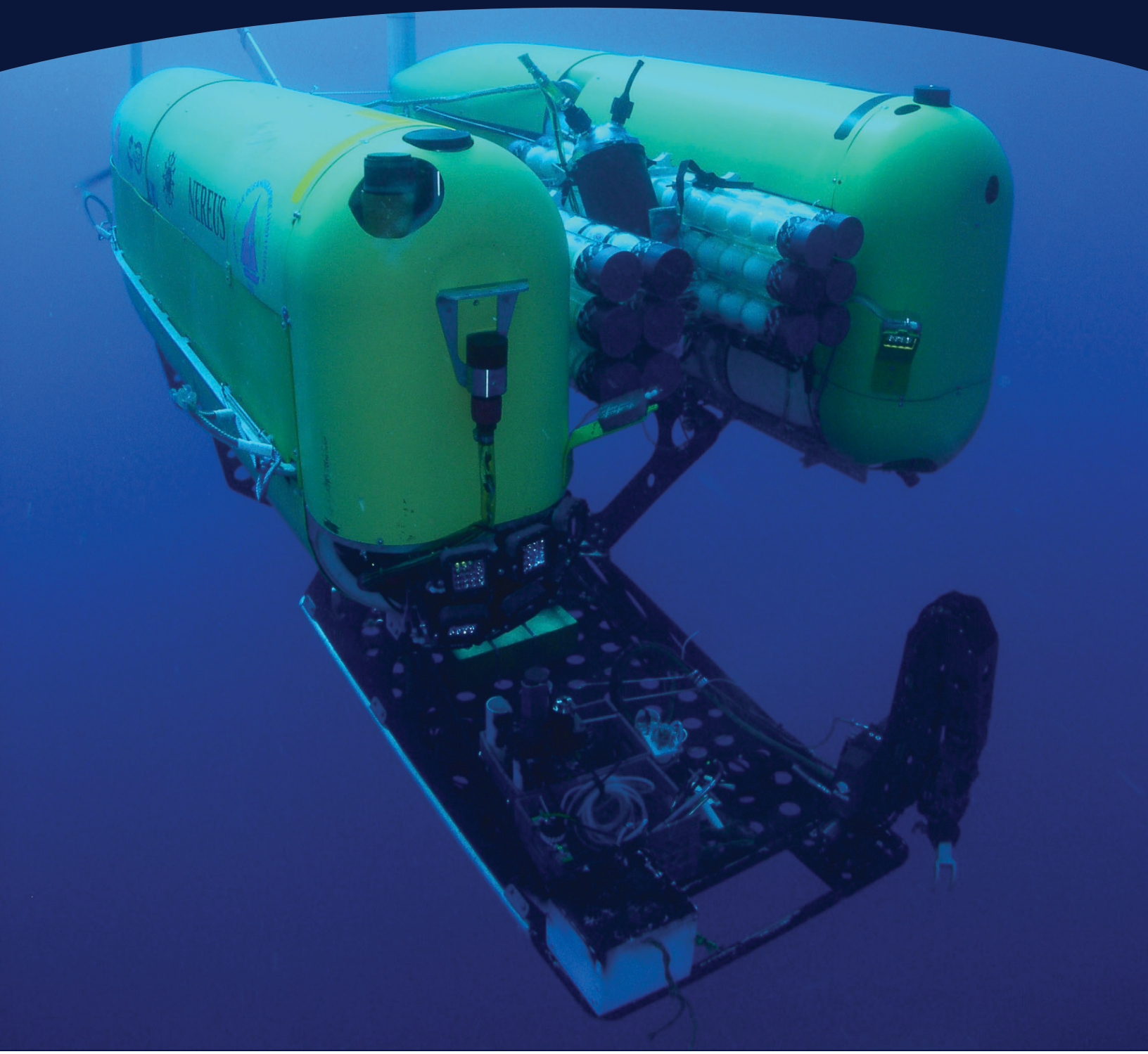
Woods Hole Oceanographic Institution

2009 Annual Report



2009 Annual Report

Woods Hole Oceanographic Institution is a private, nonprofit, marine research and engineering, and higher education organization. Its mission is to understand the oceans and their interaction with the Earth as a whole, and to communicate a basic understanding of the ocean's role in the changing global environment. Established in 1930 on a recommendation from the National Academy of Sciences, the Institution is organized into five scientific departments, interdisciplinary research institutes, and a marine policy center. The Institution conducts a joint graduate education program with the Massachusetts Institute of Technology.

COVER: In October 2009, a renowned team of oceanographers and astrobiologists set out to explore one of the deepest points in the Caribbean Sea, known as the Mid-Cayman Spreading Center, searching for life in extreme seafloor environments.

Using the new hybrid underwater robotic vehicle *Nereus*, these scientists extended their investigations beyond the reach of other research submersibles to the bottom of the Mid-Cayman Rise, whose maximum depth is just over 6,800 meters (4.2 miles) deep. (Advanced Imaging and Visualization Laboratory, Woods Hole Oceanographic Institution)

Woods Hole, MA 02543 • 508-457-2000 • www.whoi.edu

Letter from Susan K. Avery, President and Director

In 2009, WHOI was able to navigate a volatile global economy and meet a variety of challenges head-on. In a fashion typical of WHOI, we adapted to unprecedented financial pressures with collective, if occasionally painful, deliberation. We are fortunate to be a private and independent organization, with our fate determined by steps we choose to take rather than by measures imposed by others. Yet inevitably, consensus is difficult in stressful times.

Staff at all levels of the Institution worked with our trustees to determine options and implement solutions on two critical fronts: the need to transition from a defined benefit to a defined contribution retirement plan in order to restore long-term stability to our employee benefits package, and the need to strategically trim costs and increase revenue in order to reduce a shortfall in our unrestricted budget. The ultimate choices did not satisfy everyone, but everyone had an opportunity to participate in the process, and our course is now set for the greater good of all.

As usual, the Institution's research and engineering efforts added new highlights to our reputation and to our common book of knowledge about the ocean. Nereus, the latest addition to our remarkable fleet of remotely-operated and autonomous vehicles (in this case a hybrid of both), made history by returning a human presence 6.8 miles down to the Mariana Trench, the deepest part of the ocean.

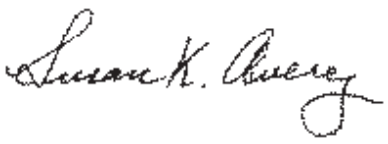
The new Ocean Observatories Initiative got underway, with WHOI as the lead implementing organization for a program that will transform ocean science through far-reaching, ocean-observing infrastructure. We also received a green light from the National Science Foundation to proceed with the next phase in the design and construction of the replacement vehicle for *Alvin*.

Overall, WHOI received $43 million in funding from the American Recovery and Reinvestment Act, nearly all of it for top-rated research proposals previously submitted but unfunded because of federal budget constraints. We attracted 12 new scientific staff members to the Institution, the MIT/WHOI Joint Program awarded 30 degrees and our researchers continue to be national and international leaders in the ocean science community.

We also formed new connections that we expect will bring additional opportunities for research collaboration. We refreshed our ties with the Korea Ocean Research and Development Institute, strengthened our relationships with Cornell University on undersea robotics and with Rensellaer Polytechnic Institute on ocean informatics, and are looking forward to expanded work in the Red Sea with King Abdullah University for Science and Technology. In December, I and several of our scientists traveled to Copenhagen to participate in the first Oceans Day at the World Climate Conference, where we joined with our partners in the Woods Hole Consortium to host a dinner for guests that included President Obama's Chief Science Advisor John Holdren. We expect the result to be new opportunities to work with international organizations and agencies in ocean observations and ocean policy.

WHOI's President and Director, Susan Avery, speaks at the first Oceans Day at the World Climate Conference held in Copenhagen.

Basic scientific research remains fundamentally an enterprise of curiosity, driven by a spirit of exploration and discovery. But WHOI does not focus on data collection and analysis alone. We also strive to share knowledge, to identify and communicate how the natural world affects all of us and how, in turn, our activities change terrestrial, atmospheric, and marine environments. WHOI has always been forward-looking by nature, building on what we know by going to sea with new vehicles, new sensors and new hypotheses. Curiosity knows no economic cycles, and so we begin a new year as strongly motivated as ever to understand Planet Ocean and to inform the public of everything we learn.



Letter from Laurence P. Madin, Director of Research

In a year of continued national economic uncertainty, WHOI continued to exhibit the promise of a strong future in both our fundamental research mission and new applications. The economic situation affected research and academic institutions across the U.S., but WHOI fared well overall in 2009. Despite a downturn in unrestricted revenue, our research continued to be exciting, important, productive and well supported.

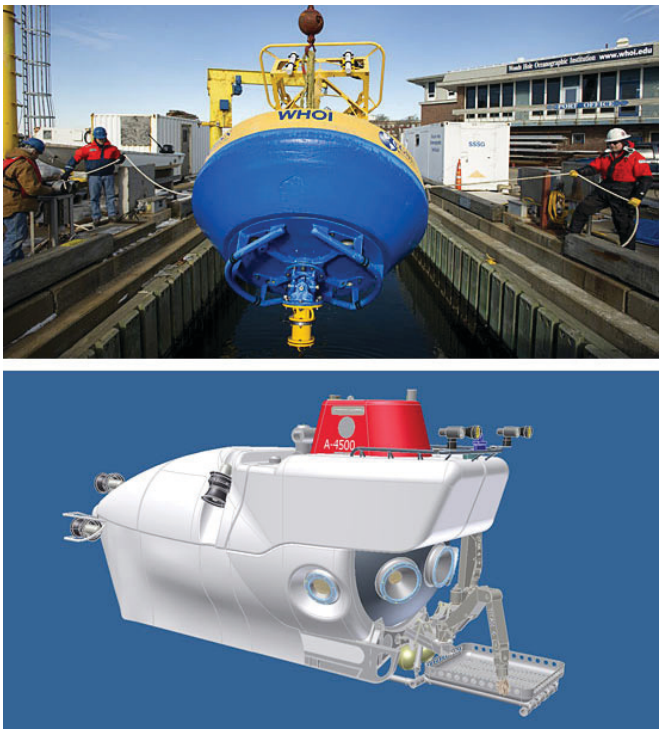
We received more federal stimulus funding in 2009 than any of our peer institutions. Stimulus dollars to the National Science Foundation benefitted WHOI in many ways. Our lead role in the Ocean Observatories Initiative (OOI) had a jump start with $15 million, and two Major Research Instrumentation projects were funded. Even better, there were 37 basic science proposals already submitted to NSF that received another $33 million, reflecting the strength of our proposals across many disciplines and programs.

Two important beginnings were made in 2009—the OOI program and the replacement Human Occupied Vehicle (RHOV) program. Both are major design and construction projects that exceed in scale and complexity anything WHOI has done in the past. Both require new staff, and the hiring of engineers, technicians and project managers began in 2009.

To provide needed space for OOI, we expect to soon begin construction of the new Laboratory for Ocean Sensors and Observing Systems, funded by a grant from the National Institute of Standards and Technology. Besides accommodating the OOI program, the Laboratory will provide expanded space for the Ocean Bottom Seismometer Lab and the Martha's Vineyard Coastal Observatory, and provide a focal facility for development of sensors and instruments across the Institution. We look forward to its opening in the summer of 2012.

These large projects will be an important part of WHOI for years to come, and they have raised questions about the nature of WHOI's future portfolio. What is the effect of large contract-based projects on our basic mission of oceanographic research? Will this new funding, and need for additional staff, space and facilities strengthen the Institution or distract us from our principal focus? Will our criteria and process for hiring and promotion need to evolve?

I am confident that WHOI will adjust to and benefit from these new ventures and responsibilities without diluting our independent, curiosity-driven research. These new opportunities arise precisely because of our strong core of academic excellence. They build upon our scientific work. Moreover, WHOI will be the institution best equipped to transform scientific visions into operational realities.



Two important beginnings were made in 2009—the Ocean Observatories Initiative (OOI) program and the replacement Human Occupied Vehicle (RHOV) program. Both are major design and construction projects that exceed in scale and complexity anything WHOI has done in the past. In the top photo, the first buoy designed for the OOI program undergoes testing at the dock. The bottom image is an engineering drawing showing the most recent RHOV design. (Woods Hole Oceanographic Institution)

WHOI scientists, engineers and technicians will continue to be innovators and creators, generating new scientific knowledge and technologies. As we broaden and diversify our base of support, we help ensure the future growth and stability of the Institution, and strengthen our ability to weather future economic setbacks.

WHOI's future looks both strong and diverse. We will continue to build that future on the foundation of independence, creativity and scholarship that has been our defining culture for 80 years.

Larry Madin

Christopher J. Winslow, CFO and Vice President for Finance and Administration

We are pleased to present the 2009 unaudited financial statements of the Woods Hole Oceanographic Institution (WHOI). WHOI completed 2009 in good financial condition largely because of the strong returns of the endowment and the support of organizations and individuals who recognize the long term benefits of basic research.

Statement of Financial Position

WHOI continues to have a strong balance sheet. At December 31, 2009, WHOI's total assets were $480 million, total liabilities were $199 million and total net assets were $281 million.

Net assets represent the accumulated financial strength of a not for profit organization and are an important gauge of its ability to carry out its mission. Included in the liabilities is the Massachusetts Health and Educational Facilities Authority bond debt of $63.4 million.

The endowment, $310 million represents 65% of the total assets at December 31, 2009.

Statement of Activities

WHOI's total operating revenues increased by $3 million: from $169 million in 2008 to $172 million in 2009.

$15.3 million of endowment income and appreciation was distributed to operations as follows:

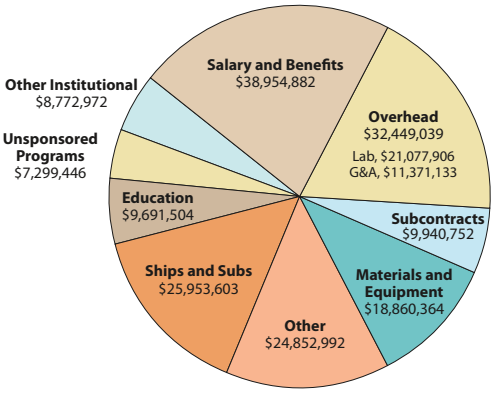
- Education $6.3 million
- Research $5.3 million
- Unrestricted $3.7 million

The Institution had overhead costs of $76.5 million, and approximately 62% of that amount, $47.2 million, was recovered from the government and non-government research. The remainder was an institutional expense.

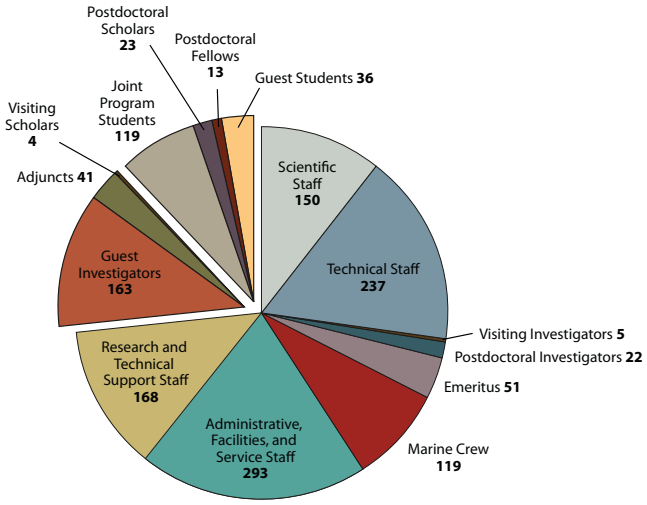
WHOI paid $5.1 million in interest during 2009 and $.7 million in principal payments on the $63.4 million outstanding debt in 2009. The Federal government allows us to include interest and depreciation in our overhead rates and will reimburse us for these expenses.

Summary

The Institution's commitment to understanding the oceans is unchanged; however, the federal funding environment continues to challenge our investigators. WHOI has responded by finding new funding sources in other government agencies and in industry. We are also continuing the process of evaluating our administrative systems and allocating resources to support an evolving strategic plan.



2009 Operating Expenses



2009 People

WHOI employees totaled 1045 in 2009, students and postdocs totaled 191, and others affiliated with the Institution totaled 208.

Marine Operations

WHOI has a long history of operating a variety of research vessels and developing innovative vehicles, instruments and other technologies that provide access to the sea for observations, experimentation, and data collection. In 2009 the three large research vessels that WHOI operates—Knorr, *Atlantis* and *Oceanus*—continued to serve the U.S. scientific community with cruises in the eastern Pacific and North Atlantic oceans, and the Mediterranean Sea, while our coastal vessel, Tioga, operated in New England waters.

The National Deep Submergence Facility, consisting of the HOV *Alvin*, the ROV Jason, and the AUV ABE/Sentry, had vehicles working in the western and eastern Pacific and in the Caribbean Sea. The Center for Ocean, Seafloor and Marine Observing Systems (COSMOS) continued to oversee the Martha's Vineyard Coastal Observatory and coordinate observing systems under development at WHOI, while the NSF-funded Ocean Observatories Initiative accelerated its efforts to design and construct new marine observing systems for global and regional use.

