Woods Hole Oceanographic Institution

2008 Annual Report

2008 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: Through a research agreement with King Abdullah University of Science and Technology, WHOI scientists are studying coral reef ecosystems, fisheries, and water circulation along Saudi Arabia's Red Sea coast. The first priority is to assess the health of extensive coral reefs and identify environmental factors affecting them. This work involves commercial dive boats, local dive-tour operators, and coral measurements by WHOI scientists, including MIT/WHOI Joint Program student Jessie Kneeland, shown here. These studies will provide a baseline for monitoring this vital and still-unspoiled ecosystem in a time of ongoing coastal development and climate change. (Photo by Konrad Hughen, Woods Hole Oceanographic Institution)

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

Letter from Susan K. Avery, President and Director

The year 2008 will be forever remembered for two historic moments in our nation's life: the election of Barack Obama, the first African American President, and the start of an economic contraction on a scale not seen since the Great Depression, with fiscal tremors reaching around the globe and affecting billions of people. For WHOI, both events had almost immediate impact, and framed a year alternately encouraging and disheartening.

On the positive side, the President-elect and his transition team were eager to reinvigorate the informing role of science in national policy, and to quickly urge budget increases for the National Science Foundation, the National Oceanic and Atmospheric Administration, and other federal agencies that provide the bulk of our grants and contracts. As a result, at this writing in 2009, the outlook for sponsored research in the next several years is more hopeful and stable than it has been in nearly a decade.

The negative counterbalance was the hard blow to our endowment portfolio landed by the economic downturn. Thanks to the vigilance and talent of our Board's Investment Committee, our losses were less severe than those suffered by many other organizations, though grave nonetheless. Of course, losses on the financial markets inevitably affected philanthropy, and unrestricted gifts declined for the year.

It was certainly a challenging first year for me, but in unexpected ways, as financial winds dictated a course shift in my original plans.

My intent was to focus on a developing comprehensive strategic plan for the Institution, to embrace wider research collaborations and new directions—including the burgeoning field of ocean informatics that will be essential for managing, analyzing, and sharing the oceans of data that we pull from the seas. Instead, I needed to stem the outflow of our unrestricted resources and search for ways to increase efficiency and reduce costs without undermining essential support for science. Further, I hoped to introduce improvements in organizational structure and processes, but had to press the 'pause' button after reviewing our needs, and concentrate instead on the crisis in funding for our employee retirement plan.

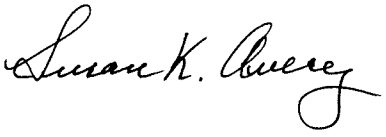
But WHOI was also proactive in 2008: We explored new opportunities for local, regional, and international collaborations and are working more closely than ever with other major research organizations, in the common cause of setting an ambitious agenda for national and global ocean research.

We laid the groundwork for managing the largest science program in our history, the Ocean Observatories Initiative. We closed our Depth of Leadership campaign at year's end with $194.6 million raised over the course of the last nine years—an average of more than $22 million per year. This was a milestone achievement for an organization of our size, due in large measure to the remarkable generosity of our Trustees and Corporation Members, who were responsible for 45% of the total.

Susan Avery with Newt Merrill, chairman of the Board of Trustees.

Overarching all, the constant pace of exploration, discovery, and application of ocean knowledge that is our daily regimen in Woods Hole has nurtured my enthusiasm. After making the rounds of the departments, after getting to know scientists, engineers, technicians, students, marine crew members, and administrative staff, my gratitude for the opportunity to be here has grown steadily. These are such talented, spirited, and hard-working people, and they are, separately and together, so dedicated to the mission of WHOI, that they inspire optimism for the future.

That mission's essential contribution to society endures, and the Institution, itself born during the Great Depression, will also continue. As we all know, economic cycles pass like storms, and WHOI has pounded through rough seas before. In 2008, our ships, vehicles, moorings, and floats continued to extend our global reach and expand our understanding of the ocean. In 2009 Knorr, Oceanus, and Atlantis will sail, Alvin and our many vehicles will dive, and in 2009 our passion for science will again bring exciting new knowledge about our Planet Ocean.



Letter from Laurence P. Madin, Executive Vice President & Director of Research

Located at 42° North latitude, WHOI is squarely in the temperate zone, just about halfway between the equator and the North Pole. But our geographic location has never dictated where our scientists work, and 2008 saw the initiation or continuation of significant research programs at both extremes, the Arctic and the tropics. While these regions seem opposite in every way, both lie on the front lines of global climate change and its multiple effects on the world ocean.

