree Recipients

Doctor of Philosophy

Shannon M. Bard
Université de Nantes, France, Diploma
Stanford University
Special Field: Biological Oceanography
Dissertation: Characterization of P-glycoprotein Expression as a Multixenobiotic Resistance Mechanism in Fish

Jennifer E. Georgen
University of Virginia, Charlottesville
Special Field: Marine Geophysics
Dissertation: Interactions between Mantle Plumes and Mid-Ocean Ridges: Constraints from Geophysics, Geochemistry, and Geodynamical Modeling

Allegra Hosford-Scheirer
Brown University
Special Field: Marine Geophysics
Dissertation: Crustal Accretion and Evolution at Slow and Ultra-Slow Spreading Mid-Ocean Ridges

Nicole Poulton
Virginia Polytechnic Institute
Special Field: Biological Oceanography
Dissertation: Physiological and Behavioral Diagnostics of Nitrogen Limitation for the Toxic Dinoflagellate Alexandrium fundyense (Dinophyceae)

Makoto Saito
Oberlin College
Special Field: Chemical Oceanography
Dissertation: The Biogeochemistry of Cobalt in the Sargasso Sea

Paulo Salles
National Autonomous University of Mexico
MIT/WHOI Joint Program, SM
Special Field: Oceanographic Engineering
Dissertation: Hydrodynamic Controls on Multiple Tidal Inlet Persistence

Mario R. Sengco
Long Island University, Southampton
Special Field: Biological Oceanography
Dissertation: The Aggregation of Clay Minerals and Marine Microalgal Cells: Physicochemical Theory and Implications for Controlling Harmful Algal Blooms

Alexandra H. Techet
Princeton University
Special Field: Ocean Engineering
Dissertation: Experimental Visualization of the Near Boundary Hydrodynamics About Fish-Like Swimming Bodies

Rebecca E. Thomas
Duke University
Special Field: Biological Oceanography
*Dissertation: Relating Behavioral Context to Acoustic Parameters of Bottlenose Dolphins (*Tursiops truncatas*) Vocalizations*

Joseph D. Warren
Harvey Mudd College
Special Field: Applied Ocean Sciences
Dissertation: Estimating Gulf of Maine Zooplankton Distributions Using Multiple Frequency Acoustic, Video and Environmental Data

Wen Xu
University of Science & Technology of China
Institute of Acoustics, China, MS
MIT/WHOI Joint Program, SM
Special Field: Ocean Engineering
Dissertation: Performance Bounds on Matched-Field Methods for Source Localization and Estimation of Ocean Environmental Parameters

Master of Science

Juan Botella
School of Marine Sciences, Mexico
Autonomous University of Baja, California, Mexico, MS
Special Field: Physical Oceanography
Dissertation: Mesoscale Variability and Mean Flow Interaction Near the Gulf Stream as Seen by Satellite Altimetry and Numerical Modelling

Heather E. Deese
Georgetown University
Special Field: Physical Oceanography
Dissertation: Chaotic Advection and Mixing in a Eastern Boundary Current-Recirculation System: Laboratory Experiments

Christie L. Haupert
University of Minnesota
Special Field: Chemical Oceanography
Dissertation: A Seasonal Study of Alkaline Phosphatase Activity in a Coastal Cape Cod Pond

Jody Katrein
Maine Maritime Academy
Special Field: Ocean Engineering
Dissertation: Evaluation of Transport Relative to the Tidal Mixing Front on Southern Georges Bank

Sarah Marsh
Rice University
Special Field: Biological Oceanography
Dissertation: Morphometric Analyses of Ears in Two Families of Pinnipeds

Amy R. McKnight
Colgate University
Special Field: Marine Geophysics
Dissertation: Structure and Evolution of an Oceanic Megamullion on the Mid-Atlantic Ridge at 27˚N

Timothy J. Prestero
University of California, Davis
Special Fields: Ocean Engineering and Mechanical Engineering
Dissertation: Verification of a Six-Degree of Freedom Simulation Model for the REMUS AUV

Anna Fortunato Rhodes
Massachusetts Institute of Technology
Special Field: Biological Oceanography
Dissertation: Nutritional Factors and Toxic Trace Metals Affecting Growth of the Marine Cyanobacterium Prochlorococcus

Matthew B. Sullivan
Long Island University
Special Field: Biological Oceanography
Dissertation: Prochlorococcus cyanophage*: Isolation, Characterization, and Natural Abundances*

Erin N. Sweeney
Virginia Polytechnic Institute
Special Field: Chemical Oceanography
Dissertation: Monthly Variability in Upper Ocean Biogechemistry due to Mesoscale Eddy Activity in the Sargasso Sea

Alison E. Walker
University of Sydney, Australia
Special Field: Physical Oceanography
Dissertation: Linear Normal Mode Analysis of Baroclinic Instability in a Meridional Channel

Degree Statistics

	2001	1968–2001
WHOI Ph.D.	0	4
MIT/WHOI Ph.D.	11	415
MIT/WHOI Sc.D.	0	32
MIT/WHOI Engineer	0	55
MIT/WHOI S.M.	11	125
MIT/WHOI M.Eng.	0	4
Total Degrees Granted	22	635

MIT/WHOI Joint Program 2001-2002 Fall Term

AmyMarie Accardi-Dey
Rensselaer Polytechnic Institute

Erik J. Anderson
Gordon College

Claudia A. Augusto Martins
Faculdade de Ciencias de Universidade de Lisboa, Portugal

Mark D. Behn
Bates College

Bridget A. Bergquist
University of Wisconsin

Margaret S. Boettcher
Brown University

Christopher G. Bohner
North Carolina State University

Katie Rose Boissoneault-Cellineri
University of Massachusetts, Dartmouth
MIT/WHOI Joint Program, SM

Michael G. Braun
Brown University

Rosemarie E. Came
Boston College, BS, MS

Regina P. Campbell-Malone
State University of New York, Buffalo

Susan J. Carter
Harvard University

Mea Young S. Cook
Princeton University

Anna M. Cruse
University of Missouri, BS, MS

Kristina A. Dahl
Boston University

Brian J. DeMartin
Georgia Institute of Technology, BS, MS

Amy G. Draut
Tufts University

Nicholas J. Drenzek
Rensselaer Polytechnic Institute

Donald P. Eickstedt
Michigan Technological University
Johns Hopkins University, MS

Amy C. Englebrecht
Lake Superior State University

Ryan M. Eustice
Michigan State University

J. Thomas Farrar
University of Oklahoma BA, BS

Melanie R. Fewings
Western Washington University
Cornell University, MS

Baylor T. Fox-Kemper
Reed College
Brandeis University, MS

Heidi L. Fuchs
University of Wisconsin, Madison
University of Wyoming

Masami Fujiwara
University of Alaska, BA, MS

Geoffrey A. Gebbie
University of California, Los Angeles

Annette F. Govindarajan
University of Connecticut BS, MS

Carolyn M. Gramling
University of Pennsylvania
Florida International University

Rebecca E. Green
California Institute of Technology

Kristin E. Gribble
Lawrence University

Lara K. Gulmann
University of California, Berkeley

Jennifer A. Hammock
Massachusetts Institute of Technology

Heather M. Handley
James Cook University, Australia

Marc A. Hesse
Technische Universität, Munchen, Germany
University of Edinburgh, Scotland

Fernanda G. Hoefel
Universidade Federal do Rio de Janeiro, Brazil, BS, MS

Qiao Hu
University of Science & Technology of China, BS, MS

Jason Hyatt
University of Pennsylvania
University of California, Berkeley, MS

Michael V. Jakuba
Massachusetts Institute of Technology

Robert M. Jennings
University of Michigan

Markus Jochum
Universität Des Saarlandes, Germany
Universität Kiel, Germany

Seth G. John
Carleton College

Linda H. Kalnejais
University of Western Australia, BS, BE

Robyn K. Kelly
University of South Carolina

Shinichiro Kida
University of Tokyo, Japan

Tin Klanjscek
University of Zagreb, Croatia

Petra Klepac
University of Zagreb, Croatia

Vanja Klepac
Beloit College

Andrea L. Kraay
George Mason University

Astri J. Kvassnes
University of Bergen, Norway, BS, MS

Joy M. Lapseritis
Smith College, BA, MS

Gareth L. Lawson
McGill University, Canada
Memorial University of Newfoundland, Canada, MS

Stephen C. Licht
Yale University

Emily L. Lilly
Smith College

Weichang Li
Harbin Ship Building Institute, PRC, BS, MS
Massachusetts Institute of Technology, SM