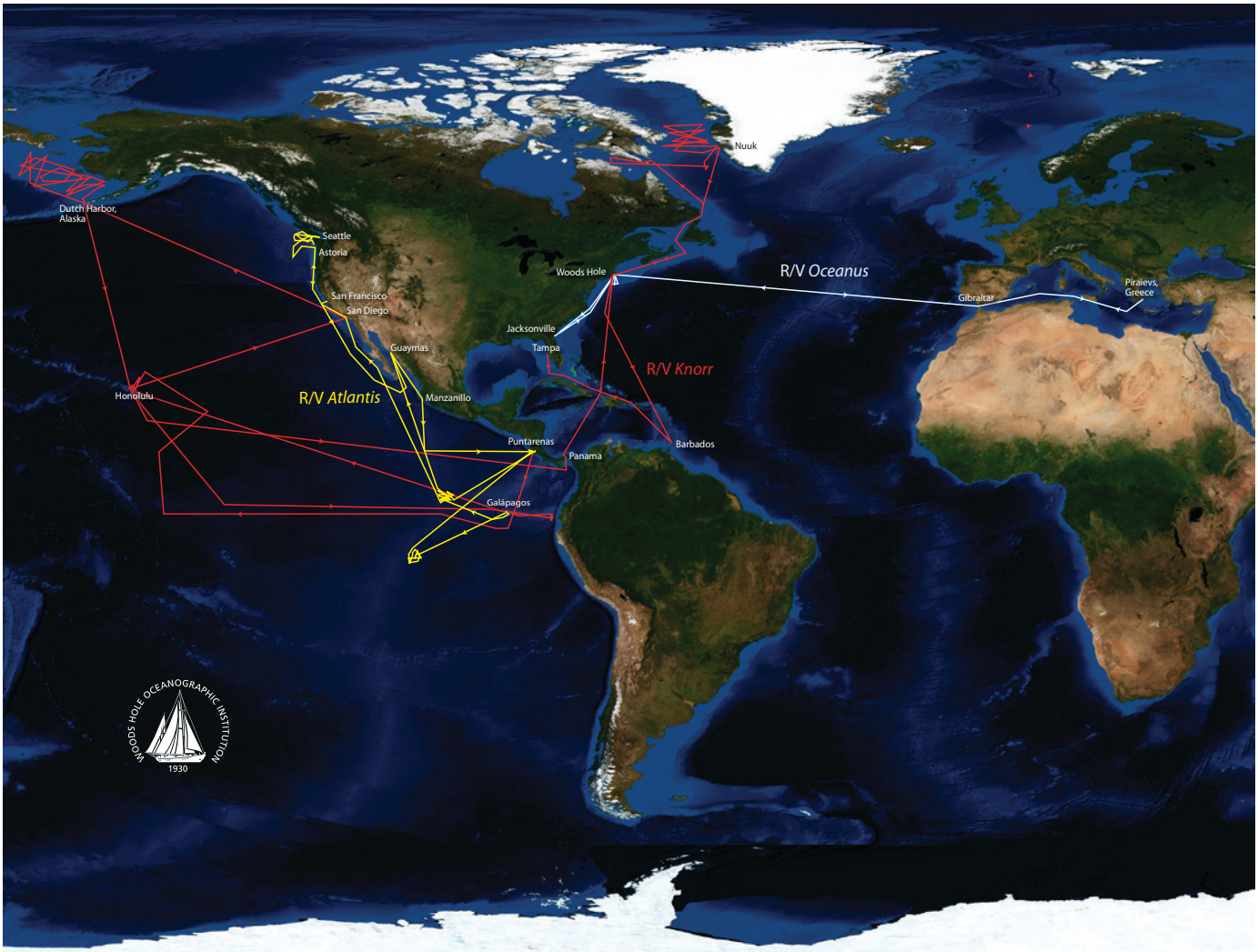
WHOI continues to build on its very strong tradition of developing cutting-edge underwater technology for deep-sea research. In May, Nereus—a newly-built vehicle that can operate either as an autonomous underwater vehicle or as a remotely operated vehicle—successfully conducted a dive to Challenger Deep (10,902 meters) in the Mariana Trench in the western Pacific Ocean. As the only vehicle in the world capable of reaching the deepest parts of the ocean, Nereus opens up a whole new and previously inaccessible part of the planet for exploration by the U.S. community.

Substantial progress was also made this year on the NSF-funded project to complete a major upgrade to the HOV *Alvin*. A major milestone in the construction of the new personnel sphere (capable of withstanding pressures at 6,500 m water depth) was reached in August with the successful welding together of the two titanium hemispheres that were forged in 2008. Work continues on insert welding for the hatch, penetrator plate, and viewports. This is the first time that a project involving forging and welding of such thick (3") titanium has ever been undertaken in the U.S., making the design and fabrication of the sphere very challenging. However, with much of the technically difficult work complete, we look forward to delivery of the personnel sphere in March 2011.

A brown pelican (Pelecanus occidentalis) checks out the WHOI-operated research vessel *Atlantis* off the coast of the Galápagos Islands in January 2009. The research vessel and the *Alvin* submersible were in the area recovering ocean-bottom seismometers and other seafloor instruments. (Photo by Brendon Todd, Woods Hole Oceanographic Institution)

A second milestone that was reached in December was the successful completion of a Preliminary Design Review conducted by a panel selected by the National Science Foundation. This involved a complete review of the engineering design and scope, budget, schedule and management of the first stage of the project, due to be completed by the end of 2011, which includes installation of the new personnel sphere into *Alvin*'s modified frame. This vehicle, while still diving to only 4,500 meters, will provide improved viewport configuration for the pilots and observers, more interior space, improved imaging and lighting systems and an increased ability to carry equipment and samples. The second stage, to be completed when battery technology and funding permit, will upgrade all other vehicle components to a 6,500 meter depth capability, and will also install a different type of batteries that will enable the submersible to make longer dives. The result will be a next-generation submersible that can reach 98% of the seafloor.

—Susan Humphris,
Acting Vice President of Marine Facilities/OPS



Woods Hole Oceanographic Institution • 2009 Cruise Tracks

R/V *Atlantis*

Days at sea: 212; Cruises: 11; *Alvin* dives: 92
Investigators Served: 233; Nautical miles: 22,108

In January, R/V *Atlantis* recovered 45 ocean bottom seismometers that had been deployed for a year in an area of active transform faults on the East Pacific Rise. The purpose of this work was to investigate earthquake predictability by examining foreshock sequences of earthquakes.

The second cruise of the year focused on retrieving instruments and data from two Ocean Drilling Program boreholes at the subduction zone off Costa Rica. Together with data collected previously, these new results will provide a valuable long-term record of hydrologic, geochemical, and geodynamic activity at this subduction zone. During this cruise, DSV *Alvin* completed its 4,500th dive!

This was followed by another cruise on the Costa Rica margin to investigate the structure, function and evolution of methane-derived carbonate ecosystems. R/V *Atlantis* then spent two months out of service in San Diego, Calif. The vessel then departed for *Alvin* dives and the deployment of resistivity probes at hydrothermal vents on the Juan de Fuca Ridge. This was followed by operations using the remotely-operated vehicle ROPOS to install nodes for the Neptune cable observatory on the Juan de Fuca tectonic plate as part of the Ocean Observatories Initiative, and then *Alvin* dives at ODP sites to download data and collect instruments from subseafloor observatories.

During the following transit to San Francisco, two VIP

dives were conducted—one for Susan Avery and a representative from NSF, and one for two Navy representatives. The next cruise involved exploration and evaluation of petroleum seeps using *Alvin* and the AUV Sentry. R/V *Atlantis* then headed for the Guaymas Basin in the Gulf of California. The first cruise there used sidescan sonar and seafloor imaging to investigate the distribution of off-axis sills and their implications for the thermogenic flux of carbon in this sedimented rift basin.

Two cruises followed to study the distribution and diversity of thermoacidophiles associated with hydrothermal vent deposits. This included collection of vent deposits and deployment of thermocouple arrays to study microbial colonization and succession.

R/V *Knorr*

Days at sea: 251; Cruises: 9
Investigators Served: 184; Nautical miles: 46,233

At the beginning of this year, R/V *Knorr* conducted two cruises with the new long-coring system: the first to study the oceanographic control and distribution of subseafloor microbial life along a transect to Hawaii, and the second near the Galápagos Islands for paleoceanographic purposes.

These cruises were followed by collaborative research with the HOTS (Hawaii Ocean Time-series: Biogeochemistry and Ecology Component) program off Hawaii, and sampling for the GEOTRACES program. R/V *Knorr* then transited to Dutch Harbor, AK, for investigations of the impacts of sea ice on the hydrographic structure and nutrients of the Eastern Bering Sea shelf during summer.

The end of July brought the vessel back to Honolulu, HI, where it began work for the Navy using multiple autonomous underwater vehicles. After a long transit to Woods Hole, R/V *Knorr* prepared for departure to Nuuk, Greenland, to recover several moorings and conduct water column work. The vessel then participated in a continuing interna-

tional effort to quantify and monitor the variability of fluxes connecting the Arctic and North Atlantic Oceans. The measurements collected in this seven year program will help researchers understand the role of the Arctic and Sub-Arctic in steering decadal scale climate variability.

In mid-November, *Knorr* made the transit from Woods Hole to Tampa, FL, for a major maintenance and shipyard period.

R/V *Oceanus*

Days at sea: 113; Cruises: 7
Investigators Served: 49; Nautical miles: 18,412

Although we had expected R/V *Oceanus* to be laid up for 2009, final negotiations with NSF and ONR resulted in the ship being assigned 112 days of work, most of which occurred in the second half of the year. After being out of service for the month of January, R/V *Oceanus* transited to Jacksonville, Florida, for maintenance during a yard period. It was then out of service from the beginning of March through early June when it departed to perform various mooring operations at the continental slope off Woods Hole.

In late July, the vessel departed for Piraeus, Greece, to perform water column sampling and coring operations to investigate how certain micro-organisms are adapted to living in hypersaline waters. At the end of July, R/V *Oceanus* departed Piraeus, Greece, for transit to Port Everglades, FL, but was re-routed to Woods Hole due to a delay in the planned scientific activities off Florida. A short cruise was then conducted to collect live benthic foraminifera.

At the beginning of October, R/V *Oceanus* departed Woods Hole for the delayed cruise to deploy two buoys on a single-point, inverse-catenary mooring to measure wind stress and surface wave properties at a planned anchor position about 300 nautical miles due east of Jacksonville, FL.

Upon completion of scientific activities, the vessel began its return to Woods Hole when it was determined that the mooring had broken loose. R/V *Oceanus* was diverted for reconnaissance and was able to recover one of the buoys. It then conducted a cruise in the Gulf of Maine and Bay of Fundy where scientists studied red tides (toxic Alexandrium blooms) and collected suspended cyst samples just off the northern flank of Georges Bank.

R/V *Tioga*

Days at sea: 92; Investigators Served: 57

In January, one of two gear bearings on R/V Tioga's port propulsion engine failed leading to an unscheduled maintenance period. The engine was reinstalled in early February with sea trials conducted the following day. Tioga was then involved in a variety of coastal projects in Massachusetts Bay, as well as continuing to support work at Martha's Vineyard Coastal Observatory (MVCO). Mooring and tripod deployments were completed south of Martha's Vineyard, and a new multi-corer was tested successfully.

The month of May was almost completely devoted to right whale tagging and the deployment of whale detection moorings in the shipping lanes east of Cape Cod, with Tioga mainly operating out of Chatham, Mass. June and July brought the expected seasonal return of red tide blooms to New England. Tioga conducted some "emergency" duty operating out of Portland, ME, and Portsmouth, NH. The summer months kept R/V Tioga busy with a full schedule of varying types of work.

As in years past, one week in early August was dedicated to educational day trips in Buzzards Bay for the WHOI Summer Student Fellows. R/V Tioga also worked in Nantucket Sound and south of Martha's Vineyard with tripod

recoveries, CTD surveys, and AUV REMUS work. Many days were spent at MVCO performing maintenance and installations.

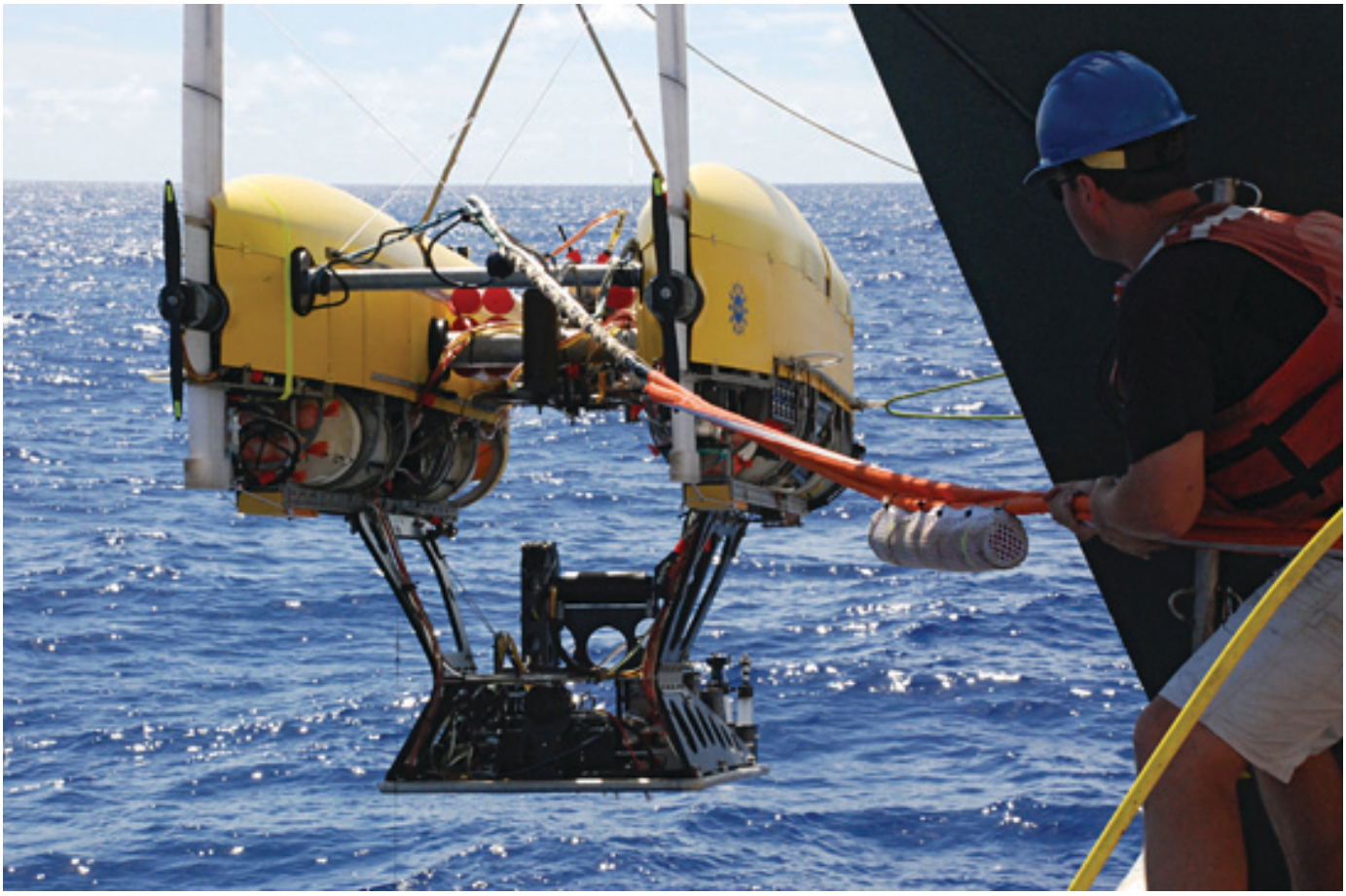
In September, Tioga operated out of Scituate Harbor to support an Oregon State University project on board the R/V Sharp performing dye studies and the study of shoaling internal waves in Massachusetts Bay. Work was also performed at Massachusetts Maritime Academy's pier at Taylor's Point conducting ADCPs and bathymetry surveys.

Applied Ocean Physics & Engineering

Applied Ocean Physics & Engineering (AOPE) personnel and robotic vehicles made headlines this past year by diving to the deepest ocean depths, recording an underwater volcanic eruption and attending the climate change conference in Copenhagen, in addition to continuing cutting-edge scientific research and technological development in the core departmental disciplines.

The newly-built Nereus completed a successful dive to 10,902 meters (6.8 miles) into the Mariana Trench in May 2009 and returned with video and samples of the location. Nereus dove nearly twice as deep as other currently operating research submarines and had to withstand pressures 1,000 times greater than at Earth's surface. This unique hybrid vehicle is an autonomous underwater vehicle (AUV) and a remotely operated vehicle (ROV), able to either autonomously map large areas of the seafloor or connect to a surface ship via a lightweight fiber-optic tether to send back images and collect samples with its manipulator arm. During autonomous operations and un-tethered ascents, the vehicle uses the WHOI Micro-Modem to provide an acoustic communication link to the surface for monitoring and control.