Perhaps nowhere on earth is climate change having as dramatic and rapid an effect as in the Arctic, where ice cover, ocean water circulation, geochemistry, and ecosystems are all responding to the pervasive rise in air and sea temperatures. These changing conditions will not only alter the future of that region and its human inhabitants, but will likely affect conditions far to the south. Arctic research continues to be a major focus for WHOI scientists. Supported by federal and internal sources, they participated in 18 separate expeditions into the Arctic region, at sea, on ice, or land.

Camped out on the Greenland ice sheet, Sarah Das and colleagues (photo) documented the dramatically sudden drainage of meltwater lakes through crevasses that appear to carry the water all the way to bedrock beneath the ice, potentially lubricating and accelerating the movement of the ice sheet toward the sea. On the Arctic tundraMarco Coolen, Tim Eglinton, and Liviu Giosan collected samples for geochemical and microbial studies.

Many other studies were conducted at sea. On three separate cruises, researchers deployed WHOI-designed and built Ice Tethered Profilers from Canadian, Russian, and German icebreakers. These devices, mounted on drifting ice floes, measure properties of the water with an instrument package that travels up and down through the water column beneath the ice. On other research cruises, Bob Pickart, Carin Ashjian, Andrey Proshutinsky, and Fiamma Straneo focused on the Arctic Ocean's planktonic ecosystems or the flow of water into or out of the Arctic region.

Fifteen new Arctic projects were funded in 2008 by WHOI's Arctic Research Initiative, a program within the Ocean and Climate Change Institute that supports a wide range of investigations on the physics, chemistry, and biology of the Arctic basin. The underlying goals of the Initiative are to understand the consequences of changes in the Arctic for sea ice, ocean circulation, and global climate, as well as effects on ecosystems within and beyond the Arctic. Understanding these changes in the Arctic will help us predict changes elsewhere in the world, perhaps pointing to ways to mitigate or adapt to climate change impacts.

While warming water and loss of ice are driving big changes in the Arctic, in the tropics the temperature and chemistry of surface waters bathing coral ecosystems are also starting to change. Warmer temperatures cause coral bleaching, (expulsion of their symbiotic algae), which leads to much greater coral mortality and widespread die-offs across entire reefs. An additional climate-related stress that may become significant in the next 50 years is ocean acidification—a change in the chemistry of seawater due to absorption of excess CO_2 from the atmosphere—which is expected to make it increasingly difficult for corals and many other animals to build their calcium carbonate skeletons. This is a serious concern—not only for corals but also for thousands of other reef-associated species—if reefs begin to disintegrate.

Scientist Sarah Das and colleagues documented the sudden drainage of meltwater lakes through cracks on the Greenland ice sheet that appear to carry the water all the way to bedrock beneath the ice. (Photo by Chris Linder, Woods Hole Oceanographic Institution)

WHOI scientists are studying coral ecosystems and their responses to environmental and climate change in multiple locations and on different time scales. As part of WHOI's collaboration with King Abdullah University of Science and Technology, Anne Cohen, Konrad Hughen, and colleagues (bottom photo) took coral samples in the Red Sea to analyze for effects of temperature, disease, and acidification stress, using chemical and skeletal markers that reveal conditions in the ocean and within the corals themselves. Because large coral heads can be hundreds of years old, these markers also give us a picture of past environmental history and the corals' responses. This backward look can provide clues to how corals may cope with changes in the coming decades, and perhaps help us identify stresses that we can mitigate.

Though half a hemisphere apart, the Arctic and the coral reefs of the tropics are probably the two environments most strongly and immediately affected by global climate change. The changes that we are beginning to study and understand now will have implications for the climate and weather, biodiversity, and economic resources of much of the rest of the planet. The physics, chemistry, and biology of the ocean are central actors in climate change. Gaining a fundamental understanding of how these changes are happening is the essential foundation for any efforts of mitigation or adaptation that society might make.