Xingwen Li
University of Science & Technology of China

Ana Lucia L. Lima
Universidade do Estado do Rio de Janeiro, Brazil
Universidad Politecnica de Catalunya, Spain, MS

David C. Lund
Carleton College
Oregon State University, MS

Wenyu Luo
Ocean University of Qingdao, PRC
Institute of Acoustics, CAS, MS

William J. Lyons
Connecticut College
University of Wyoming, MS

Daniel G. MacDonald
University of New Hampshire
Cornell University, MS

Matthew C. Makowski
State University of New York, Binghamton

Amanda A. McDonald
University of North Carolina
Michigan State University, MS

Carlos F. Moffat
Universidad de Concepción, Chile, BS, MS

Eric W. Montie
University of Rhode Island
Clemson University, MS

Andrew D. Mosedale
Harvard University
Cooper Union
Rutgers University, MS

Rajesh R. Nadakuditi
Lafayette College

Mitchihiro Ohiwa
University of Tokyo, Japan

Payal P. Parekh
University of Michigan

Susan E. Parks
Cornell University

Yale J. Passamaneck
University of California, Santa Cruz

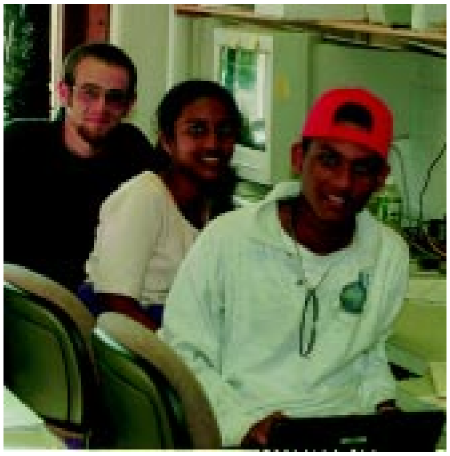
Oscar R. Pizarro
Universidad de Concepción, Chile, BS, MS

Diane K. Poehls
University of California, Santa Barbara

Travis L. Poole
Luther College

Jayne Doucette

Joint Program students say farewell as they leave aboard Sea Education Association's *Westward* for the annual new student summer cruise.



Photos by Tom Kleindinst

The Education Office was host in September 2001 for the International Worldwide Young Researchers for the Environment 10-day research camp sponsored by Deutsche Bank and Jugend forscht. Seven national competition prize winners, including, left to right, Peter Adamik of Slovakia and Nancy Cardinez and Maurice Oudith, both of Trinidad and Tobago, participated in a range of oceanographic activities, including a coastal collecting trip (photo at right).

Welkin H. Pope
Massachusetts Institute of Technology

Timothy J. Prestero
University of California, Davis

Tracy M. Quan
University of California, San Diego

Rebecca A. Rapoza
Dartmouth College
Humboldt State University, MA

Linda L. Rasmussen
California State University
Mexico State University, MA
Florida State University, MS

D. Benjamin Reeder
Clemson University

Matthew K. Reuer
Carleton College

Christopher N. Roman
Virginia Polytechnic Institute
University of California, San Diego, MS

Sarah L. Russell
Pomona College

James J. Ruzicka
Oregon State University
University of Hawaii, MS

Cara M. Santelli
University of Wisconsin

Theodore H. Schroeder
University of Missouri

Sheri L. Simmons
Princeton University

Emily F. Slaby
Carnegie Mellon University

Luiz A. Souza
Faculdade da Cidade, Brazil
Naval Postgraduate School, Brazil, MS

J. Jeffrey Standish
Colgate University
University of Idaho, MS

Rachel Stanley
Massachusetts Institute of Technology

Charles A. Stock
Princeton University
Stanford University, MS

Matthew B. Sullivan
Long Island University
MIT/WHOI Joint Program, SM

Fabian J. Tapia
Universidad de Concepción, Chile, BS, MS

Janelle R. Thompson
Stanford University, BS, MS

James M. Thomson
Middlebury College

John D. Tolli
San Diego State University

Andrew C. Tolonen
Dartmouth College

Caroline B. Tuit
Beloit College

Emily M. Van Ark
Northwestern University

Matthew R. Walter
University of Illinois

Benjamin D. Walther
University of Texas, Austin

Jessica M. Warren
University of Cambridge, UK, BA, MS

Jennifer A. Watson
University of Massachusetts Amherst, BS, MS

Stephanie L. Watwood
University of Nebraska, Lincoln

Judith R. Wells
Radcliffe/Harvard University
University of California, Berkeley, MCP
University of Massachusetts Boston, BS

Helen K. White
University of Sussex, England

Clare M. Williams
University of Leeds

Joanna Y. Wilson
McMaster University, Canada
University of Victoria, Canada, MS

Joshua D. Wilson
University of Idaho

Rachel J. Wisniewski
University of Georgia

Rhea K. Workman
University of Missouri

Jinshan Xu
Ocean University of Qingdao, PRC, BS, MS

Postdoctoral Scholars/Fellows

Abdallah S. Al-Zoubi
St. Petersburg Mining Institute, Russia
Fullbright Postdoctoral Fellow

Annalisa Bracco
University of Genoa, Italy
USGS Postdoctoral Scholar

Ilya V. Buynevich
Boston University
USGS Postdoctoral Scholar

Jay T. Cullen
Rutgers University
J. Seward Johnson Fund Postdoctoral Scholar

Colomban de Vargas
University of Geneva, Switzerland
Swiss NSF Postdoctoral Fellow

Claudio DiBacco
Scripps Institution of Oceanography, University of California, San Diego
NSERC Postdoctoral Fellow

Jeffrey P. Donnelly
Brown University
USGS Postdoctoral Scholar

Sonya T. Dyhrman
Scripps Institution of Oceanography, University of California, San Diego
Stanley W. Watson Chair/ Seaver Foundation Postdoctoral Scholar

Virginia P. Edgcomb
University of Delaware
NRC/NASA Astrobiology Institute MBL/WHOI Postdoctoral Research Associate Fellow

Falk Feddersen
Scripps Institution of Oceanography, University of California, San Diego
J. Seward Johnson Fund Postdoctoral Scholar

Raffaele Ferrari
Scripps Institution of Oceanography, University of California, San Diego
J. Seward Johnson Fund Postdoctoral Scholar

Andrew J. Fredricks
Rensselaer Polytechnic Institute
Office of Naval Research Ocean Acoustics Postdoctoral Fellowship

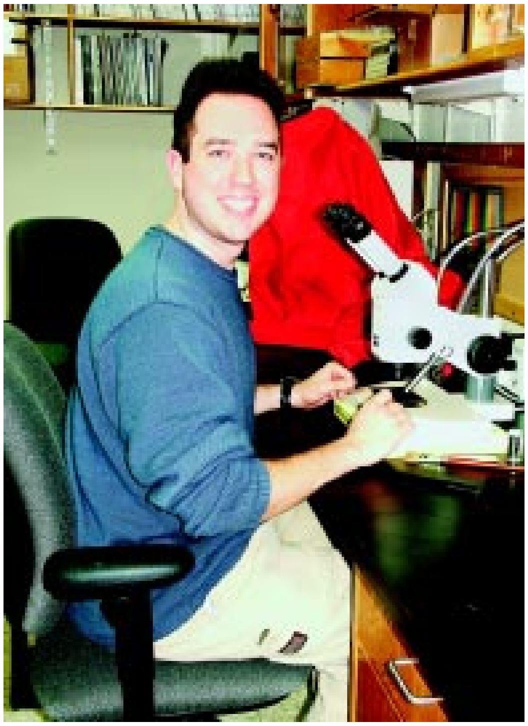
Deborah Fripp
MIT/WHOI Joint Program
NRSA/NIH Postdoctoral Fellow

Liviu Giosan
State University of New York at Stony Brook
CICOR Postdoctoral Scholar

Seon M. Han
Rutgers University
J. Seward Johnson Fund/ Johnson Chair Postdoctoral Scholar

Tom Kleindinst

Nicole Hill of the University of Delaware was a 2001 Summer Student Fellow in John Stegeman's lab. Here she aspirates media from a cell culture.



Jayne Doucette

Matt Makowski was a Summer Student Fellow in 1997 and entered the Joint Program in 1999 as a Geology and Geophysics student.