A team of engineers led by Principal Investigators Andy Bowen, Louis Whitcomb, and Dana Yoerger tackled and solved the many engineering challenges that arose while attempting to construct a vehicle capable of reaching the deepest areas of the ocean. Because traditional robotic systems with steel-reinforced cables were too heavy to be used in the extreme pressures found at the desired depth, fiber-optic technology was adapted to replace the heavier cables. Ceramic spheres were designed to be used for flotation instead of the traditional syntactic foam found on vehicles like *Alvin* or Jason, creating a product that could withstand 16,500 pounds of pressure per square inch yet would shatter if dropped. AOPE engineers also developed the Nereus robotic manipulator arm so that it would operate under intense



The new deep-sea explorer Nereus is launched from the research vessel Kilo Moana during a June 2009 expedition to the Challenger Deep in the Mariana Trench. James Buescher from SPAWAR Systems Center Pacific, which developed the fiber-optic cable link used for real-time communications with the vehicle, tends the umbilical that runs from Nereus to the float pack of the depressor during the launch. (Photo by Catherine Offinger, Woods Hole Oceanographic Institution)

pressure and extreme temperatures.

Another historic event occurred when the ROV Jason, also developed by a team of AOPE engineers and researchers, recorded an underwater volcanic eruption, the first time such an event has ever been captured on film. National Geographic named the resulting video as one of the top 10 of the year.

Rich Camilli and Judy Fenwick were among the WHOI contingent that traveled to Copenhagen to attend the international climate change conference, which for the first time included an Oceans Day focusing on the important role of the ocean in climate change and the health of the Earth as a whole. Other international outreach efforts included a keynote address by Brendan Foley for the US-Egypt Joint Science and Technology Fund at the State Department headquarters in Washington, DC and the promotion of interdisciplinary science programs in Algeria and Egypt.

Lifetime achievements by AOPE staff were also recognized in 2009. Jim Lynch received the Walter Munk Award from The Oceanography Society in recognition of his distinguished work and research in ocean acoustics. Dana Yoerger was honored with the 2009 Lockheed Award for Ocean Science and Engineering, presented each year to an individual who has demonstrated the highest degree of technical accomplishment in the field of marine science, engineering or technology. Steve Elgar was selected by the Office of the Secretary of Defense to be a National Security Science and Engineering Faculty Fellow (NSSEFF) and is the only earth scientist in the group of selected fellows. The fellows are granted significant research funding for five years and help to advise the Office of the Secretary of Defense on science issues.

Beyond the international headlines, the day-to-day scientific and technological work continues, often without fanfare or recognition while important puzzle pieces containing some of Earth's mysteries are snapped together. For example, Jim Ledwell and Dennis McGillicuddy are working with numerous colleagues in the East Pacific Rise Experiment to investigate larval dispersion at a mid-ocean ridge. Britt Raubenheimer and Steve Elgar conducted a three-month field experiment with students and colleagues in the Skagit Bay tidal flat area of Washington. The field observations are being used by joint-program student Vera Pavel and student Fellows Dana Giffen, Sean Kilgalin, Regina Yopak, and Seth Zippel to investigate tides, waves and currents on a tidal flat with a large river and associated distributory channels. Dave Ralston, Rocky Geyer, and Jay Sisson deployed quadpods in the Hudson River to determine the influence of surface waves on re-suspension of sediment in the river's shallow reaches. Jim Preisig is leading a team of researchers to study underwater acoustic propagation and communications at the Martha's Vineyard Coastal Observatory.

Often, the best results came from collaborations. Mark Grosenbaugh, Don Peters, and Walter Paul teamed up with other engineers and scientists to design buoys that will listen for whale calls and communicate with satellites to warn ships whenever whales are detected in a given area. Hopefully, these buoys will help mitigate the threat that increasing ship traffic represents to the remaining population of less than 400 North Atlantic right whales. The Digital Recording Tags (DTAG) team tagged right whales and humpback whales in the Stellwagen Bank and the Arctic Polar Circle with tags designed and built by the team to study their behavior. Hanu Singh and John Bailey worked together to build and modify a model airplane designed to take aerial images of Arctic Ocean ice floes.

The Acoustic Communications Group, including Peter Koski and Lee Freitag, provided Acoustic Communications (ACOMMS) support to Arctic Submarine Laboratory's ICEX2009 exercise. These exercises are held bi-annually north of Prudhoe Bay, Alaska, where a temporary ice camp is built to support the tracking and communications systems. The 2009 exercise included two Los Angeles class submarines, the SSN Helena and SSN Annapolis. Acoustic communications is a key technology for arctic operations and exploration, providing long-range wireless connectivity for submarines or unmanned vehicles operating below the ice.

The building of the new *Alvin* is scheduled to occur in the coming decade, when it will first be overhauled to continue to operate at 4,500 meters, with a second phase of construction planned to allow *Alvin* to reach depths to 6,500 meters. With high-tech tools like *Alvin*, Jason and Nereus, together with the collaborative research skills represented by this department, we look forward to a new era of ocean exploration in the coming decade.

— John Trowbridge, Department Chair and Sheila Hurst, Administrative Professional

Biology

Staff members in the Biology Department contribute extensively to the broader scientific community, nationally and internationally. The staff provides leadership and other service to federal agencies, scientific journals, universities, the National Research Council and other national and international committees. Staff members also fill lead roles in the WHOI Ocean Institutes, the Center for Oceans and Human Health, the newly formed NOAA Cooperative Institute CINAR, and the vital fleet committee of the University-National Oceanographic Laboratory System.

Two contributions are particularly noteworthy during 2009: (1) Don Anderson's Congressional testimony to the U.S. House of Representatives Committee on Science and Technology Subcommittee on Energy and Environment on harmful algal blooms; and (2) the recognition of the International Polar Bear Science Team, of which Hal Caswell is a member, as a finalist for the Service to America - Environmental Medal. Such leadership activities benefit our own scientific enterprise and help maintain the vitality of oceanography.

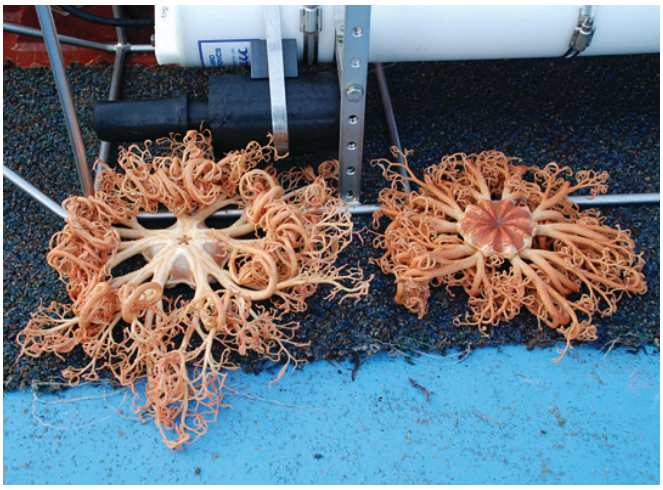
In its research endeavors, the Biology Department strives to improve its understanding of the ecology and evolutionary biology of living organisms in the sea. Our scientists use a variety of tools to observe, experiment and model interactions among species and between species and their environments.

In 2009, members of the WHOI Biology Department continued their worldwide investigations of life in bodies of water from oceans to lagoons. Their subjects ranged in size from microscopic to massive marine mammals; their interests from genes to entire ecosystems.

Among the expeditions undertaken by Biology staff in 2009 were a cruise to the Phoenix Islands Protected Area near the Republic of Kiribati in the South Pacific; studies of the corals of the Red Sea through collaboration with the King Abdul University of Science and Technology (KAUST); a multi-disciplinary voyage to the Bering Sea aboard the U.S. Coast Guard Cutter Healy to examine the effects of climate change on the Arctic ecosystem; and coastal cruises to examine the distribution of harmful algal blooms in the North Atlantic.

Four new Assistant Scientists joined the staff of the Biology Department in 2009, adding new expertise in a variety of sub-disciplines and contributing to the intellectual energy of the department.

• Matt Johnson is a microbial ecologist with interests in the ecology of microzooplankton grazers and the evolution and ecology of acquired phototrophy through endosymbiotic associations of organisms (such as corals and ciliates) with algae. He combines experimental approaches and molecular analyses to determine the ecological and evolutionary relationships of phototrophs and their hosts.



Basket stars were collected in Barrow Canyon, Alaska, using a Tucker Trawl during a research cruise led by biologist Carin Ashjian in 2009. Basket stars are a type of brittle star that have a series of complexly branched arms which are used to catch plankton. (Photo courtesy of Carin Ashjian, Woods Hole Oceanographic Institution)

• Julie Kellner is a conservation biologist who focuses her research on population and community dynamics within the context of spatial heterogeneity, human impacts and environmental regulations. She uses modeling techniques in theoretical ecology and spatial analysis to better understand the scientific elements of marine spatial planning.

• Sam Laney is a phytoplankton ecologist who develops new tools to examine photosynthesis and growth in oceanic phytoplankton and measure the growth of individual cells. He uses experimental and observational techniques, numerical modeling and satellite remote sensing to examine phytoplankton ecological dynamics.

• Gareth Lawson is a biological oceanographer whose interests focus on the physical and biological factors that influence the distribution and movement of pelagic organisms. His research is highly collaborative with physical oceanographers and ocean engineers and he is developing new acoustic tools to study zooplankton and their predators.

—Judy Mcdowell, Department Chair

Geology & Geophysics

The Department of Geology & Geophysics (G&G) carries out research that ranges from the coastline to the deep ocean and from the ice sheets of Greenland to islands in the tropics. In 2009, the total G&G Department staff numbered approximately 77, plus 36 Postdoctoral investigators, scholars, Fellows and WHOI/MIT Joint Program (JP) graduate students.

It was an active year for promotions in the G&G Department with a total of nine promotions, including tenure for Associate Scientists Glenn Gaetani, Olivier Marchal, Jeff McGuire and Jeff Donnelly. Three scientists were promoted to Associate Scientist: Sarah Das, Alison Shaw and Adam Soule. On the Technical Staff, Virginia Edgcomb was promoted to Research Specialist and Kathryn Rose to Research Associate II. Tim Kane was promoted to Engineering Assistant III in the Ocean Bottom Seismology (OBS) group and Skye Moret-Ferguson to Research Assistant II in the Coastal Systems Group.

The two new additions to the Scientific Staff in 2009 were Kris Karnauskas, a climate dynamics researcher, and Yajing Liu, a theoretical geophysicist working on subduction earthquakes; they joined the department as Assistant Scientists. Bob Detrick and Debbie Smith continued their assignments at NSF, Bob as Director of the Earth Science Division (EAR) and Debbie as Program Manager in Ocean Drilling Program (OCE). Departures included Ken Sims who went to University of Wyoming and Ilya Buynevich, who went to Temple University. Among those receiving notable awards and recognition in 2009 was Senior Scientist Jian Lin, who was honored at the end of 2008 as a Fellow of American Association for the Advancement of Science (AAAS) and who also received a WHOI Senior Scientist Chair in 2009.

Summer Student Fellow Garrett Mitchell (right), of the University of Maryland at College Park, spent his summer working with WHOI geologist Adam Soule. The two used seafloor imagery collected by Autonomous Benthic Explorer (ABE) to map lava flows, hydrothermal vents, and biologic communities on the Southern Mid-Atlantic Ridge (5˚S). The image behind them is a mosaic, where each of the several thousand seafloor photographs is pieced together like a puzzle based on the location and attitude (pitch, roll, yaw) of the vehicle. (Photo by Tom Kleindinst, Woods Hole Oceanographic Institution)

Associate Scientist Sarah Das received the 2009 Penn State University Alumni Achievement Award that recognizes alumni 35 years and younger for their extraordinary professional accomplishments.

As always, members of the G&G Department traveled to all corners of the world over the course of the year to carry out their research. Staff participated in research cruises in the Pacific, Atlantic and Indian Oceans and the Mediterranean Sea on board US, Dutch and Japanese research vessels. Land-based fieldwork and lab work was conducted around the US and in Belize, Bermuda, Greenland, Guam, Northern Canada, Oman, Pakistan, Romania and Tahiti.

The year began with the first full science missions for the Long Core facility on the Research Vessel *Knorr*, the culmination of several years of development and testing. This facility is capable of taking giant piston cores up to 46 meters (150 feet) in length, using a specially modified winch and handling system installed on R/V *Knorr*. Jim Broda, Bill Curry, Al Gagnon and Kathryn Rose of the G&G Department participated in these cruises, with Jim as head of operations. The cruises were a success despite suffering from a serious problem during one cruise, which required reengineering the brake on the main cable spool. Kudos go to Jim and Al for their stellar efforts in getting the equipment back on line. The *Knorr* has a fully booked schedule coming up in 2010 with the Long Core facility.

Springtime brought an international InterRidge meeting to Woods Hole, along with a Morss public colloquium, "Deep-Sea Mining of Seafloor Massive Sulfides: A Reality for Science and Society in the 21st Century." The workshop brought 98 researchers, policy makers, conservation organizations and industry representatives from more than 20 nations, including Nii Odunton, the Secretary General of the International Seabed Authority (ISA). The ISA is the United Nations body tasked with regulating the seafloor resources of the sea beyond national jurisdictions. Early in 2008 the ISA issued draft regulations for authorizing the leasing of large tracts of the open ocean seafloor for commercial exploration for metal minerals (see the Web site, http://www.whoi.edu/workshops/deepseamining). The InterRidge workshop was convened to bring various stakeholders together and to discuss this potential development and to provide ISA with input on their regulations.

Jeff Donnelly and the Coastal Systems Group were active this summer with fieldwork, mostly on Martha's Vineyard, aimed at understanding the evolution of sandy barriers in southern New England. The goal is to understand how the barriers have responded to past changes in storm patterns and rates of sea-level rise. As part of this effort, Andrew Ashton is developing numerical shoreline models and Marine Policy Center colleagues Porter Hoagland, Hauke Kite-Powell and Di Jin are developing behavioral/economic models, which together should be able to simulate future barrier changes under a variety of predicted climate change scenarios.

Liviu Giosan participated in the first scientific cruise to the Indus delta shelf on the Pakistan coastline, using the Dutch Research Vessel Pelagia to collect over 1,000 km of chirp-sonar and multichannel seismic data along with sediment cores. These data are expected to shed new light on sediment transfer from the continents to the oceans and on monsoon development during the Holocene and its impact on continental margin development. Liviu also did additional fieldwork on the Himalayan Indus tributaries in Pakistan to understand the interaction between the Indus civilization and the river within the dynamic environment of the Indus floodplain.

In September, a second Morss colloquium, "Where the land meets the sea: Managing Shoreline Change Over the Next 100 Years," was convened by Bill Thompson. The colloquium followed a very successful Geodynamics Seminar course on Climate Change earlier in the year. Finally, in November, Anne Cohen and Dan McCorkle along with other WHOI and MBL researchers hosted a popular and timely short course on Ocean Acidification, with 35 participants from 14 countries.

—Maurice Tivey, Department Chair

Marine Chemistry & Geochemistry

Marine Chemistry and Geochemistry (MC&G) Department scientists are engaged in a broad array of research topics that examine the workings of the ocean—from its surface to, and even below, the seafloor—as well as the interactions between the ocean and other components of the Earth system. The questions they address encompass processes that take place over a wide range of spatial and temporal scales and include anthropogenic influences on the ocean.

Our approaches to these questions are continually evolving and include field sampling and experiments, laboratory-based experimental studies, laboratory-based analytical measurements, and computer modeling efforts. These questions also encompass different scales of study. In this context, MC&G scientists continue to undertake a blend of small, single-investigator projects, and to coordinate and participate in large multi-investigator and often multi-institutional initiatives. The ability to execute projects at these different scales is one of the factors that contribute to the on-going success of the research endeavors within MC&G and WHOI as a whole.

At the multi-institutional level, 2009 saw the launch of a major NSF-funded project led by Bernhard Peucker-Ehrenbrink that involves scientists from WHOI, the Woods Hole Research Center and the University of New Hampshire, and partnerships with East China Normal University, Shanghai, China; the Centre de Recherches Pétrographiques et Géochimiques, Nancy, France; and the University of the Fraser Valley, British Columbia, Canada. A major goal of this project is to initiate sustained observations of carbon cycling and related biogeochemical processes in six large rivers around the world—the Yangtze (Changjiang), Ganges, Brahmaputra, Congo, Lena and Fraser. Field programs were conducted on the Yangtze and Fraser rivers this past summer, with the latter expedition being spearheaded by Peucker-Ehrenbrink in conjunction with Research Associate Daniel Montluçon and MIT/WHOI Joint-Program student Britta Voss.

Other field activity this year included visits by MC&G scientists to Antarctic ice shelves, deep-sea hydrothermal systems in the Pacific and coral reefs in the Red Sea. Mak Saito and members of his research group made two visits to McMurdo Sound in Antarctica in 2009. In conjunction with

MC&G scientist Bernhard Peucker-Ehrenbrink and MIT/WHOI Joint Program student Britta Voss collect water samples from the Fraser River, British Columbia during a field program in the summer of 2009. (Photo by Daniel Montlucon, Woods Hole Oceanographic Institution)

his colleagues at the J.C. Venter Institute, Saito is using a combination of proteomics and genomics to examine the diversity of phytoplankton that form the base of the food chain.