Larry Madin

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

We are pleased to present the 2008 financial statements of the Woods Hole Oceanographic Institution (WHOI) and to describe some of the new reporting requirements that impacted the statements. WHOI completed 2008 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, 2008, WHOI's total assets were $488 million, total liabilities were $254 million and total net assets were $234 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 $117.8 million. On December 2, 2008 WHOI refinanced the Series A Bond and retired the bonds on January 2, 2009, the earliest possible call date, using the Series B bond proceeds maintained in the debt service fund at December 31, 2008. The Series A Bond was $53.7 million, with a net outstanding debt of $64.1 million as of December 2008.

The endowment, $265 million represents 54% of the total assets. This reduction in the Institution's endowment was due solely to market conditions. Its growth from $347 million in 2006 to $384 million in 2007 accounts for the increase in total net assets within those years.

Statement of Activities

WHOI's total operating revenues increased by $10 million: from $154 million in 2007 to $164 million in 2008.

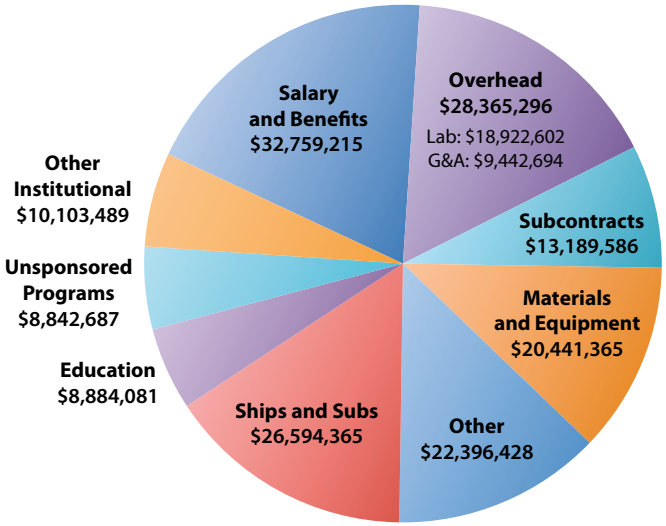
$16.5 million of endowment income and appreciation was distributed to operations as follows:

Education	$6.7 million
Research	$6.1 million
Unrestricted	$3.7 million

The Institution had overhead costs of $65.0 million, and approximately 77% of that amount, $49.8 million, was recovered from the government and non-government research. The remainder was an institutional expense.

WHOI paid $4.3 million in interest during 2008 and $1.2 million in principal payments on the $54.9 million outstanding debt in 2008. The Federal government allows us to include interest and depreciation in our overhead rates and will reimburse us for these expenses.

2008 Operating Expenses



New Reporting Requirements

The Financial Standards Accounting Board (FASB) ,The American Institute of Certified Public Accountants (AICPA) and the Internal Revenue Service (IRS) have issued new guidelines, interpretations and rules on topics such as fair value measurement and a revised Form 990.

FAS 157 Fair Value Measurements

On January 1, 2008, the Institution adopted Financial Accounting Standards Board ("FASB")

Statement No. 157, *Fair Value Measurements*, which establishes a framework for measuring fair value in generally accepted accounting principles ("GAAP") and expands disclosures about fair value measurements. FASB Statement No. 157 clarifies that fair value is an exit price, representing the amount that would be received to sell an asset or paid to transfer a liability in an orderly transaction between market participants. As such, fair value is a market-based measurement that should be determined based on assumptions that market participants would use in pricing an asset or liability. As a basis for considering assumptions, FASB Statement No. 157 establishes a three-tier fair value hierarchy, which prioritizes the inputs used in measuring fair value as follows:

Level 1 – Observable inputs such as quoted prices in active markets;

Level 2 – Inputs, other than the quoted prices in active markets, that are observable either directly or indirectly; and

Level 3 – Unobservable inputs in which there is little or no market data, which require the reporting entity to develop its own assumptions.

Christopher J. Winslow (continued)

Assets and liabilities measured at fair value are based on one or more of three valuations techniques noted in FASB Statement No. 157. The three valuation techniques are as follows:

Market approach – Prices and other relevant information generated by market transactions

involving identical or comparable assets or liabilities;

Cost approach – Amount that would be required to replace the service capacity of an asset

(i.e., replacement cost); and

Income approach – Techniques to convert future amounts to a single present amount