Martin Hasselov
Göteborg University, Sweden
Knut & Alice Wallenburg Foundation MIT Postdoctoral Scholarship Fellow

David Hurther
Swiss Federal Institute of Technology, Switzerland
J. Seward Johnson Fund/ Allyn Vine Senior Technical Staff Award Postdoctoral Scholar

Houshuo Jiang
Johns Hopkins University
George D. Grice Postdoctoral Scholar

Heather N. Koopman
Duke University
Devonshire Foundation Postdoctoral Scholar

Anke Kremp
University of Helsinki, Finland
German Academic Exchange Service/Academy of Finland Postdoctoral Fellow

Kara L. Lavender
Scripps Institution of Oceanography, University of California, San Diego
J. Seward Johnson Fund Postdoctoral Scholar

Andone Lavery
Cornell University
J. Seward Johnson Fund Postdoctoral Scholar

Jae-Il Lee
Seoul National University
Korea Science and Engineering Foundation Postdoctoral Fellow

James A. Lerczak
Scripps Institution of Oceanography, University of California, San Diego
CICOR Postdoctoral Scholar

Pamela Lezaeta Sotomayor
Freie Universität Berlin, Germany
Fundación Andes Chilean Postdoctoral Fellow

Aibing Li
Brown University
J. Seward Johnson Fund Postdoctoral Scholar

Joseph M. Licciardi
Oregon State University
Woods Hole Oceanographic Institution Postdoctoral Scholar

Gillemette Menot
University of Bern, Switzerland
Swiss NSF Postdoctoral Fellow

Rebeka R. Merson
University of Rhode Island
National Institutes of Health/ Donaldson Foundation/ Cabot Marine Environmental Science Fund Postdoctoral Fellow

Laurent G. J. Montesi
Massachusetts Institute of Technology
USGS Postdoctoral Scholar

Jennifer L. Morford
University of Washington
Cabot Marine Environmental Science Fund/J. Seward Johnson Fund Postdoctoral Scholar

Ann E. Mulligan
University of Connecticut
USGS Postdoctoral Scholar

Douglas Nowacek
MIT/WHOI Joint Program
NRC/NOAA Postdoctoral Associateship Fellow

Naohiko Ohkouchi
University of Tokyo, Japan
Japan Society for the Promotion of Science Postdoctoral Fellow

Steven T. Petsch
Yale University
USGS Postdoctoral Scholar

Helen E. Phillips
University of Tasmania, Australia
Vetlesen Foundation Postdoctoral Scholar

Karin E. Rengefors
Uppsala University, Sweden
Swedish Foundation for International Cooperation in Research and Higher Education Postdoctoral Fellow

Timothy M. Shank
Rutgers University
Devonshire Foundation Postdoctoral Scholar

Robert K. Shearman
Oregon State University
Devonshire Foundation Postdoctoral Scholar

Stefan Sievert
University of Bremen, Germany
Townsend Postdoctoral Scholar

Gregory F. Slater
University of Toronto, Canada
NSERC/J. Seward Johnson Fund Postdoctoral Fellow

Fiamma Straneo
University of Washington
CICOR Postdoctoral Scholar

Tracey T. Sutton
University of South Florida
Ocean Life Institute Postdoctoral Scholar

Aaron M. Thode
Scripps Institution of Oceanography, University of California, San Diego
Secretary of the Navy–MIT Postdoctoral Fellow

Rodrigo Torres
Göteborg University, Sweden
Fundación Andes Chilean Postdoctoral Fellow

Joseph D. Warren
MIT/WHOI Joint Program
Office of Naval Research Ocean Acoustics Postdoctoral Fellowship

Eric A. Webb
University of Wisconsin, Madison
J. Seward Johnson Fund Postdoctoral Scholar

Christopher J. Zappa
University of Washington
J. Seward Johnson Fund Postdoctoral Scholar

Geophysical Fluid Dynamics Seminar Fellows (GFD)

Helen C. Andersson
Göteborg University, Sweden

Fiona J.R. Eccles
University of Oxford, England

Edwin P. Gerber
Princeton University

Takamitsu Ito
Massachusetts Institute of Technology

Shreyas D. Mandre
Northwestern University

Matthew S. Spydell
University of California, San Diego

Lianke A. Te Raa
Utrecht University, The Netherlands

Chiara Toniolo
University of Genoa, Italy

GFD Staff and Visitors

James L. Anderson
Stevens Institute of Technology

Neil J. Balmforth
University of California, Santa Cruz

David Battisti
University of Washington

Andrew J. Bernoff
Harvey Mudd College

Joseph A. Biello
Rensselaer Polytechnic Institute

Sebastien Bigorre
Florida State University

Giulio Boccaletti
Princeton University

Gregory Buck
Saint Anselm College

John Bush
Massachusetts Institute of Technology

Jayne Doucette

Joint Program student Sarah Marsh, right, and Research Assistant Scott Cramer work with marine animal specimens in a Redfield wet lab.

Jayne Doucette

Joint Program student Margaret Boettcher is in her third year of studies in the Geology and Geophysics Department.

Sandro Calmanti
Istituto di Cosmogeofisica del CNR, Italy

Paola Cessi
University of California, San Diego

Eric P. Chassignet
University of Miami

Liam Clarke
University of Oxford, England

Arnaud Czaja
Massachusetts Institute of Technology

Agatha DeBoer
Florida State University

Paul J. Dellar
St. John's College, England

William K. Dewar
Florida State University

Henk Dijkstra
Utrecht University, The Netherlands

Abebech Dione
University of Miami

Charles Doering
University of Michigan

Russell Donelly
University of Oregon

Kerry Emanuel
Massachusetts Institute of Technology

Alexey V. Fedorov
Princeton University

Dargan Frierson
Princeton University

Eric Gaidos
California Institute of Technology

Thomas W.N. Haine
Johns Hopkins University

Chris Hallstrom
Brown University

Louis N. Howard
Florida State University/ Massachusetts Institute of Technology

Thierry Huck
Université de Bretagne Occidentale, France

Christopher Jones
Brown University

Joseph B. Keller
Stanford University

Yochanan Kushnir
Columbia University

Norman R. Lebovitz
University of Chicago

Dmitri Leonov
Florida State University

Willem V.R. Malkus
Massachusetts Institute of Technology

David Marshall
University of Reading, England

John Marshall
Massachusetts Institute of Technology

Igor Mezic
University of California, Santa Barbara

Philip J. Morrison
University of Texas at Austin

Joseph J. Niemela
University of Oregon

Francesco Paparella
University of Lecce, Italy

Antonio Parodi
University of Genoa, Italy

Claudia Pasquero
Istituto di Cosmogeofisica del CNR, Italy

Giuseppe Passoni
Politecnico di Milano, Italy

Vinicio Pelino
Centro Nazionale di Meteorologia e Climatologia Aeronautica (CNMCA), Italy

Raymond T. Pierrehumbert
University of Chicago

Antonello Provenzale
Istituto di Cosmogeofisica del CNR, Italy

Alan W. Rempel
University of Washington

Claes G. Rooth
University of Miami

Tapio Schneider
New York University

Wayne H. Schubert
Colorado State University

Michael J. Shelley
New York University

Leonard Smith
London School of Economics, England

Edward A. Spiegel
Columbia University

Melvin Stern
Florida State University

Kevin Trenberth
National Center for Atmospheric Research

Eli Tziperman
Weizmann Institute of Science, Israel

Geoffrey K. Vallis
Princeton University

George Veronis
Yale University

Jeffrey Weiss
University of Colorado

John S. Wettlaufer
University of Washington

Philip A. Yecko
Columbia University

William R. Young
University of California, San Diego

Summer Student Fellows

Heather Abbott
Marshall University

Jonathan Blythe
University of California, Santa Barbara

Maureen Coleman
Dartmouth College

Francesca DeLeonardis
University of California, Berkeley

Joanne Donahue
Marlboro College

Brandon Fornwalt
University of South Carolina Honors College

Jeffrey Harris
University of Washington

Nicole Hill
University of Delaware

Laura Hmelo
Carleton College

Amy Hurford
Fairfield University

Susan Leadbetter
University of St. Andrews

Donald Lucas
University of Texas at Austin

Farah Maloof
Wellesley College

James Mistler
Susquehanna University

Danielle Mitchell
California State University

Takako Noda
Kobe University, Japan

Jonathan Nuwer
State University of New York, Syracuse

David Scott
University of Colorado

Morgan Simmons
Carnegie Mellon University

David Stuebe
Duke University

Kristen Whalen
University of North Carolina, Wilmington

Jayne Doucette

Third-year Joint Program Student Charlie Stock is proposing thesis work on harmful algal blooms in the Gulf of Maine.