Konrad Hughen undertook fieldwork in the Red Sea in a study supported by King Abdullah University of Science and Technology. Hughen's project examines the potential vulnerability of coral reefs in the Red Sea to climate and environmental changes. He is also using the coral skeletons deposited over time to infer how the Red Sea has varied in the past. For this effort, he has successfully collected cores from corals and is examining their chemical composition, which reveals past temperature variations and other surface water changes recorded in the coral skeletons. Meg Tivey, working with Anna-Louise Reysenbach (Portland State University), carried out two sets of in situ experiments in the field to investigate microbial colonization of deep-sea hydrothermal deposits in the Pacific. The experiments, conducted at hydrothermal vents in the Lau Basin (SW Pacific) using the ROV Jason 2, and in the Gulf of California (Guaymas Basin) using the HOV *Alvin*, entailed razing active chimneys and placing arrays of temperature probes over the active flow in order to record the temperature history as the chimneys grew back. Molecular biological tools are being used to reveal the members of the microbial communities that developed during the re-growth of the chimneys.

Of course, collection of unique and valuable samples of the types described above in many cases represents only the starting point of an investigation. The development and application of novel analytical methods forms an essential component of many studies and is crucial for advancing our understanding of processes that drive the cycling of chemicals in the ocean.

Such analytical innovations continued to yield important advances in 2009. For example, Phoebe Lam is using synchrotron X-ray spectroscopic techniques to examine how the chemical form of iron supplied by atmospheric and marine particles becomes available to phytoplankton communities. This project, called SIRENA (Sources of Iron to the Eastern tropical North Atlantic), involves collaborations with fellow MC&G scientist Ken Buesseler, and Henrieta Dulaiova (formerly a MC&G postdoc, now at the University of Hawaii.) Its goal is to test the hypothesis that the continental margin is an important source of iron to the water column of eastern tropical North Atlantic, a region whose main iron source is generally thought to be from Saharan dust. Aerosol, sediment and suspended marine particulate samples are analyzed at synchrotron x-ray facilities such as the National Synchrotron Light Source at Brookhaven National Laboratory and the Advanced Light Source at the Lawrence Berkeley National Laboratory. Synchrotron x-ray fluorescence mapping and x-ray absorption spectroscopy is combined to determine the distribution of iron that occurs as iron oxides, iron silicates, and iron sulfides (pyrite), which are distinguishable based on their x-ray absorption spectra. Importantly, this analytical technique has revealed the presence of pyrite in water column samples, indicating that continental margin sediments must be a source of iron to the open ocean.

Ben Van Mooy has been pioneering the use of liquid chromatography coupled with mass spectrometry to explore for novel lipids, in their intact form, produced by marine microorganisms. These studies have uncovered hitherto unrecognized organic compounds, and have led to a host of exciting new discoveries. For example, Van Mooy has found that some eukaryotic phytoplankton and cyanobacteria can substitute betaine lipids and sulfur-lipids, respectively, for phosphorus-containing lipids in order to alleviate needs for the nutrient phosphorus by the cell. This finding, which represents a fundamental change in our understanding of microbial biochemistry and physiology, also has major implications for our understanding of controls of phytoplankton growth, particularly in regions of the oceans with limited available phosphorus. Van Mooy has made other exciting discoveries related to novel organic compounds in the marine environment. These include glycosphingolipids produced by marine viruses that play an important role in the infection and demise of certain types of phytoplankton such as Emiliania huxleyi. Van Mooy, working with MC&G scientist Tracy Mincer and MIT/WHOI Joint Program student Laura Hmelo, has also been exploring quorum-sensing molecules that are increasingly recognized as being crucial in cell-cell signaling by bacteria.

Two new Assistant Scientists joined the MC&G Department in 2009. Zhaohui 'Aleck' Wang brings expertise in the development and utilization of chemical sensors for studying the chemistry and dynamics of inorganic carbon in seawater. Aleck is particularly interested in studying inorganic carbon biogeochemistry in coastal waters. Rachel Stanley uses the abundance and isotopic compositions of dissolved gases as tracers to study carbon cycling in the upper ocean, including biological productivity and air-sea gas exchange. The innovative measurement capabilities and perspectives that Aleck and Rachel bring to WHOI very nicely complement existing expertise. We are delighted and excited to have them on board.

Overall this year, MC&G scientists have continued to make major advances in our understanding of ocean chemistry and its role in processes over a range of scales—from that involving an individual organism to global biogeochemical cycles. Advances like these continue to take place through this combination of field and laboratory studies, and through the development and application of innovative analytical techniques.

—Timothy Eglinton, Department Chair

Physical Oceanography

The oceans that cover 70% of the earth's surface strongly influence Earth's climate and weather. The ocean absorbs heat from the sun in the tropics and carries it toward the poles; it carries cool water from polar regions toward the equator

Researchers in the Physical Oceanography (PO) Department seek to describe and understand this circulation and its variability and thus elucidate the role of the ocean in climate and weather. To investigate the physics of the ocean, they use laboratory experiments, analytical and numerical modeling analysis and synthesis of existing data and new observations at sea. In 2009, as in other years, work done by members of the PO Department was distinguished by a strong heritage and expertise in observing the circulation of the ocean and in developing new observational methods.

Here, we highlight some of the year's accomplishments.

• PO Department members Tom Farrar, Steve Lentz, Amy Bower, Dick Limeburner and Jim Churchill continue to do research in the Red Sea under a research partnership with King Abdullah University of Science and Technology (KAUST) [Learn more about 2009 KAUST activities]. In 2009 they deployed an air-sea interaction mooring (Figure 1), a coastal meteorological tower, three coastal moorings, and tide gauges at several coastal sites.

• High latitude oceanography remains a focus in the department. Al Plueddemann and Bob Pickart participated in fieldwork on the Alaskan Beaufort shelf in the summer of 2009. They worked with investigators from multiple institutions to study coastal circulation and stratification, sea ice variability, cross-shelf property exchange and marine mammal distributions. Pickart performed CTD surveys and recovered a moored array that had been deployed in 2008. Plueddemann sampled the mid-to-inner shelf using an Autonomous Underwater Vehicle (Figure 2).

Fiamma Straneo and Jim Ryder deploying instruments through the ice. (Photo courtesy Eric Philips, IceTrek)

• With funding from WHOI's Arctic Research Initiative, Fiamma Straneo, Ruth Curry, David Sutherland, and Jim Ryder (AOPE) investigated the intrusion of warm subtropical waters inside three glacial fjords in East Greenland. The fieldwork included deploying moorings, acoustically tracking floats, measuring salinity and temperature, as well as deploying instruments to measure temperature, salinity, and currents from sea-ice or glacial ice or from helicopters. (Figure 3) Dr. Straneo also continued work in Hudson Strait; four moorings recovered there by R/V *Knorr* in September 2009 will provide the first yearlong record of the net transport of freshwater through Hudson Strait — an important freshwater gateway for the North Atlantic.

• A five-mooring array was deployed in December by Mike McCarthy and Paula Fratantoni in the Australian-Antarctic Basin, spanning the continental slope of Antarctica, east of the Kerguelen Plateau, along longitude 113° E. The array is part of their program designed to verify the existence, and quantify the strength, of a newly-discovered cyclonic gyre located south of the Antarctic Circumpolar Current, which is thought to transport as much water as the Gulf Stream.

• John Toole and Lou St. Laurent prepared in 2009 for participation in the Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean (DIMES) field program in the Antarctic Circumpolar Current. This current is among the most energetic in the global ocean, and is believed to be the primary conduit for the upwelling of deep water in the global ocean's overturning circulation. John Toole and Lou St. Laurent tested a redesigned Mark II version of the WHOI High Resolution Profiler (HRP) (Figure 4) in 2009 to get ready for fieldwork in DIMES in January to March 5, 2010, on the R/V *Thompson*.

• Department members participated in sampling the basin scale properties of the ocean. Alison Macdonald was Chief Scientist of the first leg of P6 (Figure 5) from Brisbane, Australia to Papeete, French Polynesia (Nov 21, 2009 – Jan 2, 2010). Along with changes in temperature, salinity and dissolved oxygen in intermediate waters, changes in chlorofluorocarbon (CFC) concentrations in bottom waters were also apparent, compared to earlier occupations of P6. Ruth Curry and Elizabeth Douglass will be the chief and co-chief scientists for Leg 2, which ended in Valparaiso, Chile on Feb 11th 2010.

• In December, department members Ray Schmitt, Tom Farrar, Dave Fratantoni, Lou St. Laurent and Lisan Yu attended a planning meeting for a new study of ocean salinity. By measuring salinity from new satellites, increasing the number and quality of in-situ salinity measurements and developing better understanding of the ocean mixing processes that affect salinity, oceanographers will make valuable contributions to humankind's concerns with a changing global water cycle. A field program called "SPURS" (Salinity Processes in the Upper-ocean Regional Studies) is being planned for 2012 in the high-evaporation region of the North Atlantic, where the highest open-ocean salinities are found.

• Two new scientists joined the department, Jong Jin Park and Anthony Kirincich. Park's research interest is in mixing induced by near-inertial waves and its application to large-scale circulation and energy budget. Kirincich's research is on coastal oceanography, near-shore processes, and biophysical interactions.

• Several members of the Department were honored in 2009. Steve Lentz was named a Fellow of the American Geophysical Union. John Toole was named a Fellow of the American Academy of Arts and Sciences. Bruce Warren was named the 2010 winner of the prestigious Sverdrup Gold Medal, awarded by the American Meteorological Society (AMS) "for advancing our understanding of the general circulation of the ocean through observations and dynamical interpretation." Other members continue to work in service to the community: Mike Spall became Chief Editor of the *Journal of Physical Oceanography*; and Joe Pedlosky was awarded the Editor's Award for his reviews of manuscripts submitted to the *Journal of Physical Oceanography*.

• There are presently 20 graduate students in physical oceanography in the WHOI/MIT Joint Program. Over the past year, four students have graduated from the Physical Oceanography Joint Program with a PhD, with thesis topics ranging from the influence of eddies on western boundary currents such as the Gulf Stream to recent changes in convection in Arctic Seas.

—Robert Weller, Department Chair

Coastal Ocean Institute

As Director of the Coastal Ocean Institute (COI), I have been both excited and challenged to oversee this dynamic center of excellence. I particularly enjoy interacting with students, scientists, policymakers, and media. One goal of mine for the Institute was to increase communication and outreach. A great success in this area has been our recently launched web site on tsunamis, spearheaded by Dr. Jian Lin (Geology and Geophysics) and Web Communications Manager Danielle Fino. The site features an impressive display of graphics and scientific content that has been well received by everyone from tsunami scientists to travel writers. My plan is to continue to develop other web sites addressing coastal topics, such as beach closures, sea level rise and hurricanes.

COI makes an important contribution to WHOI by providing support to scientists, post-doctoral scholars and Joint-Program students. COI funded four research projects in 2009:

• Adam Soule (Geology & Geophysics) is using terrestrial laser-scanning to monitor bluff erosion in Boston Harbor.

* Using a high-frequency radar system, Anthony Kirincich (Physical Oceanography) is measuring inner-shelf circulation at the Martha's Vineyard Coastal Observatory (MVCO).

• Bernhard Peucker-Ehrenbrink and Zhaohui Wang (Marine Chemistry & Geochemistry) are establishing a Connecticut River Observatory to increase our understanding of how rivers influence the composition of the oceans.

• Louis St. Laurent (Physical Oceanography) is studying how turbulence on the shelf break affects biological activity, especially predation.

The Institution relies heavily on our pool of post-doctoral scientists for leading many of our research projects and for recruiting scientific staff. Hence, COI post-doctoral scientists are paramount for the current and continued excellence of coastal research at WHOI. The Institute supported several post-doctoral scholars and Joint Program graduate students in various ways in 2009. Post-doctoral scholar Juliette Smith (Biology) is studying the ecophysiology of a recently cultivated marine dinoflagellate, Dinophysis, focusing on its production of Diarrhetic Shellfish Poisoning toxins. Post-doctoral scholar Gordon Zhang (Applied Ocean Physics & Engineering) is studying the dynamics of strong along-shore currents and the accumulation of plankton at the continental shelf break off the coast of New England.

In keeping with COI's theme of studying natural and anthropogenic threats to the coastal environment, COI-sponsored graduate student Phil Lane (Geology & Geophysics) is working with Jeff Donnelly (Geology & Geophysics) to develop records of Atlantic hurricane activity going back as far as 5,000 years. These records are based on sediment cores extracted from coastal ponds and marshes that contain signatures of repeated inundation from hurricane storm surges. His field sites are located along Buzzards Bay, Massachusetts and Apalachee Bay, Florida, and are part of a sparse but growing network of paleohurricane records. Graduate student Elizabeth Halliday (Biology) is developing a quantitative and more accurate method to rapidly identify viable fecal indicator bacteria in beach sand.

COI graduate student fellow Phil Lane is working with Jeff Donnelly to develop records of Atlantic hurricane activity going back as far as 5,000 years. These records are based on sediment cores extracted from coastal ponds and marshes that contain signatures of repeated inundation from hurricane storm surges. (Photo by Tom Kleindinst, Woods Hole Oceanographic Institution)

Thank you to all who contributed their support to the COI.

—Christopher Reddy, Institute Director

Deep Ocean Exploration Institute

The deep ocean covers a large areal extent of our planet and includes a large percentage of Earth's ocean waters, yet little of it has been studied in detail. The Deep Ocean Exploration Institute (DOEI) encourages multidisciplinary study of the physical, chemical, geological, and biological processes in different areas of the deep ocean and in the planet's interior. And it recognizes the need for and fosters the development of the technology needed to access environments in the deep ocean, above, at, and below the seafloor.

In 2009, a number of projects were funded by the DOEI, many under WHOI's new Ocean Ridge Initiative (ORI). The ORI is focused on exploring the largest continuous geologic feature on Earth—the mid-ocean ridge system. It recognizes that the ridge system, 50,000 miles in length, is extremely dynamic, a locus of energy transfer as new crust is created, and a rich target for new discoveries. Funded proposals cover a range of topics and activities:

* Henry Dick and Frieder Klein (Geology & Geophysics) are funded to provide input to a new study of life, hydrothermal systems, and the evolution of the ocean crust and mantle at the ultraslow spreading Mid-Cayman Spreading Center (in the Caribbean). They will document the composition and texture of igneous and altered rocks that form the substrate for the hydrothermal systems to be studied there, which will help lay the groundwork for future investigations.

• Mark Kurz (Marine Chemistry & Geochemistry) is funded to make new measurements of noble gas tracers (helium, neon, argon) in fluids and solids (basalt glasses, gabbros, peridotites) from this same area, the Mid-Cayman Spreading Center—a portion of mid-ocean ridge that is unique due to its great water depth and very slow spreading rate.

• Mark Behn (Geology & Geophysics) will participate in a cruise to the Galapagos Spreading Center, where he will collect information to help in modeling studies aimed at understanding the effects of magma supply on normal fault evolution and eruption dynamics.

• Sean Sylva (Marine Chemistry & Geochemistry) will use ORI funds to synthesize and interpret results and prepare a publication describing his new method of calibration for compound-specific hydrogen isotope analysis. This new method is a major contribution to the field, and will greatly enhance the ability of researchers to use hydrogen isotope data to better constrain the sources of hydrogen-bearing carbon compounds.

• In spring 2010, Pablo Canales (Geology & Geophysics) is co-leading an international conference on ocean core complexes (OCCs), sections of ocean crust that are exposed on the seafloor as the result of faulting and that provide windows into deep-seated rocks and the processes that form them. He will use ORI funds to provide travel support for WHOI scientists and students to attend and participate in this conference, recognizing that WHOI is a world leader in OCC research.

Woods Hole Oceanographic Institution held a Morss Colloquium on "Precious Metals from the Deep Sea" in April 2009—it was organized by DOEI fellow Maurice Tivey. It included public presentations by stakeholders in the seafloor mining debate and a panel discussion with (from left) Caitlyn Antrim, executive director of the Rule of Law Committee for the Oceans; Sabine Christiansen of the World Wildlife Fund; Rod Eggert, director, economics and business, Colorado School of Mines; WHOI marine geochemist Chris German; Nii Odunton, secretary-general of the International Seabead Authority; Samantha Smith, environmental manager of Nautilus Minerals; and WHOI geophysicist Maurice Tivey. More about the colloquium in *Oceanus* magazine (Photo by Tom Kleindinst, Woods Hole Oceanographic Institution)

At the end of 2009 a second call for research proposals went out, yielding seven new proposals to be funded in 2010: four under the ORI and three under the new themes of the DOEI. These new themes were chosen by the DOEI Advisory Committee to encourage research into high-priority areas. The three themes are Deep Ocean Technology, which acknowledges the need for vehicles, sensors and instruments that can operate for long periods of time at significant depth; Dynamic Processes at the Seafloor, which encourages focus on processes occurring at ocean margins (ridges, subduction zones and transform faults) as well as in areas of the deep ocean where physical, chemical, or biological processes create dynamic environments (e.g., from strong bottom currents); and The Role of the Deep Earth and Ocean in Elemental Cycles, which seeks to fill critical gaps in our understanding of global element cycles, including the carbon cycle.

DOEI also continued its support of three Institute fellows. A recent *Oceanus* magazine article reports and follows up on issues related to proposed mining of deep-sea vent deposits and the MORSS Colloquium held in May and convened by DOEI fellow Maurice Tivey (G&G). Jeff McGuire (G&G) is using recordings of the seismic waves and per-

manent ground deformation produced by earthquakes to improve our understanding of the rupture process and fault structure, and is working to develop and deploy arrays of ocean-bottom seismometers in the northwest Pacific Ocean.