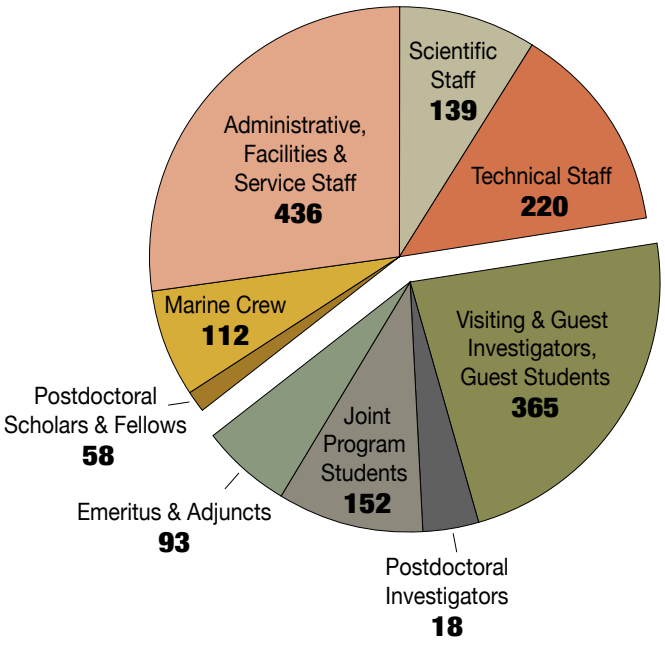
based on market expectations (including present value techniques).

Revised IRS Form 990

On December 20, 2007, the IRS released an updated version of the Form 990 for the 2008 tax year that retains the format of the redesigned draft form issued in June, but includes major revisions in response to public comments. According to the IRS, the new form allows greater opportunity for an organization to describe its activities. Major changes were made to the form's summary page, governance section, and various schedules, including those relating to executive compensation, related organizations, foreign activities, noncash contributions and tax-exempt bonds. These changes are in an effort to achieve greater transparency.

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.



WHOI employees totaled 965 in 2008; others affiliated with the Institution (separate wedge) totaled 628.

Marine Operations

During 2008, WHOI made substantial progress on the construction of two new deep submergence vehicles for the National Deep Submergence Facility.

In preparation for its first science cruise, the autonomous underwater vehicle (AUV) *Sentry* underwent sea trials from the R/V *Oceanus* in April. Funded by grants from WHOI's Access to the Sea and Hollister funds, the engineering team conducted a series of eight dives to depths of more than 2,300 meters (7,546 feet) to test the vehicle and its new geophysical and oceanographic sensors. *Sentry* was then shipped to Seattle in August for its first scientific mission on board the R/V *Thompson* in support of the new Ocean Observatory Initiative. *Sentry* conducted six dives of average length 17 hours, and mapped 46 km^2 of seafloor at very high resolution. Over the next year or so, *Sentry* is expected to replace its predecessor, *ABE*, as the autonomous vehicle of the National Deep Submergence Facility.