Marcie Workman
University of Missouri, Columbia

Minority Fellows

Shawn Arellano
University of Kansas

Arthur Hardy-Doubleday
Trinity College

Barbara Juncosa
University of Miami

Aura Obando
Duke University

Guest Students

Carlin F. Aloe
Wesleyan University

Xabier Arzuaga
University of Kentucky

Christine J. Band Schmidt
CIBNOR, La Paz, Mexico

Mark Baumgartner
Oregon State University

Christoph Beier
University of Kiel, Germany

Simone Boer
University of Oldenburg, Germany

Andrea Bogomolni
Boston University

Ryan Brown
University of Miami

Matthew S. Carson
Hunter College High School

Amanda Chase
Carnegie Mellon University

Corrina Chase
Massachusetts Institute of Technology

Ming-Qi Chu
Phillips Exeter Academy

Kathleen Colgrove
Virginia-Maryland Regional College

Susan Cosier
Wesleyan University

Tom Kleindinst

Joint Program students Rose Marie Came, left, and Kristina Dahl examine radiolarians and diatoms during a lab session of the "Pre-Pleistocene Paleoceanography" course taught by Dick Norris and Karen Bice.

Paul Craddock
Southampton University

Michael J. DeLeo III
Middlebury College

Jill Erickson
Wheaton College

Brad Evans
Boston University

Jeff Evans
Hamilton College

Karen Fisher
Cornell University

Jeanne-Marie Gherardi
École Normal Superieur, France

Rodrigo Gonzalez
University of Concepción, Chile

Lily Gray
Loomis Chaffee School

Ivo Grigorov
Southampton University

Haidi Hancock
James Cook University

Peter Huybers
Massachusetts Institute of Technology

Paal Erik Isachsen
University of Bergen, Norway

Elisabeth Jablonski
Eckerd College

Christian Jadlowic
University of Massachusetts Dartmouth

Tim Janssen
Delft University of Technology, Netherlands

Ida-Maja Karle
Göteborg University, Sweden

Evan Kingsley
University of Rochester

Nell Kurz
Falmouth High School

Phyllis Lam
University of Hawaii, Manoa

Carolina Luxoro
University of Santiago, Chile

Lisa Mangiamele
Colgate University

Hallie Marbet
Bridgewater State College

Erin Mayberry
University of California, Santa Barbara

Elena McCarthy
University of Rhode Island

Breda McKay
Boston University

Jennifer L. Miksis
University of Rhode Island

Carolyn A. Miller
Boston University

Gesine Mollenhauer
University of Bremen, Germany

Tracey Morin
University of Massachusetts, Boston

Seth Newton
University of Alabama

Katarzyna Niewiadomska
Massachusetts Institute of Technology

Kerry A. Norton
University of California, Santa Cruz

Akiko Okusu
Harvard University

Dane Percy
Bridgewater State College

Marie Python
Observatoire Midi-Pyrenees, France

Maria G. Reznikoff
Rensselaer Polytechnic Institute

Amalia Salditos
University of Massachusetts Dartmouth

Jordan Sanford
Eckerd College

Alex Sessions
Indiana University

Philip Sexton
Southampton University

Ari Shapiro
Boston College

Ketil Sorensen
University of Southern Denmark

Ann Michelle Stanley
Harvard University

Alexander Stine
Massachusetts Institute of Technology

Mindy Sweeny
Boston University

Andrew Sweetman
Southampton University

Jennifer Szlosek
Massachusetts Institute of Technology

Timothy B. Talmadge
Rensselaer Polytechnic Institute

Jackie Van Etten
Bridgewater State College

Cristian Vargas
University of Concepción, Chile

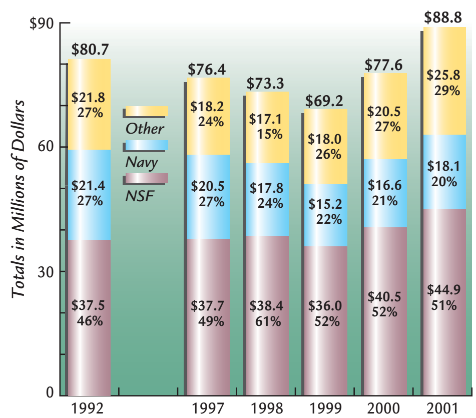
Patti Waters
Bates College

Hendrik J. Zemmelink
University of Groningen, The Netherlands

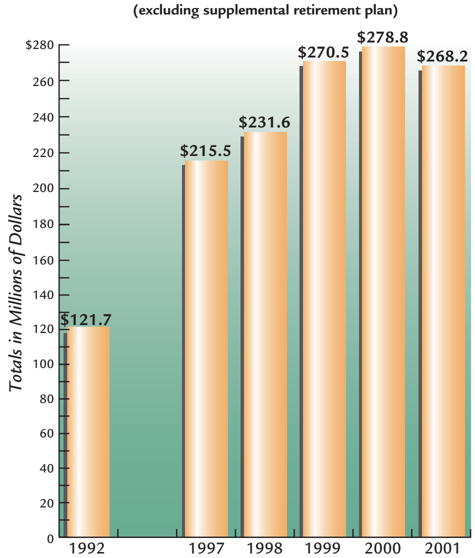
Oliver Zenk
University of Applied Sciences, Kiel, Germany

Despite the September 11 tragedy and weakness in the financial markets, the Institution's overall financial position was stable during 2001. A gift of $28 million for the Ocean Institutes from an anonymous philanthropist generated much optimism for the future and we experienced continued support from our friends who share their financial resources, their counsel, and advice.

Sources of Research Funding



Endowment Market Value
(excluding supplemental retirement plan)



Sponsored research revenue released to operations increased to $88.8 million in 2001 compared to $77.6 million in 2000, and government sponsored research, excluding ship and submersible operations, was $58 million compared to $51.5 million in 2000. This represents increases of 14 percent and 13 percent, respectively. The Institution had a modest underrecovery of overhead expenses, which we view as favorable in light of large overrecoveries in prior years.

Unrestricted income from gifts and pledges exceeded budget while the expense for bridge support, which covers salaries for scientists who are between funding, again came in under budget, contributing to an unrestricted operating surplus. These resources allowed us to continue a productive cash management program. The income received from investing current Institution financial assets has increased from approximately $100,000 in 1995 to almost $650,000 in 2001.

Gifts, grants, and pledges from private sources totaled $23.1 million in 2001, substantially exceeding 2000, which at $14.5 million had previously been the best non-campaign year ever. Outstanding pledges at the end of 2001 were $1.8 million, compared to $2.9 million in 2000.

Consistently good operating and financial performance has allowed WHOI to build a strong balance sheet. Although our endowment investment performance was better than most indices, we nevertheless experienced a decline in endowment from $278.8 million to $268.2 million. The Institution had $5 million in long-term debt on its balance sheet at year-end, and we believe the use of debt has a substantial financial benefit based on the low cost of tax-exempt borrowing. The Institution is in full compliance with all federal regulations, and in 2001, for the seventh consecutive year, all government audits are current and satisfactory.

With the support of an Ad Hoc Committee on Campus Planning that includes Trustees and Corporation members, we have developed a master plan to guide development of new laboratory space on the Quissett Campus. Additional laboratory space is essential if we are to remain competitive in the conduct of research, graduate education, and the retention and recruitment of the best scientists. In order to support a major construction program, we are preparing financing plans and long-range financial projections. We anticipate that tax-exempt borrowings will finance a substantial portion of the new construction.

We believe we must continue to develop sustainable sources of unrestricted income to meet the growing demands of research and new initiatives. In order to achieve our goals, we must build our endowment, seek research funding from the private sector, and find nontraditional sources of income. We acknowledge with gratitude that our ability to meet our objectives comes from the efforts of the people of WHOI: our scientists, students, and staff.