In 2009, Tim Shank (Biology Department) participated in two cruises, one with the ROV Jason 2 to West Mata, where an actively erupting volcano was observed and sampled and one with the new deep-diving Nereus on its maiden voyage to the Marianas trench and volcanic arc. His fellowship allowed him to study population genetics in these different areas and examine the connectivity of the shrimp at West Mata with those along the Mariana volcanic arc.

Support of education is also integral to the DOEI. In 2009, two graduate students and two post-doctoral scholars received support. Joint Program student Kevin Richberg's research on identifying primary producers in the sub-seafloor was highlighted in the DOEI summer 2009 report [pdf version of report]. Postdoctoral scholar Frieder Klein (G&G) just arrived in November, and is studying hydrothermal processes in the ocean crust and mantle, including serpentinization of peridotite, and the implications of these processes for geochemical fluxes and tectonic processes. Postdoctoral scholar Tetsuo Matsuno (AOPE) has been here since December 2008 and is using marine electromagnetic measurements off the coast of Nicaragua in the eastern Pacific to study the distribution and amount of water input into the Costa Rica-Nicaragua subduction system.

DOEI also provided funds for its very successful multidisciplinary Geodynamics Program. This year's program, Climate Change: Forcing, Responses and Geo-engineering, was supported jointly with the Ocean & Climate Change Institute. The focus was on interactions between geodynamics and climate, such as the impact of mountain building and volcanic out-gassing on climate.

—Margaret K. Tivey, Institute Director

Ocean & Climate Change Institute

In 2009, the Ocean & Climate Change Institute (OCCI) continued to concentrate most of its research activities and resources on changes in the North Atlantic and Arctic Ocean climate. OCCI distributed about $1.9 million for the Arctic Research Initiative (ARI), our five-year focused research program, supported by the Sealark Foundation, and another $500,000 for basic climate research, support of Institute Fellows, Postdoctoral Scholars and graduate students.

Combined with our research activities funded by institute funds and the Comer Science and Education Foundation, the three-year funding total for the Arctic Research Initiative is now about $6.8 million, supporting more than 45 research projects and significantly enhancing WHOI's role in understanding the changes in Arctic climate and their impacts on the marine and surrounding terrestrial ecosystems. Several new research programs were begun during 2009, including a new study of the interaction of glaciers and the warming ocean in several Greenland fjords.

ARI funding enabled us to support Emily Shroyer, a postdoctoral fellow working with Al Plueddemann in Physical Oceanography (PO). Emily is studying the wind-driven response of the Alaskan Coastal Current off Point Barrow, Alaska, a region of high biological productivity and one of the principal locations for the transport of fresh Pacific water into the Arctic Basin.

OCCI research activities also extended beyond the Arctic to include new projects to study carbon cycle dynamics, submarine groundwater discharge and tropical Pacific and Atlantic interactions that influence climate variability.

Sarah Das in Geology & Geophysics (G&G) and Young-Oh Kwon (PO) began three-year OCCI fellowships in 2009. Sarah works on developing new methods and observations to understand ice sheet melting, ice dynamics and meltwater run-off. Young-Oh is examining global climate model simulations and comparing them with the observational data, to understand the role of ocean-atmosphere coupling in long-term climate variability in the North Atlantic and North Pacific.

In 2009 OCCI continued its support of Katherine Silverthorne (MIT/WHOI Joint Program student in Physical Oceanography). She studies the development of the "18 degree water" in the North Atlantic, a water layer of consistent temperature and salinity that may play a role in climate.

Elizabeth Douglas was the 2009 OCCI postdoctoral fellow. Liz is working with Steve Jayne in PO, studying the variability of the Kuroshio Current—the Pacific equivalent of the Gulf Stream—in ocean circulation models and observations.

OCCI also played a role in two education outreach activities in 2009. The institute supported a pilot program, called the Climate Summer Internship Program, to provide high school students with a summer research experience. Delia Oppo (Senior Scientist in G&G) and Joanne Muller (Falmouth Academy science teacher and former WHOI Postdoctoral Fellow) provided seven Falmouth Academy and Falmouth High School students with hands-on experience using deep sea sediments to understand earth's climate history. OCCI will suppport this program again in 2010.

Geologist Sarah Das began a three-year OCCI fellowship in 2009. Sarah works on developing new methods and observations to understand ice sheet melting, ice dynamics and meltwater run-off. (Photo by Chris Linder, Woods Hole Oceanographic Institution)

Climate change was the theme of the 2009 WHOI Geodynamics Program, and OCCI helped to develop the curriculum and supported the activities. This program fosters interdisciplinary research in the earth sciences among faculty, MIT/WHOI Joint Program students and postdoctoral investigators. The program entails a 14-week seminar series of visiting scientists presenting their research results to the WHOI community. The talks explored the interactions between earth dynamical processes and climate, such as the impact of mountain building and volcanic out-gassing on climate, past sea level rise and the deformation of the whole earth as a result of glacial-interglacial climate cycles.

The program culminated with a group study tour to the Caribbean island of Barbados, a classic field area for the study of ice-age sea-level history. Barbados is an actively rising island at the crest of the Barbados Ridge, and is unique, in that the island's sedimentary rock base is capped by a sequence of coral terraces that grew during sea level changes of the past 700,000 years.

— William Curry, Institute Director

Ocean Life Institute

The Ocean Life Institute (OLI) supports basic research related to biodiversity, ecosystem health and new technologies. Research is supported through OLI fellowships, postdoctoral and graduate student awards, and research grants. OLI-sponsored research during 2009 covered a variety of topics related to the molecular biology of marine organisms.

The Tropical Research Initiative, administered by OLI, continued support for ongoing projects, including hormone transfer between corals, analysis of ancient ocean circulation patterns, equatorial waves, bacterial use of nutrients in the Pacific, and the importance of nitrogen-fixing bacteria in tropical estuaries.

OLI also supported ongoing studies at the Liquid Jungle Laboratory, Panama. We continued to develop a new initiative on the oceanography of coral reefs and have proposed a study off Taiwan in collaboration with colleagues there. A group of WHOI scientists visited Taiwan to begin design of a proposed project on Dongsha Atoll to study the possible role of internal waves in preventing coral bleaching.

OLI promoted research in ecosystem-based management, including the newly funded NOAA Cooperative Institute for the North Atlantic Region, which establishes the framework for a modeling-observing system in the NE US coast. OLI also supported Rubao Ji (Biology) and Dennis McGillicuddy of Applied Ocean Physics & Engineering (AOPE) to use a biological-physical ocean model to help design an ocean observing system in the Gulf of Maine-Georges Bank region.

New research in 2009 included four grantees, a postdoctoral fellow and a graduate student. Karen Casciotti of the Marine Chemistry & Geochemistry Department (MC&G) is studying the physiological diversity of the poorly known marine Crenarchaea, which make up 40% of deep ocean bacteria and are the most plentiful cell type on earth. Helen Fredericks and Ben Van Mooy (also in MC&G), have discovered two cell membrane lipids that are new to science and are important as anti-viral agents and in programmed cell death, with possible anti-cancer properties. Matt Johnson (Biology) and Tracy Mincer (MC&G) are studying anti-grazing compounds in marine bacteria and phytoplankton. Through a generous year-end gift, OLI was able to support research by John Stegeman and Jed Goldstone (Biology), who are developing molecular biomarkers in mussels for use as sentinels in detecting coastal pollution.

With funding from OLI, geochemist Benjamin Van Mooy and his colleagues found that microscopic plants growing in the Sargasso Sea make their cell membranes using 'substitute lipids' that contain no phosphorus. Though essentially unknown until now, these substitute lipids are the most abundant membrane molecules in the sea. (Photo by Tom Kleindinst, Woods Hole Oceanographic Institution)

A new OLI-sponsored WHOI postdoctoral fellow, Amy Apprill, is studying the lipids of symbiotic algae (zooxanthellae) in temperature- and disease-stressed corals. OLI also supported MIT/WHOI Joint Program students Erin Banning (Biology), who is examining the predatory behavior of coastal bacteria, and Wu-Jung Lee (AOPE), who is studying acoustic prey recognition by toothed whales.

I would like to thank all who have supported the OLI so generously during the past year.

—Cabell Davis, Institute Director

Marine Policy Center

The mission of the Marine Policy Center (MPC) is to conduct research on policy issues relating to the ocean and the coast. As this research is often directly related to actual policy issues, Center staff members are sometimes asked to provide analysis and advice to policy-makers. This takes a variety of forms.

One way is through service to the National Research Council (NRC). As an arm of the National Academies, the NRC's job is to conduct studies to support policy-making. These studies are typically requested by Congress or Federal agencies to provide advice on timely—and often controversial—issues.

In some cases, these issues are quite narrow. For example, Research Specialist Hauke Kite-Powell recently served on a committee studying the effect of an oyster aquaculture project on the seal population within the Point Reyes National Seashore in California In other cases, the issues are broad, as with MPC Director and Senior Scientist Andy Solow's service as the coordinator of a study on the future of US climate-change science.

A second avenue for participation in the policy process is service on standing advisory groups. Senior Research Specialist Porter Hoagland is a member of the advisory council to the Stellwagen Bank National Marine Sanctuary. This group provides advice to the National Oceanic and Atmospheric Administration (NOAA) about the management of this important right-whale sanctuary at the mouth of Massachusetts Bay. In a similar vein, Solow chairs a panel to advise the Environmental Protection Agency (EPA) on environmental effects relating to the Boston Harbor sewage outfall.

Sometimes, it is not necessary to be a formal member of an NRC committee or panel to affect action. For example, last year Solow was asked to provide analysis to the Office of Science and Technology Policy (OSTP) in the White House in support of vessel speed limits to protect the endangered North Atlantic right whale. The argument was accepted and the regulation put in place. In another case, Hoagland and Solow helped Governor Deval Patrick's office develop a rationale for declaring a resource emergency in Massachusetts fisheries resulting from tighter Federal fishing regulations. Asking the Secretary of Commerce to agree that a Federal management measure intended to protect fish stocks has created a resource emergency turned out to be a bit of a stretch, and the argument was rejected.

Women from Unguja Ukuu-Tindini on the island of Zanzibar off Tanzania examine a shellfish farm that they are learning to set up and tend. Hauke Kite-Powell, a Marine Policy Center research specialist, is working with scientists, fishers, and non-profit groups to promote aquaculture as an ecologically sound way to increase the yield of seafood protein for food, while also providing jobs and a saleable commodity for the villagers. (Photo by Hauke Kite-Powell, Woods Hole Oceanographic Institution)

It is a commonplace that the more objective analysis that enters the policy process, the better. However, Center staff has found that the road runs both ways: Exposure to the policy process helps Center staff members gain a better understanding of the relevant policy issues and enables them to develop more realistic models to analyze such issues.

—Andrew Solow, Center Director

Center for Ocean, Seafloor, and Marine Observing Systems

The Center for Coastal Ocean, Seafloor and Marine Observing Systems (COSMOS), established in 2006, continued in 2009 to bring scientific oceanographic research opportunities to WHOI through ocean observatories and observing systems. Ocean observing systems integrate state-of-the-art instruments with stationary and mobile platforms, to collect real-time data over a region and through time. They enable scientists to obtain more oceanographic, chemical and biological information than can be obtained from ship-going activities. Observing systems are being established worldwide, and COSMOS is working with scientists at WHOI and at other universities and institutions to advance our ability to measure, monitor and analyze the fundamental processes shaping continental shelf ecosystems.

COMOS is involved in several major programs. It oversees the Massachusetts Technological Collaborative John Adams Innovation Institute (MTCJAII) grant, which supports four ocean observing initiatives. One is to improve marine and weather forecasts for New England through enhancement of National Data Buoy Center weather buoys. The second is to establish an acoustic communications test bed at the Martha's Vineyard Coastal Observatory (MVCO) to provide opportunities for academics, corporate and government users to test developing instrument technology. The third is to improve the MVCO as a science and technology facility. The fourth is for management of the project and outreach to regional industry and corporations interested in observing systems.

Now into the second year of funding, all projects have made successful progress. COSMOS will be working with the Commonwealth of Massachusetts to secure sequential funding that was initially awarded in the John Adams

WHOI biologists Rob Olson and Heidi Sosik, the new COSMOS director, examine plankton-filled water samples on a prototype version of the Imaging FlowCytobot (IFCB) in Olson's Woods Hole laboratory. The Cytobot, which is automated and submersible, counts microscopic plants in the water and photographs them. The images and data are relayed by cable to a shore-based laboratory, where specially developed software classifies the plankton into taxonomic groups. The instrument was recently used to detect a bloom of harmful marine algae (Dinophysis acuminata) in the Gulf of Mexico and prevent human consumption of tainted shellfish.
(Photo by Tom Kleindinst, Woods Hole Oceanographic Institution)

Grant as part of a match to the OOI (Ocean Observatories Initiative) Implementing Organization Award that WHOI received from the National Science Foundation (NSF). COSMOS is working with regional and national groups of researchers to begin coordinating plans for new science activities enabled by the new ocean observing infrastructure coming from OOI.

In September 2009, the directorship of COSMOS changed from John Trowbridge, who had been director since 2006 and is now chairman of the AOP&E department, to Heidi Sosik, a senior scientist in the Biology Department. She is also chief scientist of the MVCO, a role she will continue. One of her first activities as COSMOS director was to collaborate with others groups at WHOI on a recently funded proposal to the National Institute of Standards and Technology construction program for a $10 million building at WHOI for ocean observing systems work. In addition to housing the OOI program led by Bob Weller, the new building will provide new facilities for the MVCO team.

MVCO is operated through COSMOS. For the past eight years, this cabled observatory on the southern coast of Martha's Vineyard has collected and transmitted data from offshore instruments connected through an undersea power and communications node to an onshore station and ultimately to researchers, policy-makers and industry. The MVCO platform was used by various researchers in 2009 on a diverse range of topics.

* Rob Olson (Biology) and Sosik have been advancing the ability to continuously sample single celled marine microbes through flow cytometry. They have used MVCO to improve the durability and flexibility FlowCytobot and Imaging FlowCytobot, submersible flow cytometers developed at WHOI, and to collect unique time series that show changes in phytoplankton communities on the New England shelf. This new technology will vastly improve the ability of researchers to study ecological and physiological processes of marine microbes at ocean observatories.

• Trowbridge has supplied the sensor array at the offshore tower at MVCO with additional instrumentation to measure temperature, salinity, optical transmission, velocity and bottom stress. These instruments are supported continuously by the MVCO and greatly enhance coastal oceanographic research funded by the Office of Naval Research and other agencies.

• A collaborative research project, including Trowbridge, has been using a combination of MVCO sensors to characterize aggregation and disaggregation of particles from measurements of particle size, distribution and concentration in the water column near the seabed. Utilizing acoustical, wave and current measurements from MVCO, they are improving models that link the properties of particles with how light and sound travel through the coastal ocean.

• Burkard Baschek of UCLA, a former WHOI postdoctoral scholar, has collected a high-resolution time series of dissolved gases (CO2, O2, N2) and supporting measurements (temperature, salinity, pressure, and chlorophyll a) at MVCO. Gas bubbles were measured using sound and optical cameras. These unique measurements will provide new knowledge about air-sea gas exchange mechanisms and bubble dissolution, especially how they are related to physical and chemical properties of the gases and affected by wind and wave characteristics. Ultimately this kind of knowledge will help us understand and predict effects of climate change. This research is an on-going component of the SPACE '08 program at MVCO.

• Colm Sweeney (NOAA) is monitoring CO2 and sampling air properties at MVCO offshore tower in support of the Carbon Cycle Gas Group greenhouse gas network at the NOAA Earth System Research Laboratory (ESRL). These measurements provide a vital eastern boundary data set that enables a more accurate assessment of the North American carbon ocean budget.

• Lee Freitag (AOPE) has continued research to improve underwater acoustic communication. His group will begin testing their new systems at the MVCO facility in the coming year.

• Sosik, with MVCO project manager Janet Fredericks and technicians Jay Sisson and Hugh Popenoe (all AOPE) have upgraded MVCO, adding new power and fiber-optic capabilities, enhanced continuity of core measurements, and on-line documentation and data access through the MTC-JAII grant.

Another focus of COSMOS in 2009 was to work with partner institutions in NOAA's Integrated Ocean Observatory System (IOOS) program. WHOI coordinates and manages the funding of this NOAA project to partner institutions in the Northeast: Bedford Institute of Oceanography (BIO), Universities of Maine, Connecticut, New Hampshire, Massachusetts at Dartmouth and Rhode Island, the Gulf of Maine Ocean Observing System (now merged with Gulf of Maine Research Institute), and the Northeast Fisheries Science Center. The goals of this project are to build on the accomplishments of the past by continued operation of selected existing observing systems, and to enhance present–day observing capabilities. COSMOS efforts are in parallel with the Northeastern Regional Association of Coastal Observing Systems (NERACOOS) projects awarded in 2008—to Scott Gallager (Biology) for the Northeast Benthic Observatory System; to Hauke Kite-Powell (Marine Policy Center) for maximization of the socio-economic benefit of NERACOOS; and to Fredericks to work on the integration of procedures for quality assurance and quality control in real time ocean data.