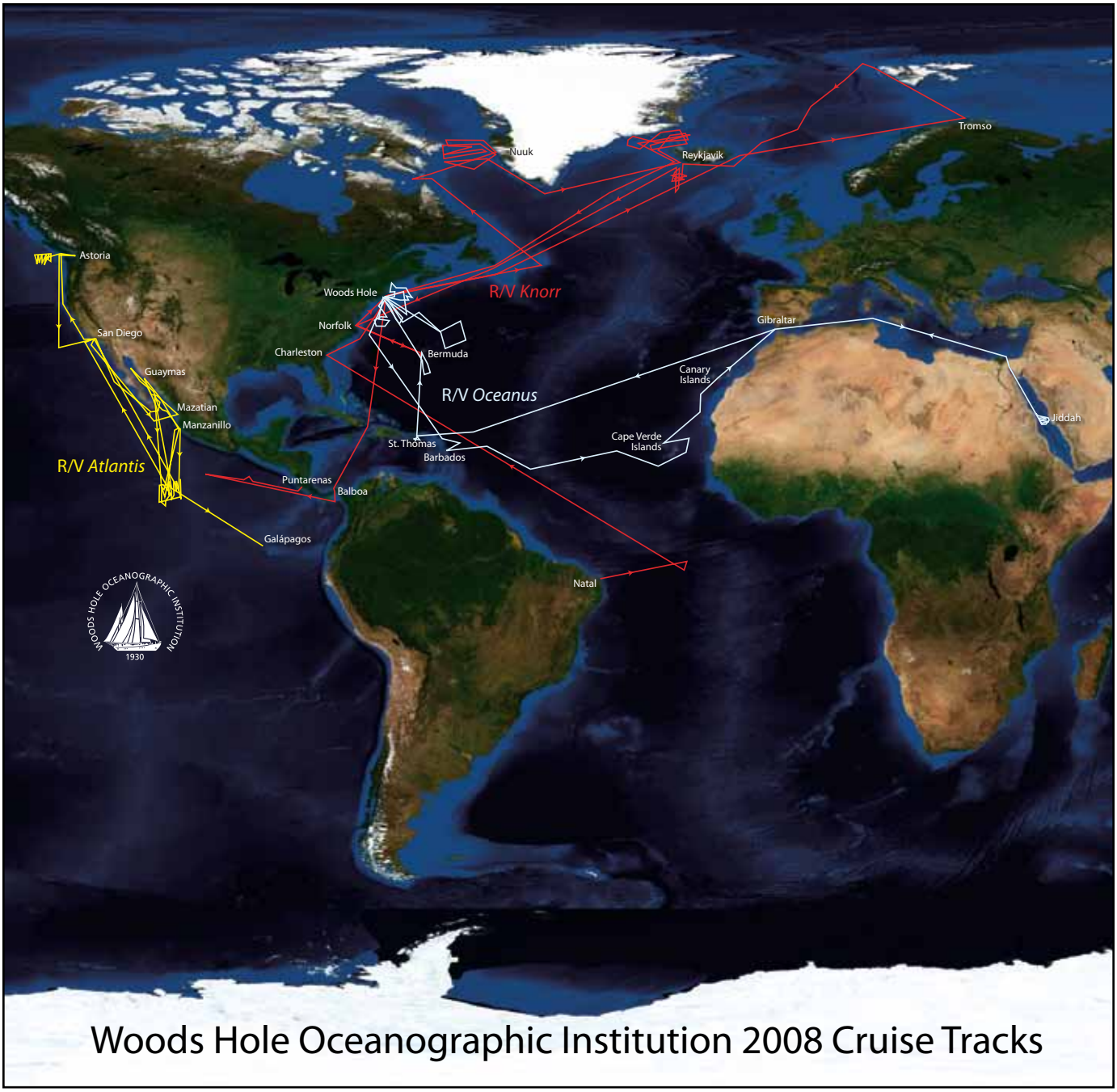
The project to construct a new human-occupied vehicle with a depth capability of 6,500 meters (21,325 feet) to replace the HOV *Alvin* continues to evolve. The original plan included contracts for the design and fabrication of the personnel sphere to Southwest Marine Institute, and of the vehicle to Lockheed Martin Corporation. In January 2008, WHOI received a detailed cost estimate indicating that the total projected cost for the project had more than doubled. With several possible options of a way forward, WHOI recommended to its external advisory committee and the National Science Foundation that fabrication of the 6,500-meter-depth personnel sphere go ahead, but that construction of the vehicle be done at WHOI, with a two-phase approach to building the vehicle to reach the 6,500 meter depth goal.

In June, the two hemispheres that will make the new, larger personnel sphere were successfully forged from large titanium disks. By the end of 2008, WHOI had submitted plans to the National Science Foundation to prepare for a preliminary design review for the first phase – installation of the completed personnel sphere, as well as new lithium ion batteries and syntactic foam rated for 6,500 meters, into *Alvin*'s current frame.

This installation is currently scheduled for late 2010 when *Alvin* will return to Woods Hole for a major overhaul. *Alvin* will then continue to operate to its current depth of 4,500 meters (14,764 feet) until funds become available for the second phase of construction – upgrading the remaining components to attain 6,500 meters. The new, state-of-the-art, 6,500 meter vehicle will ultimately provide enhanced capabilities and new opportunities for the U.S. scientific community to reach and study 98% of the ocean floor.