—**Carolyn A. Bunker,** Acting Associate Director for Finance and Administration

Statements of Financial Position as of December 31, 2001
(with comparative information as of December 31, 2000)

	2001	2000
Assets		
Cash, unrestricted	$25,279,708	$21,637,368
Cash, restricted	2,127,319	2,373,675
Reimbursable costs and fees:		
Billed	1,830,744	2,078,150
Unbilled	4,244,992	3,102,994
Interest and dividends receivable	747,738	835,835
Other receivables	489,022	415,364
Pledges receivable	1,837,433	2,875,144
Inventory	1,338,200	1,070,303
Deferred charges and prepaid expenses	632,799	314,906
Investments, pooled	255,533,434	278,691,287
Investments, nonpooled	16,914,043	11,340,898
Prepaid pension and postretirement benefit cost	7,196,027	4,629,623
Supplemental retirement	6,464,586	7,158,614
Other assets	4,255,459	4,374,491
	328,891,504	340,898,652
Property, plant and equipment:		
Land, buildings and improvements	58,416,408	54,977,722
Vessels and dock facilities	3,186,277	3,186,277
Laboratory and other equipment	12,687,970	11,036,930
Construction in process	1,714,908	1,959,353
	76,005,563	71,160,282
Accumulated depreciation	(41,311,575)	(37,627,865)
Net property, plant and equipment	34,693,988	33,532,417
Remainder trusts	10,819,303	570,317
Total assets	$374,404,795	$375,001,386
Liabilities		
Accounts payable and other liabilities	$10,099,366	$8,059,206
Accrued payroll and related liabilities	5,835,734	5,537,049
Payable for investments purchased	281,912	402,557
Accrued supplemental retirement benefits	6,464,586	7,158,614
Deferred revenue and refundable advances	7,497,139	7,545,281
Deferred fixed rate variance	2,196,646	3,595,425
Loan payable	5,067,952	3,921,516
Total liabilities	37,443,335	36,219,648
Commitments and contingencies		

Net Assets

	Unrestricted	Temporarily restricted	Permanently restricted	2001	2000
Undesignated	$7,595,488	$ -	$ -	$7,595,488	$7,828,139
Designated	1,716,744	11,800,984	-	13,517,728	13,908,054
Pledges and other	-	4,096,061	9,744,516	13,840,577	4,703,597
Plant and facilities	30,418,781	-	-	30,418,781	30,623,733
Education	-	3,389,196	-	3,389,196	2,889,562
Endowment and similar funds	64,151,461	160,938,965	43,109,264	268,199,690	278,828,653
Total net assets	$103,882,474	$180,225,206	$52,853,780	336,961,460	338,781,738
Total liabilities and net assets				$374,404,795	$375,001,386

Statement of Cash Flows For the Year Ended December 31, 2001
(with comparative information for the year ended December 31, 2000)

	2001	2000
Cash flows from operating activities:		
Total change in net assets	$(1,820,278)	$15,638,470
Adjustments to reconcile (decrease) increase in net assets to net cash provided by operating activities:		
Depreciation	3,683,710	3,338,844
Contributions and change in value of remainder trusts	(10,608,626)	530,166
Allowance for uncollective pledges	200,000	-
Discount on pledges	58,064	-
Gain on sale of property	-	(481,000)
Net realized and unrealized gain on investments	24,307,603	(3,235,539)
Contributions to be used for long-term investment	(1,080,551)	(4,787,404)
(Increase) decrease in assets:		
Restricted cash	246,356	(1,547,366)
Interest and dividends receivable	88,097	(301,974)
Reimbursable costs and fees:		
Billed	247,406	(153,145)
Unbilled	(1,141,998)	672,100
Receivable for investments sold	-	152,708
Other receivables	(73,658)	(59,862)
Pledges receivable	779,647	2,533,839
Inventory	(267,897)	(261,384)
Deferred charges and prepaid expenses	(317,893)	(255,270)
Prepaid pension and postretirement benefit cost	(2,566,404)	(2,401,239)
Other assets	478,672	261,408
Supplemental retirement	694,028	575,317
Increase (decrease) in liabilities:		
Accounts payable and other liabilities	2,040,160	146,806
Accrued payroll and related liabilities	298,685	238,499
Payable for investments purchased	(120,645)	402,557
Deferred revenue and refundable advances	(48,142)	3,462,346
Accrued supplemental retirement benefits	(694,028)	(575,317)
Deferred fixed rate variances	(1,398,779)	525,277
Net cash provided by operating activities	12,983,529	14,418,837
Cash flows from investing activities:		
Capital expenditures:		
Additions to property and equipment	(5,045,978)	(5,414,975)
Disposals of property and equipment	200,697	697,065
Short-term investments:		
Purchase of investments	(5,573,145)	-
Endowment:		
Proceeds from the sale of investments	197,143,639	203,949,829
Purchase of investments	(198,293,388)	(214,112,022)
Net cash used in investing activities	(11,568,175)	(14,880,103)
Cash flows from financing activities:		
Borrowings under debt agreement	1,146,435	922,302
Contributions to be used for long-term investment	1,080,551	4,787,404
Net cash provided by financing activities	2,226,986	5,709,706
Net increase in cash and cash equivalents	3,642,340	(5,248,440)
Cash and cash equivalents, beginning of year	21,637,368	16,388,928
Cash and cash equivalents, end of year	$25,279,708	$21,637,368
Supplemental disclosures:		
Interest paid	$154,472	$116,690

Statement of Activities for the year ended December 31, 2001
(with summarized financial information for the year ended December 31, 2000)

	Unrestricted					
	Operating	Sponsored research	Temporarily restricted	Permanently restricted	2001	2000
Operating:						
Revenues:						
Fees	$480,048				$480,048	$398,557
Sponsored research:						
Government		$57,999,323			57,999,323	51,483,430
Nongovernment		11,720,948	$3,324,977		15,045,925	11,995,608
Ships and subs operations		16,318,230			16,318,230	14,577,061
Sponsored research assets released to operations	88,784,540	(86,038,501)	(2,746,039)		-	-
Education:						
Tuition	2,422,919				2,422,919	2,300,021
Endowment income	3,507,720		1,579,582		5,087,302	4,772,920
Gifts and transfers			441,327		441,327	232,210
Education funds released from restriction	1,525,075		(1,525,075)		-	-
Investment return designated for current operations	3,324,643				3,324,643	3,347,291
Contributions and gifts	4,067,506		15,204,231	$10,283,499	29,555,236	11,375,378
Contributions in kind	569,524				569,524	
Contributions and gifts released	12,203		(12,203)		-	-
Change in split-interest agreements	(27,220)		50,564	276,210	299,554	1,058,858
Rental income	681,800				681,800	689,987
Communication and publications	230,953				230,953	204,607
Other	17,407				17,407	835,531
Total revenues	105,597,118	-	16,317,364	10,559,709	132,474,191	103,271,459
Expenses:						
Sponsored research:						
National Science Foundation	32,319,177				32,319,177	28,905,513
United States Navy	16,294,420				16,294,420	14,833,446
Subcontracts	5,602,882				5,602,882	5,885,445
National Oceanic & Atmospheric Administration	5,091,049				5,091,049	4,097,038
Department of Energy	760,432				760,432	683,316
United States Geological Survey	913,216				913,216	939,757
National Aeronautics & Space Administration	752,414				752,414	725,017
Ships Operations	12,050,433				12,050,433	10,868,821
Submersible and ROV operations	4,267,797				4,267,797	3,708,240
Privately funded grants	2,976,296				2,976,296	1,810,335
Other	7,756,424				7,756,424	5,176,329
Education:						
Faculty expense	2,396,656				2,396,656	2,288,385
Student expense	3,134,580				3,134,580	2,904,506
Postdoctoral programs	478,479				478,479	476,988
Other	630,559				630,559	560,659
Rental expenses	523,835				523,835	536,965
Communication publications and development	1,731,513				1,731,513	1,454,465
Fundraising expenses	1,783,952				1,783,952	1,642,199
Unsponsored programs	3,174,119				3,174,119	4,152,772
Other expenses	2,291,793				2,291,793	1,142,875
Write off of fixed assets	531,614				531,614	-
Total expenses	105,461,640	-	-	-	105,461,640	92,793,071
Change in net assets from operating activities	135,478	-	16,317,364	10,559,709	27,012,551	10,478,388
Nonoperating income:						
Investment return (less than) in excess of amounts designated for sponsored research, education and current operations	(8,751,729)		(22,442,548)		(31,194,277)	3,235,539
Change in prepaid pension cost	2,566,404				2,566,404	2,401,239
Nonoperating expenses: Other nonoperating expenses	(204,956)				(204,956)	(476,696)
Net asset transfers	246,459		(17,516)	(228,943)	-	-
Change in net assets from nonoperating activities	(6,143,822)	-	(22,460,064)	(228,943)	(28,832,829)	5,160,082
Total change in net assets	(6,008,344)	-	(6,142,700)	10,330,766	(1,820,278)	15,638,470
Net assets at beginning of year	109,890,818	-	186,367,906	42,523,014	338,781,738	323,143,268
Net assets at end of year	$103,882,474	$ -	$180,225,206	$52,853,780	$336,961,460	$338,781,738

Report of Independent Accounts

To the Board of Trustees of Woods Hole Oceanographic Institution: In our opinion, the accompanying statement of financial position and the related statements of activities and of cash flows present fairly, in all material respects, the financial position of Woods Hole Oceanographic Institution (the "Institution") at December 31, 2001 and the changes in its net assets and its cash flows for the year then ended, in conformity with accounting principles generally accepted in the United States of America. These financial statements are the responsibility of the Institution's management; our responsibility is to express an opinion on these financial statements based on our audit. The prior year summarized comparative information has been derived from the Institution's 2000 financial statements, and in our report dated March 9, 2001, we expressed an unqualified opinion on those financial statements. We conducted our audit of these statements in accordance with auditing standards generally accepted in the United States of America, which require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements, assessing the accounting principles used and significant estimates made by management, and evaluating the overall financial statement presentation. We believe that our audit provides a reasonable basis for our opinion.