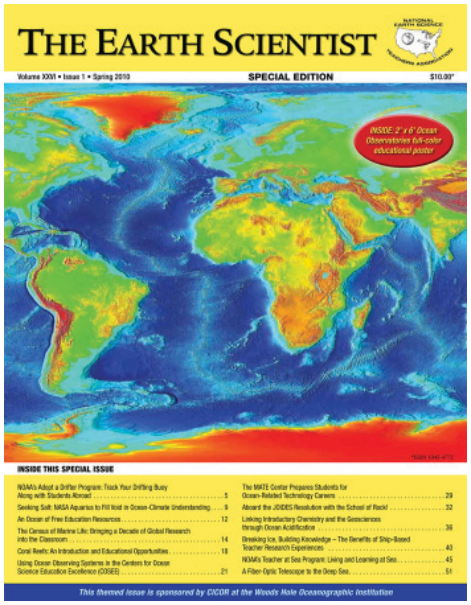
COSMOS anticipates a new decade of innovative and exciting interdisciplinary research, building on ocean observing system capabilities to provide much needed measurements of ocean properties that influence our climate and ecosystems.

—Heidi Sosik, Center Director

Cooperative Institute for Climate and Ocean Research (CICOR)

A 1998 agreement between WHOI and NOAA (the National Oceanographic and Atmospheric Administration) established a unique center at WHOI for climate research: CICOR, the Cooperative Institute for Climate and Ocean Research. For over a decade, CICOR has drawn on the leadership and research excellence at WHOI to serve NOAA's mission and goals.

With its founding agreement renewed in 2001, CICOR served as a global and national resource for scientists and strengthened the relationship between WHOI and NOAA, enabling long-term research partnerships in key areas of climate observations and analyses, marine policy, seafloor mapping and harmful algal bloom research. CICOR served as a catalyst and incubator of ideas for collaborative climate, coastal and ecosystems research.



CICOR sponsored an special edition issue of The Earth Scientist, a publication of the National Earth Science Teachers Association, on ocean observatories.

In 2009 CICOR supported 72 projects, totaling nearly $8.1 million in funding. Since 1998, CICOR has supported more than 188 research, education, outreach and program development projects, bringing its eleven-year funding total to more than $61.7 million.

NOAA decided in 2008 to replace CICOR with a new, multi-institutional, regional cooperative institute. The new WHOI-led institute, CINAR, the Cooperative Institute for North Atlantic Research, began in mid-2009, continuing the WHOI/NOAA collaboration. During the transition phase, funding for some projects has continued via CICOR until June 2010 with a no-cost extension having been approved through June 2011. This allows CICOR to maintain its administrative support and oversight of ongoing projects in the process of completing work funded under previous awards.

CICOR is proud of its contribution to NOAA and to WHOI. CICOR principal investigators (PIs) and WHOI researchers have deepened their familiarity with NOAA strategic goals for the region, and have strengthened collaborative relationships with NOAA officials and colleagues from other institutions to further these goals. CICOR scientists are actively engaged in ocean observing and regional coordination in the Northeastern U.S. and around the globe. CICOR PIs from WHOI participated in the international "OceanObs'09" workshop in Venice, Italy that worked to lay the groundwork for future global ocean observations.

The strong partnerships between WHOI and NOAA are expected to continue well into the future. Below are some highlights of how CICOR science furthered NOAA's goals.

HIGHLIGHTS

• With funding from CICOR, the U.S. Program In Marine Biotoxins and Harmful Algae office at WHOI under Don Anderson (WHOI Biology Department) provides rapid reaction to unexpected or unusual harmful algal outbreaks in different parts of the country. In 2009, the program responded to the first documented presence of diarrhetic shellfish poisoning (DSP) toxins in shellfish within the US, and a massive regional red tide in New England.

• CICOR PIs Carin Ashjian and Mark Baumgartner (both Biology) observed considerable inter-annual covariability in physical and biological oceanography during the three years of their observations (this work and the two years of the Study of the Northern Alaskan Coastal System project). Their work sheds light on the inter-annual variability in whale prey and how it is associated with larger scale atmospheric and oceanographic conditions. This in turn has implications for the success and resilience of Iñupiat subsistence whaling at Barrow and for a better understanding of how to protect and manage the Western Arctic bowhead whale population.

• Janet Fredericks (WHOI Applied Ocean Physics & Engineering Department) has led a community of data providers, I.T. specialists and domain experts working together to describe ocean sensors and quality control procedures for ocean data. This group is working on QA/QC practices for observations of waves, currents, temperature, salinity, and dissolved oxygen. As we move towards greater machine-to-machine exchange of information, a common expectation of data quality standards and practices will assure a broader trust in the data and enable interdisciplinary research.

• The Upper Ocean Processes group led by Robert Weller, Albert Plueddemann and David Hosom (all WHOI Physical Oceanography Department) and funded through CICOR by the NOAA Climate Observation Program have led the development and implementation of hardware and software that greatly increases memory capacity while simultaneously reducing memory cost for the ASIMET (Air-Sea Interaction Metorological) systems. A new ASIMET module processor/controller board was designed to improve low-temperature operation for the next generation of ASIMET electronics. The long-term goal of the "portable standard" ASIMET package is to provide climate quality meteorology from the oceanographic research fleet.

• Led by Weller, Plueddemann and Hosom, the Volunteer Observing Ship (VOS) Program continued field operations to maintain automated meteorological AutoIMET systems on two VOS routes in the Pacific and provided documentation and engineering consulting to STAR Engineering (licensee for IMET fabrication and sales) for the transfer from development to production of an ASIMET sonic anemometer wind module. Also designed, fabricated, and tested was a third-generation Iridium communication controller, Seabird SIM interface, and Benthos acoustic modem interface for inductive and acoustic telemetry of underwater instruments. The long-term goals of this work are to improve in-situ observations of marine boundary layer meteorology and air sea fluxes in order to improve understanding and prediction of the earth's climate.

• In his work on marine resource industries, regulation and waterfront land use change in New England Fishing communities, Di Jin (WHOI Marine Policy Center) found a strong spatial relationship between local fish stocks and local employment in the fishing and related industries. The study will improve our understanding of the interactions between changes in fish stocks and waterfront land uses and fishing communities' economic conditions.

* In another study on the development of commercial fishing vessel cost models, also through CICOR, Jin developed three sets of models: annual vessel fixed cost, annual labor cost, and vessel trip variable cost. Analysts often work on similar issues but in different contexts—vessel types often overlap across Fisheries Management Plans (FMPs) and protected species actions. Having standardized and pretested cost models has a number of benefits. It increases the likelihood of cost models being used in regulatory analyses; it reduces the workload on analysts; and it fosters an agreed-upon "best practice" approach to this aspect of fisheries modeling.

• Hauke Kite-Powell's (Marine Policy Center) research on the economics of observations of ocean surface vector winds indicates that a significant fraction of the approximately $500 million/year risk to commercial maritime transportation from severe storms in the North Atlantic and North Pacific oceans can be avoided with ocean surface vector wind observations and forecasts. This research contributes to the understanding of the economic value of ocean observing systems, specifically ocean surface vector wind observing instruments on satellites.

• Alison MacDonald's (Physical Oceanography) NOAA-funded research through CICOR found that the ocean inventory of bomb-produced radiocarbon (14C) is directly related to air-sea CO2 exchange and thereby provides a powerful constraint on the exchange rates. The large amount of high-quality radiocarbon data collected during the World Ocean Circulation Experiment WOCE program provides the opportunity to improve our estimate of these air-sea CO2 exchange rates and make the results available to the modeling community.

• Robert Pickart's (Physical Oceanography) work investigated for the first time the dynamics of the flow of Pacific water through Herald Canyon. Winter water entered the canyon on the western side, but switched to the eastern wall of the canyon as it flowed northward. The Russian-American Long-term Census of the Arctic (RUSALCA) program represented a fruitful collaboration of Russian and US scientists, making use of shared resources and expertise. The results from the study enhanced our knowledge of a critical part of the Arctic system, enabling us to better predict the impacts of variable inflow through Bering Strait as a result of climate change.

• Andrew Solow's (Marine Policy Center) NOAA-funded work provides further evidence that at least part of the long-term increase in the observed number of North Atlantic tropical cyclones can be attributed to incompleteness in the early part of the record. In order to manage risks associated with long-term changes in hurricane activity and intensity, society needs to understand how such risks are changing and are likely to change in response to on-going climate change. A central problem in using the observational record of hurricanes to advance this understanding is bias due to under-sampling. The work conducted under this project is aimed at developing and applying methods that can account for such under-sampling.

• Breck Owens (Physical Oceanography) reports that the WHOI contribution to the Argo Float Program has significantly accelerated and improved the performance of the floats. Improvements in both the communications system and the calibration procedures have been implemented. A significant error in the data reported from these floats has been indentified and the procedures to correct the data have been developed and implemented. The through-flow of data to the final quality controlled values has also significantly increased.

• Work on the Ocean Reference Stations (ORS) funded by the NOAA Climate Program led by Plueddemann and Weller shows that two Ocean Reference Stations (Stratus, WHOTS) are now collecting pCO2 data in addition to surface meteorology. Stratus is also collecting surface-wave data. A third Ocean Reference Station (NTAS) serves as the development site for near real-time delivery of surface meteorology and upper-ocean properties via Iridium telemetry. The Upper Ocean Processes Group web site, which serves the ORS meteorological data, has been extensively revised and re-organized. Near real-time WHOI ORS data are also available through NDBC. Six years of surface heat fluxes from the Stratus ORS site were merged and evaluated, pointing to significant errors in the ECMWF ERA-40 and NCEP-2 reanalyses. The long-term goals of this work are to improve in-situ observations of marine boundary layer meteorology and air-sea fluxes in order to improve understanding and prediction of the earth's climate.

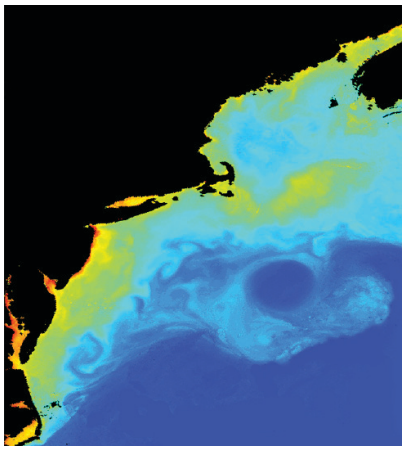
—Robert Weller, Institute Director

Cooperative Institute for the North Atlantic Region (CINAR)

In 2009, The National Oceanic and Atmospheric Administration (NOAA) awarded WHOI the Cooperative Institute for the North Atlantic Region (CINAR). The Institute, which began its operations on July 1, replaced the 10-year-old Cooperative Institute for Climate and Ocean Research (CICOR) which focused predominately on climate observations, with some emphasis on other areas of marine research.

Cooperative institutes are one of the important vehicles that enable NOAA to fund extramural research. The CINAR award from NOAA was a result of a competition that WHOI won in partnership with the University of Maryland Center for Environmental Science, Rutgers University, University of Maine and the Gulf of Maine Research Institute.

The geographic domain of CINAR is the U.S. northeast continental shelf from Cape Hatteras to Nova Scotia. Given the importance of large-scale climate and biological connectivity within the North Atlantic, CINAR's geographic scope includes basin and global-scale processes that affect the shelf ecosystem.



A primary goal of the CINAR is to use data, such as those pictured here, to conduct research that identifies and evaluates linkages among productivity, fish and fisheries, pollution, climate change and ecosystem health. This image is a three-day composite SeaWiFS image showing chlorophyll concentration for 18-21 June 2001. Higher levels of chlorophyll on the continental shelf reflect enhanced net primary production within the Northeast U.S. Large Marine Ecosystem. (Map courtesy Heidi Sosik, Woods Hole Oceanographic Institution)

The overall goal of CINAR is to engage NOAA and academic scientists in cutting-edge research that enables NOAA to make informed decisions about sustainable and beneficial management of the U.S. northeast continental shelf ecosystem. CINAR activities are organized around five broad themes: Ecosystem Forecasting, Ecosystem Monitoring, Ecosystem Management, Protection and Restoration of Resources, and Sustained Ocean Observations and Climate Research.

A major focus of CINAR, and a departure from CICOR, is Ecosystem-Based Management or EBM. An ecosystem approach to management differs from current strategies that focus on a single species by considering interconnections within the ecosystem (for example, between trophic levels or species) and among environmental regimes (terrestrial, oceanic, atmospheric), and by integrating social, economic and institutional perspectives as well. CINAR has therefore been formulated with the explicit recognition that effective management of human activities on the northeast shelf requires an understanding of how these activities interact with each other and with other processes to affect the regional ecosystem and its resources. An understanding of climate variability must be integrated if the causes of variability in change are to be indentified and understood.

CINAR is still in its formative stages. During the first months of operation, more than $3 million of research funds were moved from NOAA to the CINAR partners. Among the funded projects are efforts to apply advanced technologies to the next generation of fishery stock assessment surveys, to understand whether there is a link between marine mammal health and entanglement in fishing gear, to better predict the occurrence and intensity of harmful algal blooms (red tides) in Northeast coastal waters, and to test and evaluate new forms of fishery management.

Another expected major activity is to develop and deploy arrays of underwater vehicles and instruments needed to continuously monitor the ocean as part of the growing ocean observatory network. Central to these efforts will be arrays of meteorological and hydrographic sensors deployed in the equatorial Pacific and other areas far from the northeastern U.S. where measurements are needed to understand global climate processes that ultimately affect this region and its valuable fisheries and ecosystems.

CINAR will support a WHOI Postdoctoral Scholar each year, beginning in 2010 and continuing through the five-year agreement. The postdoctoral scholar will work with a CINAR investigator on one of the five themes identified above. CINAR is also working to provide research and education opportunities for students at several minority-serving institutions (MSIs) in the Northeast region, with the expectation that these efforts will lead to opportunities for jobs and careers within NOAA programs.

CINAR is now working with investigators at all the partner institutions to strengthen existing relationships with NOAA programs and build new ones that lead to funded research in support of the Institute's themes. Administrative staff has been hired, office space renovated, a Memorandum of Agreement drafted, and institutional arrangements established to allow an efficient transfer of funds from NOAA to the CINAR partners. With the rapidly expanding interest within NOAA and other agencies on ecosystem-based management, climate change, ocean acidification and other important oceanographic issues, CINAR can be a major regional asset that will bring significant funding and resources to WHOI and its partners.

—Donald Anderson, CINAR Director

Marine Mammal Center

Marine mammals generate intense popular and scientific interest and have a special conservation status in the U.S. Many populations are threatened or endangered because of past whaling and current fishing and shipping industries. Today the threats to marine mammals are less obvious than when whalers decimated whale populations, but the new threats may be just as dangerous. Fisheries compete with marine mammals for food; chemical and noise pollution threatens them [pdf article about the effects of noise pollution on marine mammals]. Our ignorance about the effects of these threats makes it nearly impossible to manage the impacts of human activities on the ocean environment. Protecting marine mammal populations requires the best science and technology for objective assessment of risks and for creative approaches to reduce these risks.

The mission of the WHOI Marine Mammal Center (MMC)—now in its second year—is to develop strength in basic research and technology, concentrating on conservation applications through strategic partnerships and interdisciplinary approaches. The Marine Mammal Center, funded in May 2008 by a generous gift from Pete and Ginny Nicholas and family, builds on WHOI's expertise, capabilities and facilities—including ships, vehicles, and a state-of-the-art laboratory, testing, and imaging facility. To better study marine mammals and improve prospects for their conservation, the MMC promotes the development of interdisciplinary teams and new opportunities, new research initiatives in critical areas, and important outreach activities.

Marine mammals offer unique opportunities for basic research. They can dive for more than an hour, down to 2 km, under pressures exceeding 200 atmospheres. These extreme diving capabilities are fascinating to respiratory physiologists. Marine mammals have some of the most sophisticated auditory systems among animals, are second among mammals only to humans in their abilities to modify the sounds they produce based upon what they hear, and some species have an extraordinary biosonar. Marine mammals have large and complex brains for their body sizes, but little is known about their neurobiology.

The WHOI MMC has a commitment to bring scientists together across disciplines to continue to support WHOI's tradition of innovation in studying marine mammals at sea. All of these areas of basic research are essential for conserving marine mammal populations. During 2009, the MMC issued a request for proposals for marine mammal research. There were a total of eight submissions from four WHOI Departments requesting support more than three times the amount available. The MMC is gratified that the proposals responded so well to the call for interdisciplinary innovation. Three proposals were funded—one to study whether bacteria found on the skin of humpback whales can indicate their health status, another to test whether a new broadband sonar can map whale prey, and a third to model the risk that whales may tangle in lobster traps.

Over the past eight years, an average of 220 marine mammals were stranded dead or alive on Cape Cod each year, a remarkably high number for such a small area. Live, stranded animals pose an animal welfare problem, while all stranded animals provide unique opportunities for research. The WHOI MMC has strategic partnerships with the International Fund for Animal Welfare Marine Mammal Rescue and Research Division (formerly the Cape Cod Stranding Network), which finds and cares for animals on the beach, and the National Marine Life Center in Bourne, Mass., which is building a state-of-the-art rehabilitation facility for marine mammals and sea turtles. The WHOI Marine Mammal Center contributes a state-of-the-art necropsy and imaging facility where researchers can study these animals.