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

Bosun Clindor Cacho admires a rainbow as the *Oceanus* prepares to dock at St. Thomas, U.S. Virgin Islands in November 2008, after a transit across the Atlantic. The ship, scientists, and crew were in the Caribbean to take measurements of the water-column—a conceptual slice, or column of the ocean from surface to bottom—using sensors and samplers: WHOI scientist Dave Fratantoni's ScanFish (a towed vehicle that samples while moving up and down in the water) and the Video Plankton Recorder. This research and the new ScanFish was funded by King Abdullah University of Science and Technology, part of a collaborative research agreement with WHOI. (Photo by Alexander Dorsk, Woods Hole Oceanographic Institution)


Nuuk
Reykjavik
Tromso
Astoria
Woods Hole
R/V Knorr
Norfolk
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Canary Islands
R/V Oceanus
Mazatian
Manzanillo
Jiddah
St. Thomas
Barbados
Cape Verde Islands
R/V Atlantis
Puntarenas
Balboa
Galápagos
Natal
WOODS HOLE OCEANOGRAPHIC INSTITUTION
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Woods Hole Oceanographic Institution 2008 Cruise Tracks

R/V Atlantis

Days at sea: 261; Cruises: 13; *Alvin* dives: 107
Investigators Served: 284 ; Nautical miles: 19,592

The R/V *Atlantis* began the 2008 operating year using the submersible *Alvin* to study the microbiology and biogeochemistry of hydrothermal vent communities at the East Pacific Rise (EPR) on the mid-ocean ridge. This cruise ended in San Diego, where *Alvin* was offloaded in preparation for an eight-week dry-docking of *Atlantis*. In late April, *Atlantis* transited to the Gulf of California designated site for the National Science Foundation's MARGINS research program with the ROV *Jason*, to study the transition from continental to oceanic crust. *Alvin* then resumed operations at the EPR using in situ voltammetric analyzers (metal ion analyzers) to study hydrothermal vents, and conducting a program to establish a long-term geodetic network at the Ridge 2000 Integrated Studies Site (studies of life and planetary processes at the mid-ocean ridge.) *Atlantis* then transited to Astoria, Oregon for three *Alvin* cruises at the Juan de Fuca Ridge off the Oregon-Washington coast. These cruises combined a variety of programs, including:

- The study of the biology of hydrothermal vent paralvinellids (specialized heat-tolerant deep-dwelling worms);
- Vent flow and turbulence monitoring;
- A continuing program at the ODP (Ocean Drilling Program) borehole observatories (sensors inside the seafloor crust);
- Testing optical communication sensors; modeling hyperthermophile (heat-loving bacteria) growth; and
- Continuation of the NOAA-VENTS Research Program for studies of undersea volcanoes and venting.

Atlantis and *Alvin* returned to San Diego in September for a two-week open period and the Navy INSURV ship condition inspection. In October, *Atlantis* transited to Guaymas Basin off Mexico for *Alvin* dives to study microbial carbon and sulfur cycling in the hydrothermally-altered sediments. *Atlantis* and *Alvin* continued to work between Guaymas Basin and EPR for the remaining two cruises studying abundance, diversity and activity of single-celled microorganisms and protists; studying genomes from environmental samples ("metagenomic exploration") to infer virus-host interactions in these deep-sea hydrothermal vent environments; and microbiology and biogeochemistry of autotrophic (chemosynthetic) microbes. *Atlantis* ended the year at sea near the Galapagos Triple Junction with a mapping survey to understand how deformation of Earth's crust is distributed at tectonic plate triple junctions.

R/V Tioga

Days at sea: 107; Investigators Served: 477

The 2008 schedule for the R/V *Tioga* included many trips throughout the year to the Martha's Vineyard Coastal Observatory (MVCO) for deployment and recovery of equipment, as well as for servicing and maintenance. Other operations took *Tioga* as far as Massachusetts Bay, Cape Cod Bay, Long Island Sound, and the Connecticut River. A variety of work was conducted, including engineering tests of the autonomous underwater vehicles *Sentry* and a *REMUS 600*; deployment and recovery of instruments, moorings, and sonar communications equipment; deployments of Real Time Acoustic Tracking Systems (RATS) for location and study of right whales; tagging of right whales and sea turtles; sediment coring; and Spray Glider operations. In addition, educational science trips for WHOI's Summer Student Fellows and for other groups were conducted in Buzzards Bay and Vineyard Sound.