PricewaterhouseCoopers LLP

March 8, 2002

1. Background

Woods Hole Oceanographic Institution (the "Institution") is a private, independent not-for-profit research and educational institution located in Woods Hole, Massachusetts. Founded in 1930, the Institution is dedicated to working and learning at the frontier of ocean science and attaining maximum return on intellectual and material investments in oceanographic research.

The Institution is a qualified tax-exempt organization under Section 501(c)(3) of the Internal Revenue Code as it is organized and operated for education and scientific purposes.

2. Summary of Significant Accounting Policies

Basis of Presentation

The accompanying financial statements have been prepared on the accrual basis and in accordance with the reporting principles of not-for-profit accounting.

The financial statements include certain prior-year summarized comparative information, but do not include sufficient detail to constitute a presentation in conformity with accounting principles generally accepted in the United States of America. Accordingly, such information should be read in conjunction with the Institution's audited financial statements for the year ended December 31, 2000, from which the summarized information was derived.

Net assets, revenues, and realized and unrealized gains and losses are classified based on the existence or absence of donor-imposed restrictions and legal restrictions imposed under Massachusetts State law. Accordingly, net assets and changes therein are classified as follows:

Permanently Restricted Net Assets

Permanently restricted net assets are subject to donor-imposed stipulations that they be maintained permanently by the Institution. Generally the donors of these assets permit the Institution to use all or part of the income earned and capital appreciation, if any, on related investments for general or specific purposes.

Temporarily Restricted Net Assets

Temporarily restricted net assets are subject to donor-imposed stipulations that may or will be met by actions of the Institution and/or the passage of time. Unspent endowment gains are classified as temporarily restricted until the Institution appropriates and spends such sums in accordance with the terms of the underlying endowment funds at which time they will be released to unrestricted revenues.

Unrestricted Net Assets

Unrestricted net assets are not subject to donor-imposed stipulations. Revenues are reported as increases in unrestricted net assets unless use of the related assets is limited by donor-imposed restrictions. Expenses are reported as decreases in unrestricted net assets. Gains and losses on investments and other assets or liabilities are reported as increases or decreases in unrestricted net assets unless their use is restricted by explicit donor stipulations or law. Expirations of temporary restrictions on net assets, that is, the donor-imposed stipulated purpose has been accomplished and/or the stipulated time period has elapsed, are reported as reclassifications between the applicable classes of net assets. Amounts received for sponsored research (under exchange transactions) are reflected in unrestricted sponsored research and released to operations when spent for the appropriate purpose, or as deferred revenue if expenditures have yet to be incurred.

Contributions

Contributions, including unconditional promises to give, are recognized as revenues in the period received. Contributions subject to donor-imposed stipulations that are met in the same reporting period are reported as unrestricted support. Promises to give that are scheduled to be received after the balance sheet date are shown as increases in temporarily restricted net assets and are reclassified to unrestricted net assets when the purpose or items' restrictions are met. Promises to give, subject to donor-imposed stipulations that the corpus be maintained permanently, are recognized as increases in permanently restricted net assets. Conditional promises to give are not recognized until they become unconditional, that is, when the conditions on which they depend are substantially met. Contributions other than cash are generally recorded at market value on the date of the gift (or an estimate of fair value), although certain noncash gifts, for which a readily determinable market value cannot be established, are recorded at a nominal value until such time as the value becomes known. Contributions to be received after one year are discounted at the appropriate rate commensurate with risk. Amortization of such discount is recorded as additional contribution revenue in accordance with restrictions imposed by the donor on the original contribution, as applicable. Amounts receivable for contributions are reflected net of an applicable reserve for collectibility.

The Institution reports contributions in the form of land, buildings, or equipment as unrestricted operating support.

Dividends, interest and net gains on investments of endowment and similar funds are reported as follows:

- as increases in permanently restricted net assets if the terms of the gift require that they be added to the principal of a permanent endowment fund;
- as increases in temporarily restricted net assets if the terms of the gift or relevant state law impose restrictions on the current use of the income or net realized and unrealized gains; and
- as increases in unrestricted net assets in all other cases.

Operations

The statement of activities report the Institution's operating and nonoperating activities. Operating revenues and expenses consist of those attributable to the Institution's current annual research or educational programs, including a component of endowment income appropriated for operations (see Note 3). Unrestricted endowment investment income and gains over the amount appropriated under the Institution's spending plan are reported as nonoperating revenue as investment return in excess of amounts designated for sponsored research, education and current operations.

Cash and Cash Equivalents

Cash and cash equivalents consist of cash, money market accounts, certificates of deposit and overnight repurchase agreements with initial maturities of three months or less when purchased which are stated at cost, which approximates market value. At times the Institution maintains amounts at a single financial institution in excess of federally insured limits.

Included in restricted cash at December 31, 2001 and 2000 is $1,890,053 and $2,143,974, respectively, representing advances received from the United States Navy and other U.S. Government and state agencies. Such amounts are restricted as to use for research programs. Interest earned on unspent funds is remitted to the federal government.

Also included in restricted cash at December 31, 2001 and 2000 is $237,266 and $229,701, respectively, representing cash restricted by the Massachusetts Department of Public Health. Interest earned on unspent funds is reinvested within the restricted cash account.

In addition, cash and cash equivalents include uninvested amounts from each classification of net assets (e.g., endowment).

Investments

Investment securities are carried at market value determined as follows: securities traded on a national securities exchange are valued at the last reported sales price on the last business day of the year; securities traded in the over-the-counter market and listed securities for which no sales prices were reported on that day are valued at closing bid prices. For investments in venture capital and investment partnerships, the Institution relies on valuations reported to the Institution by the managers of these investments except where the Institution may reasonably determine that additional factors should be considered.

Purchases and sales of investment securities are recorded on a trade date basis. Realized gains and losses are computed on a specific identification method. Investment income, net of investment expenses, is distributed on the unit method.

Options and Futures

An option is a contract in which the writer of the option grants the buyer the right to purchase from (call option) or sell to (put option) the writer a designated instrument at a specified price within a period of time. Premiums received on written options are recorded as negative cost basis until the contract is closed. The liability representing the Institution's obligation under a written option or the Institution's investment in a purchase option is valued at the last sale price or, in the absence of a sale, the mean between the closing bid and asked price or at the most recent asked price (bid for purchase option) if no bid and asked price are available. Over-the-counter written or purchased options are valued using dealer-supplied quotations. Over-the-counter options have the risk of the potential inability of counterparts to meet the terms of their contracts. The Institution's maximum exposure for purchased options is limited to the premium initially paid.

A futures contract is an agreement between a buyer or seller and an established futures exchange or clearinghouse in which the buyer or seller agrees to take (or make) delivery of an amount of an item at a specific price on a specific date (settlement date). Upon entering into a futures contract, the Institution deposits with a financial intermediary an amount ("initial margin") equal to a percentage of the face value of the futures contract. Subsequent payments are made or received by the Institution each day, dependent on the daily fluctuations in the value of the underlying security, and are recorded as unrealized gains or losses. The Institution will realize a gain or loss equal to the difference between the value of the futures contract to sell and the futures contract to buy at settlement date or by closing the contract. Futures contracts are valued at the most recent settlement price.

Investment Income Unitization

The Institution's investments are pooled in an endowment fund and the investments and allocation of income are tracked on a unitized basis. The Institution distributes to operations for each individual fund an amount of investment income earned by each of the fund's proportionate share of investments based on a total return policy.