The MMC will be working with our partners and the broader biomedical community to develop research opportunities with stranded marine mammals, consistent with the highest standards of animal welfare and husbandry. Partners will include an animal welfare organization that decides about the disposition of animals on the beach, a rehabilitation facility responsible for top quality care of captive animals, and the research group at WHOI. The relationship offers a unique opportunity for research on animals that simultaneously meets needs for animal welfare, conservation and research. We believe that this collaboration can create unique opportunities for basic research on diving, physiology, cognition and neurobiology of marine mammals. At the same time, the research can help to identify factors contributing to mortality from strandings, entanglement in fishing gear and other conservation issues.

The WHOI MMC has partnered with the Nicholas School of the Environment at Duke University to enhance opportunities for graduate education with a competitive fellowship for graduate students at either Duke or WHOI to perform conservation-related research projects with scientists at the other institution. The 2009 call for applications resulted in the funding of six Duke graduate students to work with WHOI advisors from several departments. The MMC also helped to organize a course on Marine Mammal Science for the WHOI/MIT Joint Program.

In addition to activities at WHOI, MMC is developing other outreach efforts, including workshops, web sites and databases for open access to critical data and projects, and funds to scientists for interacting with media or providing testimony and expert advice on marine mammal research and conservation issues. The first workshop—"Gulf of Maine Seals—populations, problems and priorities" was held at the end of May and hosted 67 scientists.

Three speakers gave special MMC talks at WHOI during 2009. As an example of published outreach, we include a link

In this Dec. 17 snapshot of activity in the Marine Research Facility Necropsy Lab, researchers investigate the body of a common dolphin that died the day before in Harwich. The animal is being examined for gross pathology and being sampled to determine how it died. The ears and lungs will be used for ongoing research projects. At far left, Misty Niemeyer from the International Fund for Animal Welfare, Marine Mammal Rescue Research Division, records data. Examining the dolphin at left are independent researcher Gregory A. Early, Colby Moore, a WHOI guest student and grad student at Baylor University, and Rui Prieto, a University of Azores graduate student visiting from Horta, Azores. At right, Maya Yamato, a MIT/WHOI grad student, is removing the ears, as Alex Zosuls, from Boston University, observes. Andreas Fahlman, a WHOI research specialist in biology, is preparing the lungs for a study of their compliance at different pressures. (Photo by Michael Moore, Woods Hole Oceanographic Institution)

to a recent article in Physics Today describing the effects of sound on marine mammals. Another project, recently presented at an international marine mammal science meeting in Quebec, Canada, concerns the development of a hyperbaric chamber suitable for use within the WHOI CT scanner. This has enabled the first ever, detailed visualization of the respiratory system of diving mammals at different water pressures. The study is ongoing, but has shown great promise for major improvements to models of diving physiology and our understanding of how marine mammals manage decompression sickness.

— Peter Tyack, Center Director

Woods Hole Sea Grant Program

The Woods Hole Sea Grant Program is part of NOAA's national Sea Grant network of 32 programs that promote cooperation between government, academia, industry, scientists, and the private sector to foster science-based decisions leading to better understanding, conservation, and use of coastal resources.

More than half of Woods Hole Sea Grant's annual budget of $1 million supports multi-year research projects in environmental technology, estuarine and coastal processes, and fisheries and aquaculture, as well as smaller, "new initiative" grants. Sea Grant research addresses local and regional needs, and many projects have national or even global implications.

In 2009, Sea Grant supported nine projects at WHOI and other institutions that focused on topics ranging from toxic Alexandrium blooms in the Nauset Marsh to molecular indicators of dioxin sensitivity in birds. Houshuo Jiang and Peter Traykovski are examining wave energy dissipation over muddy seafloors, while Jesús Pineda and colleagues are investigating the accumulation of zooplankton in internal waves and how this affects the foraging behavior of fish and humpback whales. Other studies are focused on processes related to salt marsh dieback on Cape Cod and the dynamics of QPX disease in quahog populations.

More than one-third of Woods Hole Sea Grant's budget is dedicated to outreach and education, including the translation and dispersion of research to the general public. Sea Grant reaches its audience through one-on-one advice, training programs, web sites, workshops and lectures. The program continues to publish its joint newsletter with MIT Sea Grant, Two If By Sea. Collaboration with the Cape Cod Cooperative Extension service brings outreach and demonstration projects to local communities in fisheries and aquaculture and coastal processes. Successful projects in 2009 included a Fundamentals of Shellfish Farming class that is being repeated in 2010.

In the ocean science education field, Woods Hole Sea Grant has developed workshops for K-12 teachers and provided innovative publications directed at a general audience, such as Beachcomber's Companion©, an award-winning publication and Web site highlighting common Atlantic marine invertebrates.

Woods Hole Sea Grant is proud of its track record of creating opportunities to promote effective research—through outreach partnerships with WHOI, as well as initiating efforts to reduce marine debris and plastics in the ocean. In 2009, marine debris efforts included the organization of several beach cleanups with coastal residents as well as a partnership with the Friends of Sengekontacket on Martha's Vineyard aimed at reducing shore-based trash through education and mitigation.

—Judith E. McDowell, Program Director

Sea Grant Coastal Processes Specialist Greg Berman looks on as Daniel Cressey, a WHOI Ocean Science Journalism Fellow, looks through a transit while profiling Stony Beach in Woods Hole. The fellows spent a day with Berman and Aquaculture Specialist Diane Murphy, learning about the work that Sea Grant does. (Photo by Tom Kleindienst, Woods Hole Oceanographic Institution)

Woods Hole Center for Oceans and Human Health

Much activity took place in the Woods Hole Center for Oceans and Human Health (WH-COHH) during 2009. In June, the Center was awarded a $1.8 million grant from the National Science Foundation for continued research on harmful algal bloom issues and human pathogens in coastal waters. The award is a two-year Accomplishment Based Renewal, and is distributed to researchers at the major research groups in the three constituent institutions in the Center—WHOI, the Marine Biological Laboratory (MBL) and Massachusetts Institute of Technology. In August, the Woods Hole Center was awarded a supplement from the National Institutes of Health for nearly $300,000 for continuing center research.

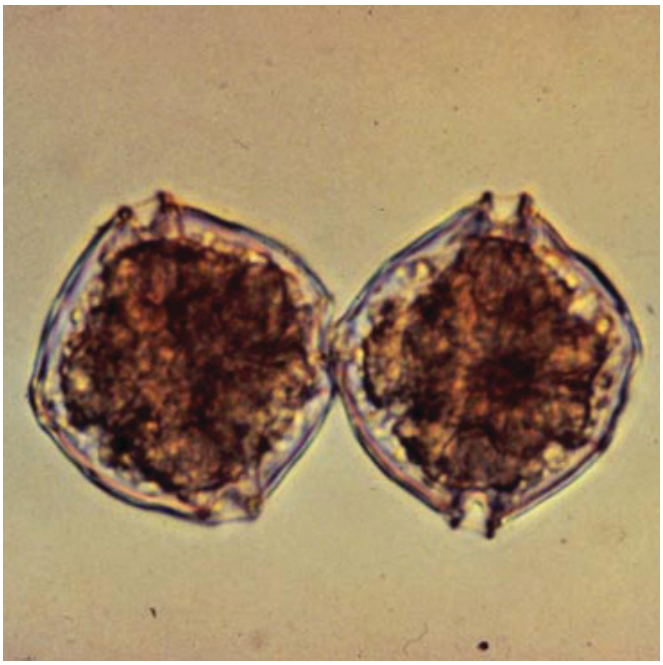
During 2009, the Center also solicited applications and made five awards for pilot projects. The awards are for studies on:

- Spatial and Temporal Variability in Beach Water Contamination (Hauke Kite-Powell, Marine Policy Center, WHOI)
- Investigation of Bioactive Lipids in the Harmful Algae Aureococcus anophagefferens (Ben Van Mooy, MC&G, WHOI)
- Characterization of Small Molecules Responsible for Allelopathy and Quorum-sensing Inhibition from Marine Bacteria (Tracy Mincer, MC&G, WHOI)
- Shewanella Ecotypes of Coastal Waters: Their Distribution and Genome Properties as Tools for Water Quality Assessment (Anton Post, MBL)
- Impact of Currents, Wind and Harbor Water Residence Time on Beach Bioindicators (Becky Gast, Biology, and Dave Ralston, AOP&E, WHOI).

These studies expand the activities of the center.

Research highlights include new findings on harmful algal blooms in the Nauset Marsh System, a major tourist and shellfish resource location. Don Anderson (Biology, WHOI) and his group studied Alexandrium cyst seedbeds in the system and identified three sites at which the Nauset blooms originate. Using molecular markers, they also determined that in the fall, the system has an input of harmful algal bloom cells from offshore, which may contribute to the seedbeds.

At MIT, center investigator Martin Polz has expanded the genomic knowledge of Vibrio bacteria, finishing the sequencing of 75 genomes from his unique Vibrio collection, an addition of approximately 7.5% of the total number of bacterial genomes sequenced. He currently is sequencing 400 plasmids from Vibrio populations, which will add about 25% to the plasmid sequence database. This will greatly enhance ability to identify pathogens in coastal systems.



Research highlights include new findings on harmful algal blooms in the Nauset Marsh System, a major tourist and shellfish resource location. Don Anderson (Biology Department) and his group studied Alexandrium (cells shown above) cyst seedbeds in the system and identified three sites at which the Nauset blooms originate. Using molecular markers, they also determined that in the fall, the system has an input of harmful algal bloom cells from offshore, which may contribute to the seedbeds. (Photo by Don Anderson, Woods Hole Oceanographic Institution)

The center investigators continued to publish high-impact papers and leverage new grant support.

—John Stegeman, Center Director

Ocean Observatory Initiative

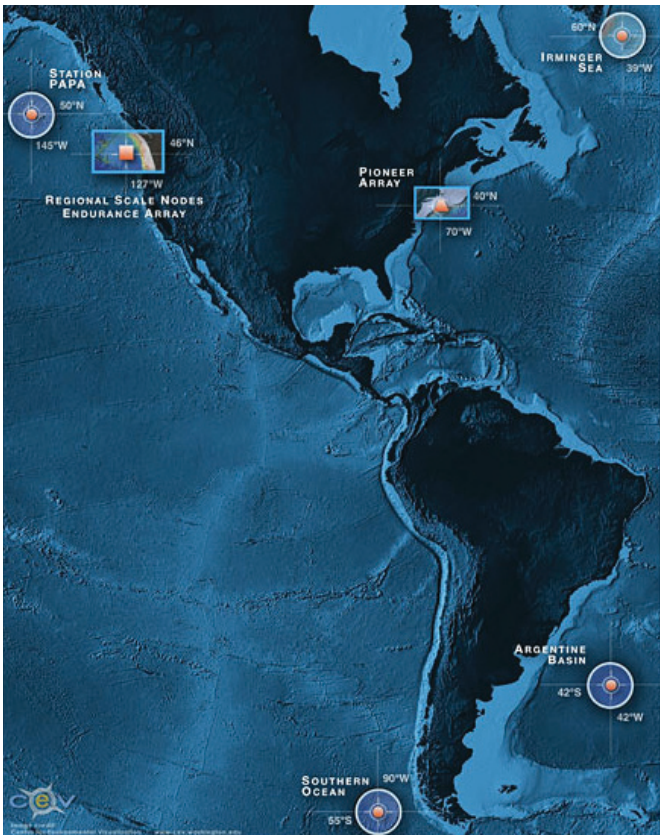
In 2009, staff from WHOI's Physical Oceanography and Applied Ocean Physics and Engineering departments began work on the National Science Foundation's (NSF's) new Ocean Observatories Initiative (OOI). The project is intended to provide cutting-edge ocean observing infrastructure for the ocean science community.

WHOI, the lead contractor on the Coastal and Global Scale Nodes (CGSN) component of the OOI, has been planning the project since it was awarded in 2007. WHOI is assisted by partners at Oregon State University and Scripps Institution of Oceanography and by Raytheon Integrated Defense Systems.

The successful Final Design Review of the OOI effort occurred in March 2009. The availability of funds from the American Recovery and Reinvestment Act of 2009 brought the start of the project forward from the planned date of July 2010 to September of 2009.

The early start enabled significant planning and preparation in 2009. This was done along with completion of a revised program of preliminary design and development work intended to advance the project between the design review and the start of the project, called a Major Research Equipment and Facilities Construction, or MREFC. The team at WHOI has worked with the support of the WHOI administration to build a sound foundation for the OOI effort—putting in place the staff, and obtaining space at a leased facility on Carlson Lane in Falmouth, Mass. to be used beginning in January 2010. Our partners at OSU and SIO have also worked to set up the teams to support the 5-year period of the MREFC in which the designs are completed, the infrastructure built, and the initial deployments carried out.

A fiber and copper cable on the seafloor on the Juan de Fuca plate off Washington provides bandwidth and power for the Regional Scale Node (RSN) component of the OOI, which will design and field a cabled seafloor and water column observatory. The RSN effort is led by the University of Washington. The CGSN and RSN observatories data will be collected, stored, and made freely available to users by the Cyber Infrastructure (CI) component of the OOI led by the University of California, San Diego. The Consortium for Ocean Leadership is the overall project lead for the OOI.



Overview map of the National Science Foundation's Ocean Observatories Initiative (OOI), showing the four global sites and the two coastal sites of the WHOI-led Coastal and Global Scale Nodes (CSGN) component of OOI. (Image courtesy Center for Environmental Visualization, University of Washington)

Coastal and Global Scale Nodes

The CGSN component includes two coastal observatories and four global observatories (Figure 1). The two coastal observatories, the Endurance Array off Oregon and Washington (Figure 2) and the Pioneer Array in the mid-Atlantic Bight (Figure 3), combine moorings and autonomous vehicles. At the Endurance Array and at the Pioneer Array, ocean gliders, which change their buoyancy and 'glide' forward as they rise and fall through the water column, provide the ability to sample across their respective geographic regions. They also may be tasked to specific sampling patterns in response to different events, such as the passage of an eddy through their ocean regions over the passage of a storm across the sea surface. The gliders move slowly, about 1/2 knot, and will be used to sample the regions spanning the moored arrays. At the Pioneer Array, powered autonomous underwater vehicles (AUVs) will also be used to sample, between and close by the moorings of the moored array.

The Endurance Array has two sets of moorings—one set of 6 aligned east-west off Newport, Oregon, with a pair of moorings at 25 m, 80m, and 500m depth; and a similar set off Gray's Harbor, Washington. Each pair has a surface mooring and a subsurface mooring. The subsurface moorings and benthic packages at the 500m and 80m Newport sites are attached to the fiber and copper cable of the RSN.

The Pioneer Array has 10 moorings, a mix of surface moorings and profiling moorings. At the base of some moorings of both the Endurance and Pioneer Arrays structures will be installed on the seafloor to serve as platforms for mounting sensors and, at the Pioneer Array, to provide a place

for the AUVs to dock to exchange data and obtain power.

Two of the four global observatories will be deployed in the northern hemisphere: one in the Irminger Sea southeast of Greenland, and one in the Gulf of Alaska in partnership with NOAA's Pacific Marine Environmental Laboratory (PMEL). The other two global observatories will be deployed in the southern hemisphere, one off southern Chile and one in the Argentine Basin.

Each global array (Figure 4) combines the use of four moorings and three ocean gliders. The four moorings include a surface mooring, an adjacent mooring with two profiling instrument packages—one that moves from about 200 m depth to the surface and one that moves from 200 m depth to near the sea floor—and two taut subsurface moorings. The moorings will form a four-sided moored array whose sampling will be complemented by sampling done by three ocean gliders. These gliders will also use acoustic modems to collect data from the subsurface moorings and make it available in near-real time, along with data to be telemetered from the surface mooring and the adjacent profiler mooring.

Across the CGSN observatories the sampling is designed to provide data from the full water column, from the sea surface to the sea floor. More than 680 sensors will be deployed across the CGSN sites, making observations of air-sea exchanges and physical, chemical, biological, and geological variability and processes. As much as possible, data will be made available in near-real time; and all data will be collected by the CI group for public access.

The initial deployments of the CGSN observatories are now scheduled. Deployment times are chosen to provide the wind and wave conditions most conducive for work at sea and to accommodate the planned 12-month turn around schedule for global arrays and 6-month turn around schedules for coastal moorings. Coastal gliders will be serviced every three months.