The Board of Trustees has appropriated all of the income and a specified percentage of the net appreciation (depreciation) to operations as prudent considering the Institution's long and short-term needs, present and anticipated financial requirements, expected total return on its investments, price level trends, and general economic conditions. Under the Institution's current endowment spending policy, which is within the guidelines specified under state law, between 4 percent and 5.5 percent of the average of the market value of qualifying endowment investments at September 30 of each of the previous three years is appropriated. This amounted to $11,106,742 and $10,109,203 for the years ending December 31, 2001 and 2000, respectively, and is classified in operating revenues (research, education, and operations). The Institution has interpreted relevant state law as generally permitting the spending of gains on endowment funds over a stipulated period of time.

Inventories

Inventories are stated at the lower of cost or market. Cost is determined using the first-in, first-out method.

Contracts and Grants

Revenues earned on contracts and grants for research are recognized as related costs are incurred.

Property, Plant and Equipment

Property, plant and equipment are stated at cost. Depreciation is provided on a straight-line basis at annual rates of 8 to 50 years on buildings and improvements, 28 years on vessels and dock facilities, and 3 to 5 years on laboratory and other equipment. Depreciation expense on property, plant, and equipment purchased by the Institution in the amounts of $3,583,734 and $3,238,068 in 2001 and 2000, respectively, has been charged to operating activities.

Depreciation on certain government-funded facilities (the Laboratory for Marine Science and the dock facility) amounting to $99,976 and $100,776 in 2001 and 2000, respectively, has been charged to nonoperating expenses as these assets were gifted by the Government.

Included in construction in process is $526,059 and $42,700 at December 31, 2001 and 2000, respectively, relating to campus planning.

Use of Estimates

The preparation of the financial statements in accordance with accounting principles generally accepted in the United States of America requires management to make estimates and assumptions that affect the reported amounts of assets and liabilities and the disclosure of contingent assets and liabilities at the date of the financial statements and the reported amounts of revenues and expenses during the period. Actual results could differ from those estimates.

Reclassification of Amounts

Certain prior year amounts have been reclassified to conform to the December 31, 2001 presentation.

3. Investments

The cost and market value of investments held at December 31 are as follows:

	2001		2000	
	Cost	Market	Cost	Market
U.S. Government and government agencies	$10,884,250	$10,706,678	$6,010,333	$6,205,973
Corporate bonds	39,449,169	39,747,540	42,266,542	42,396,551
International bonds	11,463,914	11,719,036	6,290,635	5,911,656
Equity securities and mutual funds	90,717,251	108,384,925	95,417,513	123,939,867
International equities	42,946,376	38,653,939	50,557,666	47,850,287
Hedge fund limited partnerships	23,920,000	31,516,655	18,920,000	32,251,037
Venture Capital and private equity	15,974,232	14,590,510	13,410,006	19,800,254
Other	192,773	192,773	299,465	299,465
Subtotal investments	235,547,965	255,512,056	233,172,160	278,655,090
Purchased call options	59,618	21,903	66,294	38,387
Written call options	(1,358)	(40)	(19,653)	(1,006)
Written put options	(20,394)	(485)	(17,625)	(1,184)
Total investments	$235,585,831	$255,533,434	$233,201,176	$278,691,287

Amounts held in Venture Capital and Investment Partnerships and other investments are invested in securities or other assets for which there is not necessarily a publicly-traded market value or which are restricted as to disposition. The return on such investments was $7,773,970 and $7,095,950 for the years ended December 31, 2001 and 2000, respectively, including dividends, distributions and changes in the estimated value of such investments.

The following schedule summarizes the investment return and its classification in the statements of activities:

	Unrestricted	Temporarily restricted	2001 Total	2000 Total
Dividend and interest income	$4,526,534	$1,579,582	$6,106,116	$5,550,890
Investment management costs	(1,233,720)	-	(1,233,720)	(1,307,813)
Net realized gains	394,069	840,836	1,234,905	15,826,500
Change in unrealized appreciation	(2,259,124)	(23,283,384)	(25,542,508)	(5,796,075)
Total return on investments	1,427,759	(20,862,966)	(19,435,207)	14,273,502
Investment return designated for:				
Sponsored research	(3,347,125)	-	(3,347,125)	(2,917,752)
Education	(3,507,720)	(1,579,582)	(5,087,302)	(4,772,920)
Current operations	(3,324,643)	-	(3,324,643)	(3,347,291)
Total distributions to operations	(10,179,488)	(1,579,582)	(11,759,070)	(11,037,963)
Investment return (less than) in excess of amounts designated for sponsored research, education and current operations	$(8,751,729)	$(22,442,548)	$(31,194,277)	$3,235,539

Investment return distributed to operations includes $652,328 and $928,760 earned on non-endowment investments for the years ended December 31, 2001 and 2000, respectively.

Endowment income is allocated to each individual fund based on a per unit valuation. The value of an investment unit at December 31, is as follows:

	2001	2000
Unit value, beginning of year	$4.5650	$4.5884
Unit value, end of year	4.0787	4.5650
Net change for the year	(.4863)	(.0234)
Investment income per unit for the year	.0655	.0536
Total return per unit	$(.4208)	$.0302

4. Pledges Receivable

Pledges receivable consist of the following at December 31:

	2001	2000
Unconditional promises expected to be collected in:		
Less than one year	$982,658	$1,979,540
One year to five years	1,112,839	895,604
Reserve for uncollectible pledges receivable	(200,000)	-
Unamortized discount	(58,064)	-
	$1,837,433	$2,875,144

5. Contribution Receivable from Remainder Trusts

The Institution recorded $10,819,303 and $570,317 at December 31, 2001 and 2000, respectively, relating to various charitable remainder trusts in its statement of financial position. The receivable and related revenue is measured at the present value of estimated future cash flows to be received and recorded in the appropriate net asset category based on donor stipulation. During the term of these agreements, changes in the value are recognized based on amortization of discounts and changes in actuarial assumptions.

6. Deferred Fixed Rate Variance

The Institution receives funding or reimbursement from federal government agencies for sponsored research under government grants and contracts. The Institution has negotiated fixed rates with the federal government for the recovery of certain fringe benefits and indirect costs on these grants and contracts. Such recoveries are subject to carryforward provisions that provide for adjustments to be included in the negotiation of future fixed rates. The deferred fixed rate variance accounts represent the cumulative amount owed to or due from the federal government. The Institution's rates are negotiated with the Office of Naval Research (ONR), the Institution's cognizant agency.

The composition of the deferred fixed rate variance is as follows:

Deferred Fixed Rate Variance (liability), December 31, 1999	$(3,070,148)
2000 indirect costs	34,876,295
2000 adjustment	(76,092)
Amounts recovered	(35,325,480)
2000 change in liability	(525,277)
Deferred Fixed Rate Variance (liability), December 31, 2000	(3,595,425)
2001 indirect costs	39,546,829
2001 adjustment	(63,312)
Amounts recovered	(38,084,738)
2001 change in liability	1,398,779
Deferred Fixed Rate Variance (liability), December 31, 2001	$(2,196,646)

As of December 31, 2001, the Institution has recovered a cumulative amount in excess of expended amounts of $2,196,646 which will be reflected as a reduction of future year recoveries. This amount has been reported as a liability of the Institution.

7. Loan Payable

On May 27, 1999, the Institution entered into a $3,000,000 loan agreement with the Massachusetts Health and Educational Facilities Authority (the "Authority") to finance various capital projects. On January 31, 2000, the agreement was amended to increase the maximum loan commitment to $6,000,000. As of December 31, 2001, $5,067,952 had been drawn down on the loan and was outstanding at year-end. Drawdowns are expected to occur during an eighteen-month period subsequent to the amendment to the loan agreement. During this period, no principal payments are due on the loan, but the Institution is required to pay interest on the drawdowns at a variable rate established by the Authority, which was 3.25% at December 31, 2001. Once the final drawdown has occurred or the eighteen-month period has lapsed, a schedule of principal payments will be established by the Authority until the final payment due on July 1, 2010.

On March 1, 2001, the Institution entered into a $11,000,000 loan agreement with the Massachusetts Health and Educational Authority (the "Authority") to finance additional capital projects. As of December 31, 2001, no amount had been drawn down on the loan. Drawdowns are expected to occur during an eighteen-month period. During this period, no principal payments are due on the loan, but the Institution is required to pay interest on the drawdowns at a variable rate established by the Authority. Once the final drawdown has occurred or the eighteen-month period has lapsed, a schedule of principal payments will be established by the Authority until the final payment due on July 1, 2010.

The loan agreements have covenants, the most restrictive of which requires the Institution to maintain unrestricted net assets at a market value equal to at least 1.0x outstanding indebtedness.

8. Retirement Plans

The Institution maintains a noncontributory defined benefit pension plan covering substantially all employees of the Institution, as well as a supplemental benefit plan which covers certain employees. Pension benefits are earned based on years of service and compensation received. The Institution's policy is to fund at least the minimum required by the Employee Retirement Income Security Act of 1974.

	Qualified Plan Pension Benefits	
	2001	2000
Change in Benefit Obligation:		
Benefit obligation at beginning of year	$127,889,230	$115,969,678
Service cost	3,933,908	3,669,981
Interest cost	9,652,748	9,085,277
Actuarial (gain)/loss	9,003,337	4,860,581
Benefits paid	(8,315,517)	(5,696,287)
Benefit obligation at end of year	$142,163,706	$127,889,230
Change in Plan Assets		
Fair value of plan assets at beginning of year	$182,595,594	$179,573,553
Actual return on plan assets	(14,025,221)	8,718,328
Benefits paid	(8,315,517)	(5,696,287)
Fair value of plan assets at end of year	$160,254,856	$182,595,594

	Qualified Plan Pension Benefits	
	2001	2000
Funded status	$18,091,150	$54,706,364
Unrecognized actuarial (gain)/loss	(21,492,494)	(61,207,888)
Unrecognized portion of net obligation/(asset) at transition	-	(642,223)
Unrecognized prior service cost	9,808,545	10,984,544
Net amount recognized	$6,407,201	$3,840,797
Amounts recognized in the statement of financial position consist of:		
Prepaid benefit cost	$6,407,201	$3,840,797
Weighted-Average Assumptions:		
Discount rate as of December 31	7.25%	7.75%
Expected return on plan assets for the year	10.00%	10.00%
Rate of compensation increase as of December 31	3.50%	3.50%
Components of Net Periodic Benefit Cost:		
Service cost	$ 3,933,908	$ 3,669,981
Interest cost	9,652,748	9,085,277
Expected return on plan assets and reserves	(15,167,435)	(13,982,038)
Amortization of:		
Transition obligation/(asset)	(642,223)	(647,070)
Prior service cost/(credit)	1,175,999	1,247,238
Actuarial loss/(gain)	(1,519,401	(1,774,627)
Net periodic benefit cost/(income)	$(2,566,404)	$(2,401,239)

The Institution has reflected the net periodic benefit income in nonreporting income as the change in prepaid pension cost.

	Supplemental Plan Pension Benefits 2001	2000
Change in Benefit Obligation:		
Benefit obligation at beginning of year	$3,178,410	$3,277,024
Service cost	84,148	90,501
Interest cost	227,879	233,808
Actuarial (gain)/loss	2,918	(154,526)
Benefits paid	(250,334)	(268,397)
Benefit obligation at end of year	$3,243,021	$3,178,410
Change in Plan Assets		
Fair value of plan assets at beginning of year	$ -	$ -
Employer contribution	250,334	268,397
Benefits paid	(250,334)	(268,397)
Fair value of plan assets at end of year	$ -	$ -
Funded status	(3,243,021)	(3,178,410)
Unrecognized actuarial (gain)/loss	(405,902)	(534,216)
Unrecognized portion of net obligation/(asset) at transition	-	127,993
Net amount recognized	(3,648,923)	(3,584,633)
True up to earmarked reserves	(2,815,663)	(3,573,981)
Total earmarked reserves	$(6,464,586)	$(7,158,614)
Amounts recognized in the statement of financial position consist of:		
Accrued benefit liability	$(6,464,586)	$(7,158,614)
Weighted-Average Assumptions:		
Discount rate as of December 31	7.25%	7.75%
Expected return on plan assets for the year	10.00%	10.00%
Rate of compensation increase as of December 31	3.50%	3.50%
Components of Net Periodic Benefit Cost:		
Service cost	$84,148	$90,501
Interest cost	227,879	233,808
Expected return on plan assets and reserves	(270,575)	(279,486)
Amortization of:		
Transition obligation	127,993	128,957
Actuarial loss/(gain)	(39,384)	(50,131)
Net periodic benefit cost/(income)	130,061	123,649
Investment return on invested reserves	184,563	184,631
Total periodic cost	$314,624	$308,280

The earmarked reserves are matched by a "Rabbi" Trust with $6,464,586 and $7,158,614, respectively as of December 31, 2001 and 2000

9. Other Postretirement Benefits

In addition to providing retirement plan benefits, the Institution provides certain health care benefits for retired employees and their spouses. Substantially all of the Institution's employees may become eligible for the benefits if they reach normal retirement age (as defined) or elect early retirement after having met certain time in service criteria.

	Other Postretirement Benefits 2001	2000
Change in Benefit Obligation:		
Benefit obligation at beginning of year	$20,694,387	$19,030,443
Service cost	449,011	361,902
Interest cost	1,692,874	1,490,203
Plan participants' contributions *	-	-
Actuarial (gain)/loss	2,409,584	630,033
Benefits paid	(1,046,819)	(907,756)
Plan participants' contributions	106,619	89,562
Benefit obligation at end of year	$24,305,656	$20,694,387
Change in Plan Assets:		
Fair value of plan assets at beginning of year	$15,642,206	$15,866,313
Actual return on plan assets	(1,069,644)	129,370
Employer contribution	900,520	464,718
Plan participants' contributions *	-	-
Benefits paid net of plan participants' contributions	(940,200)	(818,195)
Fair value of plan assets at end of year	$14,532,882	$15,642,206

* plan participants' contributions are netted out of benefit claims

	2001	2000
Funded status	$(9,772,774)	$(5,052,181)
Unrecognized actuarial (gain)/loss	4,332,017	(715,548)
Unrecognized portion of net obligation/(asset) at transition	9,389,045	10,242,594
Unrecognized prior service cost/(credit)	(3,159,462)	(3,686,039)
Net amount recognized	$788,826	$788,826
Amounts recognized in the statement of financial position consist of:		
Prepaid benefit cost	$788,826	$788,826
Weighted-Average Assumptions:		
Discount rate as of December 31	7.25%	7.75%
Expected return on plan assets for the year	10.00%	10.00%

For measurement purposes, a 10% annual rate of increase in the per capita cost of covered healthcare benefits was assumed for 2002 for both pre-65 and post-65 benefits.

These were assumed to decrease gradually to 5.0% and remain at that level thereafter.

	2001	2000
Components of net periodic benefit cost:		
Service cost	$449,011	$361,902
Interest cost	1,692,874	1,490,203
Expected return on plan assets and reserves	(1,568,337)	(1,574,077)
Recognized actuarial (gain)/loss	-	(69,043)
Amortization of:		
Transition obligation/(asset)	853,549	853,549
Prior service cost/(credit)	(526,577)	(526,577)
Net periodic benefit cost/(income)	$900,520	$535,957

The Institution has reflected the net periodic benefit cost in operating expenses, as the amount is reimbursed through federal awards.

Assumed health care cost trend rates have a significant effect on the amounts reported for the health care plan. A one-percentage-point change in assumed health care cost trend rates would have the following effects:

	December 31, 2001	
	1-Percentage Point Increase	1-Percentage Point Decrease
Effect on total of service cost and interest cost	$ 403,732	$ (296,270)
Effect on the postretirement benefit obligation	3,588,614	(2,915,007)

10. Commitments and Contingencies

The Defense Contract audit Agency (DCAA) is responsible for auditing both direct and indirect charges to grants and contracts on behalf of the ONR. The Institution and the ONR have settled the years through 2000. The current indirect costs recovery rates, which are fixed, include the impact of prior year settlements. While the 2001 direct and indirect costs are subject to audit, the Institution does not believe settlement of this year will have a material impact on its change in net assets or its financial position.

The Institution through its endowment fund is committed to invest $53,040,000 in certain venture capital and investment partnerships, of which $20,104,260 has been contributed as of December 31, 2001.

The Institution is a defendant in legal proceedings incidental to the nature of its operations. The Institution believes that the outcome of these proceedings will not materially affect its financial position.


Doug Weisman

R/V *Oceanus* heads into Woods Hole from Vineyard Sound as *Atlantis*, in the distance, begins a new voyage on September 10, 2001.

WOODS HOLE OCEANOGRAPHIC INSTITUTION

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