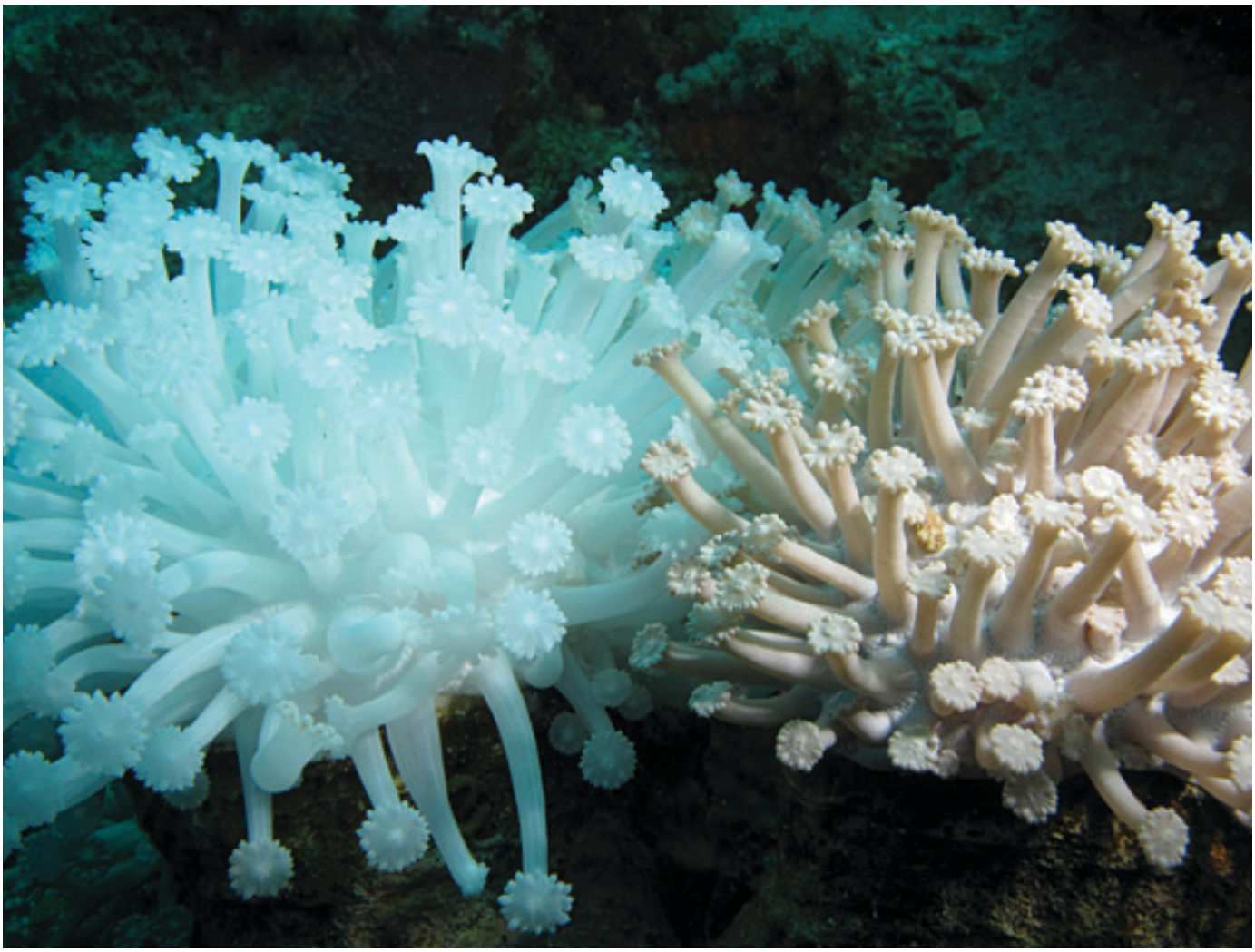
The gliders of the Endurance and Pioneer Arrays will be deployed first, in mid-2012. The Pioneer Array moorings would be added in 2013 to complete that observatory. Additional elements of the Endurance Array are deployed in turn, the un-cabled moorings of the Newport Oregon line, the Washington mooring line, and finally the cabled elements of the Newport line. The Endurance Array will be completed in 2014; the Argentine Basin observatory will be deployed in the winter of 2012-2013; the Gulf of Alaska and Irminger Sea observatories will be deployed in the summer of 2013; and the observatory off southern Chile will be deployed in the winter of 2013-2014.

WHOI Partnership with King Abdullah University of Science and Technology (KAUST)

After just two years, the collaboration of WHOI and King Abdullah University of Science and Technology (KAUST) is already reaping scientific benefits. The past two years of research have increased our understanding of the hydrography of the Red Sea and its influence on the chemistry, biology and fisheries of coral reefs.

The second year of the WHOI-KAUST collaboration has included scientific advances in the 13 research projects and the inauguration of the University by King Abdullah in October 2009. WHOI President and Director Susan Avery and Jesús Pineda represented WHOI at the inauguration and symposium. They were joined by thousands of other Saudi and international guests. The opening of the University has accelerated the collaboration and transfer of scientific expertise between WHOI and KAUST scientists.

Tom Farrar has collected one full year of hydrographic and meteorological data from the WHOI-KAUST onshore meteorological tower and the offshore mooring, and collection of a second year of data is underway. These data and those from near-shore pressure gauges deployed by Richard Limeburner are being used to look at seasonal wind patterns over the Red Sea and how they affect seasonal along-shore and cross-shelf currents. The meteorological data are being used by Ru Chen, WHOI graduate student, to study the influence of wind jets on the general circulation and currents in the Red Sea. Data from the deployed instruments are also being incorporated into a circulation model and a high-resolution tidal model developed by Larry Pratt and colleagues.



Many corals and other marine animals contain dinoflagellate symbionts that provide nutrition to the host from photosynthesis. These symbionts can be expelled from the host following exposure to elevated temperature or other stressors, resulting in a pale appearance or "bleaching." This partially bleached soft coral was observed in relatively deep waters (50 ft) during an August trip to the Red Sea. (Photo by Ann Tarrant, Woods Hole Oceanographic Institution)

The models are being transferred to KAUST in collaboration with KAUST postdoctoral researchers.

The role of hydrodynamics on reefs and coral biology is being investigated in several studies. On the central Saudi coast near KAUST, the coral reef crests are shallow, relatively narrow and are aligned parallel to the shore. Waves and the dominant wind push water from the exposed side of the reef, over the top of the crests, to the protected shoreward side. WHOI postdoctoral scholar Kristen Davis is investigating the influence of wind and waves on the currents that move water over the reef. She is working with Steve Lentz and Jim Churchill, who are measuring cross- shelf hydrodynamic forces that affect currents and heat flux on reefs. They have found that offshore water is on the reef crests for about one hour, and there are diurnal differences in temperature on the reefs. Pineda and Davis are also investigating diurnal and seasonal small-scale temperature differences on the reef crests and on offshore and near shore reefs.

Pineda and Vicke Starczak have conducted a field experiment to investigate the response of coral to these temperature changes. Ann Tarrant and post-doctoral investigator Adam Reitzel have analyzed coral samples from different locations on reefs and from this experiment, and preliminary results indicate that symbiont diversity differs among reef sites that are exposed to different temperature regimes.

Water sampling and analysis by Dan McCorkle has provided a picture of the immediate chemical environment of the corals, and the influence of the reefs on seawater chemistry. Nutrient availability and seawater carbonate chemistry help explain patterns of coral calcification and growth. Analysis of water samples shows that the surface waters of the Red Sea are strongly supersaturated with respect to the calcium carbonate mineral aragonite, a situation that promotes coral calcification.

Anne Cohen, WHOI postdoctoral investigator Neal Cantin, and Tarrant are developing and applying new tools to quantify the impacts of climate change and direct anthropogenic activity on the health of coral reefs in the central Red Sea. Reef-building corals and calcifying algae contribute up to 90% of the reef's calcium carbonate budget through the process of skeletal building. Their project addresses the impact of rising sea-surface temperatures, ocean acidification and nutrient loading on the ability of regionally important reef-building coral species to build skeletons. Results from their coral samples link changes in coral growth over the past decade to rising sea-surface temperatures, which suggests that CO2-induced climate changes have begun to negatively impact coral reef health in this region. Using their data in the Intergovernmental Panel on Climate Change (IPCC) model projections of future climate changes, they hope to predict changes in the Red Sea coral reef ecosystem over the coming century.

Konrad Hughen and colleagues have been conducting molecular analysis of lipids in coral zooxanthellae, symbiotic algae that live within coral hosts, to develop novel indicators of coral health. They have been studying the relative abundance of healthy and diseased corals in the Red Sea in order to relate stress factors such as temperature, turbidity and pollution to the distribution patterns of coral Yellow Band Disease. They are also analyzing trace metals in long drill cores obtained from massive coral colonies to reconstruct sea surface temperatures back more than 400 years.

Rapid ecological surveys of coral-reef ecosystems in Saudi waters were conducted to broaden coverage to include the Farasan Bank region of the southern Red Sea. The survey team was led by Simon Thorrold and KAUST scientist Michael Berumen, and included an international team of coral reef experts. They documented an abundant and diverse assemblage of corals and fishes. As part of Thorrold's study of fish connectivity, Kelton McMahon, an MIT/WHOI Joint Program student, is analyzing stable isotopes in fish otoliths (ear bones) to determine movement patterns of snapper among mangrove, seagrass and coral-reef habitats in the Red Sea. He finds that seagrass beds may be more important than mangroves in fueling productivity in coastal ecosystems of the southern Red Sea. Thorrold and collaborators are also tracking movements of large fish: They have successfully tagged seven whale sharks. The tags are due to report in the spring of 2010, and will provide the first glimpses of whale-shark movements in the Red Sea.

Hauke Kite-Powell, Porter Hoagland, Di Jin, Andy Solow, and Michael Neubert are working with officials of the Saudi Arabian Ministry of Agriculture to assemble a detailed data set on fishing effort and catch along the Saudi Red Sea coast, and are incorporating these data into a bio-economic model of the Saudi Red Sea traditional fishery. Their preliminary results suggest that the present fishing fleet and fishing activities may be too large to sustain fish stocks at optimal levels. This work will expand to include additional data on the southern (Jizan) region traditional and industrial fisheries. The team will also assist Saudi Ministry of Agriculture officials in their efforts to improve collection of data on commercial and recreational fishing, provide advice on the design of management measures for protected areas in the Farasan Islands and provide input to design of research studies and management measures for a proposed reef protected area near KAUST.

The success of the research collaboration will continue into next year, with greater opportunities for interactions between WHOI and KAUST scientists, postdoctoral researchers and students.

Academic Programs

During the 2008-2009 academic year, the Massachusetts Institute of Technology/WHOI Joint Program awarded 33 masters and doctoral degrees in ocean science and engineering. As of fall 2009, the Joint Program (JP) has awarded 843 degrees. Nineteen new students enrolled in the program in 2009, and the total fall enrollment was 120.

Ten Postdoctoral Scholar awards were given (seven women and three men) with a 50:50 split between U.S. and foreign nationals. At any given time, WHOI averages about 65 to 70 postdoctoral Scholars, Fellows and Investigators in residence.

The topic for the 2008 Geophysical Fluid Dynamics (GFD) summer program was "Perspectives and Challenges in GFD." Staff members used this opportunity to examine past developments in the field and then considered the future by describing concurrent and new avenues for research. Ten fellows (7 men, 3 women), eight guest students, 72 staff members and 5 guest lecturers participated in the program.

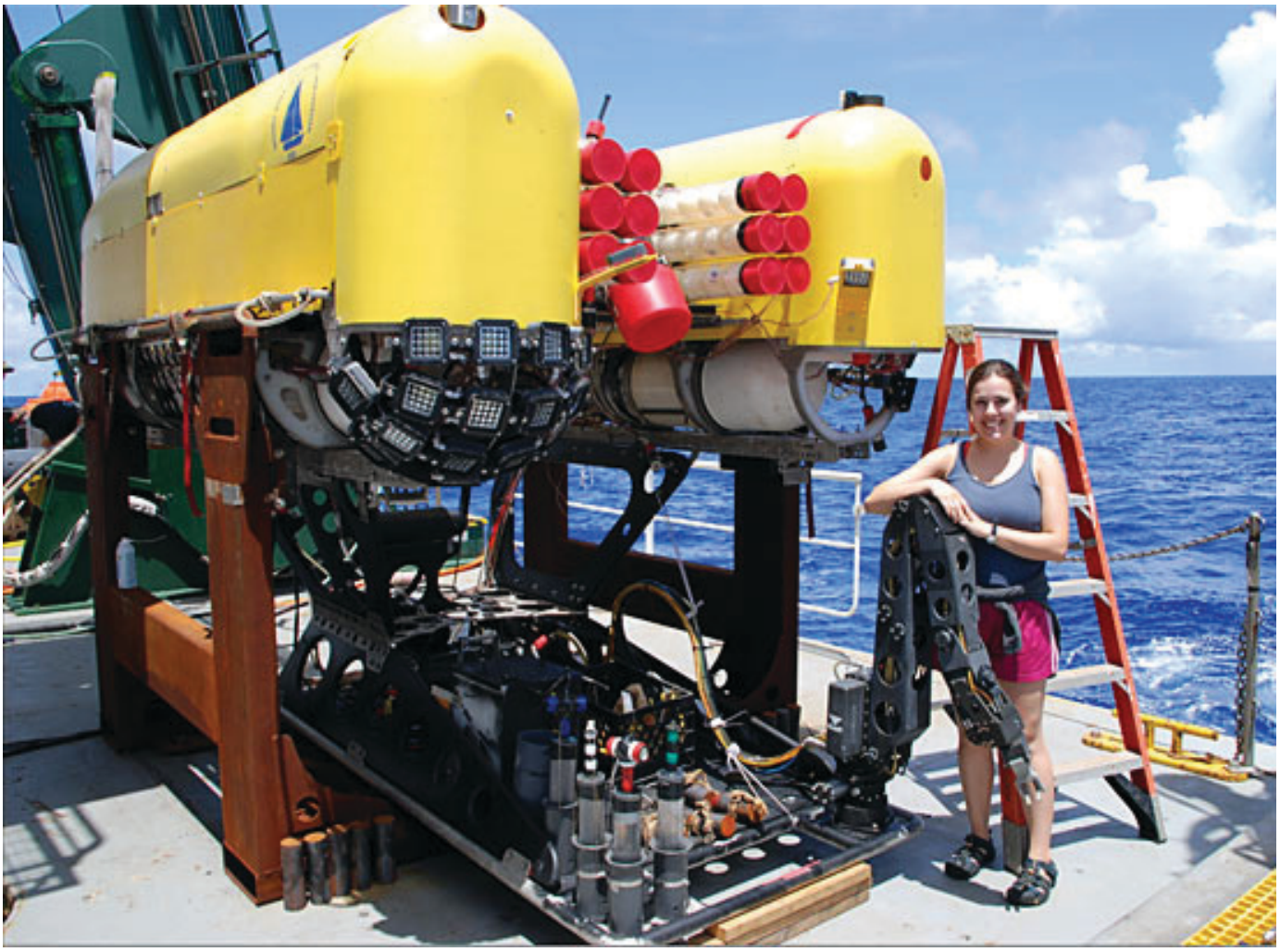
Twenty-eight Summer Student Fellows (SSF) representing 26 colleges and universities were chosen from a record-high 212 applicants. These undergraduates and a few recent graduates spent 10-12 weeks in the summer working on research projects with WHOI scientists, attending lectures and workshops, and enjoying themselves on Cape Cod (time permitting!). The SSF program is enthusiastically supported by WHOI scientists, who enjoy working with the undergraduates and appreciate how much they contribute to WHOI research programs. Many students go on to apply for graduate school in the JP and other ocean science graduate programs.

Our office participated in 2 new education programs in 2009. Along with the other five science organizations based in Woods Hole that are partners with us in the Woods Hole Diversity Initiative (WHDI), we joined in a new summer program entitled Woods Hole Partnership Education Program (PEP). PEP is a summer diversity program for undergraduates that specifically encourages applications from students from minority populations under-represented in STEM (Science, Technology, Engineering and Mathematics) fields. The 2009 PEP class consisted of 16 students from 11 universities. The students took a for-credit course during their first month, which included instruction in physical and chemical oceanography from 2 JP students. The rest of the summer, the students worked with science mentors from the WHDI institutions—five of the students worked with WHOI scientists.

The second new program, supported by the A.V. Davis Foundations, is a winter internship program for undergraduate students attending liberal arts colleges. Four students from 3 colleges participated in the first winter of the program and were on the WHOI campus for 3 weeks. The students received one hour of instruction per day on basic concepts in oceanography taught by senior JP students, and spent the rest of the day working in the laboratories of the WHOI scientists who hosted them.

Students and postdocs bring energy, enthusiasm and new ideas to WHOI's research portfolio and help us move in new directions. We appreciate the support we receive from individual donors and foundations that support these fine education and training programs.

—James Yoder, Vice President for Academic Programs & Dean



While her Oberlin classmates accepted their diplomas at a graduation ceremony in Ohio, Summer Student Fellow Eleanor Bors was aboard the R/V Kilo Moana along with her advisor, WHOI biologist Tim Shank. The voyage marked the first deployment of the robotic vehicle Nereus, which successfully dove to Challenger Deep—the deepest part of the ocean—on May 31, 2009. Back in Woods Hole, Bors worked on genetic methods for larval identification as part of a study of how worm communities recolonize after hydrothermal vent eruptions. Read more about her experience as a fellow in the blog, "In an Octopus's Garden." (Photo by Timothy Shank, Woods Hole Oceanographic Institution)

BACK COVER: WHOI biology adjunct scientist Jelle Atema and students Julia Spaet, Danielle Dixson, and Joel Buytkins perform a shark sensory experiment in the Environmental Systems Lab. The research team is testing effects of elevated carbon dioxide levels on the odor discrimination capabilities of sharks. This shark (smooth dogfish) is swimming upstream in the "laminar" flume where odor is released from behind a turbulence generating obstacle (brick). Rhodamine dye is used to visualize the shape and extent of the odor plume. (Photo by Tom Kleindinst, Woods Hole Oceanographic Institution)

WOODS HOLE OCEANOGRAPHIC INSTITUTION

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