R/V Knorr

Days at sea: 287; Cruises: 9
Investigators Served: 212; Nautical miles: 40,844

The R/V *Knorr* began her operating year exploring deep-sea hydrothermal vents and testing communications between multiple autonomous underwater robotic vehicles off Ascension Island. *Knorr* then transited to Charleston, SC for a thirty-day shipyard period before returning to Woods Hole. In March, *Knorr* departed for the first of two legs of a north Atlantic polar air sampling program called *Icealot*. NOAA's *Icealot* program brought *Knorr* just above 80°N latitude, the most northern point traveled for the vessel. *Knorr* continued to work off Iceland with a cruise using autonomous gliders for measurements of the North Atlantic phytoplankton bloom. In May, *Knorr* transited to Norfolk to support the first of the US GEOTRACES intercalibration cruises off Bermuda (GEOTRACES is an international program to study marine biogeochemical cycles—turnover of different chemical forms—of trace elements and isotopes, and intercalibration is to ensure comparable results from different cruises and labs.) Operations began again in August with two mooring deployments during a transit to Nuuk, Greenland. From Nuuk, *Knorr* continued to support a multi-year project in the Davis Strait, monitoring the variability of water mass fluxes (exchanges) between the Arctic and Atlantic Oceans. *Knorr* then transited to Iceland for a collaborative research project to study the dynamics of ocean shelf-ocean basin exchange south of the Denmark Strait. This cruise included an extensive web-based at-sea outreach program with U.S. and Icelandic schools, with vessel tours for local school children in Iceland and Woods Hole. *Knorr* returned to Woods Hole in November for the Navy INSURV ship condition inspection. *Knorr* then loaded the Long Core system and transited to Panama for a Pacific program that investigated the marine ecosystems processes in the oxygen minimum zone. *Knorr* ended the 2008 operating year at sea off of Costa Rica.

R/V Oceanus

Days at sea: 209; Cruises: 13
Investigators Served: 186; Nautical miles: 29,588

The R/V *Oceanus* began operations in April with a study of plankton and the carbon cycle in surface waters between Maine and Bermuda. The second cruise of the year supported the testing and sea trials for the autonomous underwater vehicle *Sentry*. At the end of April and again in May, *Oceanus* carried out two biology cruises to determine the extent of natural genetic diversity of the harmful algae *Alexandrium* in the Gulf of Maine and to better understand the forces that structure phytoplankton communities. In early May, *Oceanus* carried out a continuing physical oceanography study of the mechanism and rates of North Atlantic Deep Water (cold, dense, saline water sinking at high latitutes) export to lower latitudes at line "W" off Bermuda. *Oceanus* then completed an extensive sediment-coring program to collect deep-sea benthic foraminifera (shelled single-celled animals used for investigating sediment ages and past ocean temperature proxies.) In July, *Oceanus* accommodated an ongoing unscheduled NOAA program that services an array of moorings in the northwest tropical Atlantic from Guadeloupe to Barbados. From Barbados, *Oceanus* began a trans-Atlantic CTD (conductivity, temperature, depth) sampling cruise with multiple Principal Investigators studying the role of trace metals in regulating ocean biogeochemical cycles and upper-ocean mixing. The first leg of this program ended in Cape Verde and the second leg ended in the Canary Islands. In September, the *Oceanus* transited through the Suez Canal to Jeddah, Saudi Arabia to support collaboration between WHOI and King Abdullah University of Science and Technology (KAUST) with two cruises in the Red Sea, including a water column study and a study of deep brine pools. On completion of these cruises, *Oceanus* transited to St. Thomas, US Virgin Islands, to continue the KAUST project testing equipment and collecting data in environments similar to those in the Red Sea. *Oceanus* then conducted the Bermuda Atlantic Time-series (BATS) and Hydrostation 'S' cruise and ended its operating year at Woods Hole in December.

Applied Ocean Physics & Engineering

Many years ago, as a 14 year old, I routinely took the bus and subway to the 1964 World's Fair in Flushing Meadows, New York. At that amazing fair, science and technology were spotlighted as keys to the future. The Bell Telephone System featured the history and future of communications, DuPont Chemicals produced "The Wonderful World of Chemistry" (the first time I saw artificial bioluminescence), General Electric sponsored "Progressland", and General Motors, in a happier day, produced the spectacular "Futurama" ride that 26 million people eventually took.

It is now 45 years later. What has happened to fulfill the technology dreams glowingly described by these corporate giants many years ago?

Looking just at the technical aspects, I have to say: Yes, they got it right! What I live and work with in the AOP&E Department — the science and technology being used daily to study the ocean, a half century after that brilliant fair— is absolutely the "science fiction" described there. Let me show you some comparisons.

The DuPont exhibit highlighted chemistry: We do chemistry within AOP&E, and have strong links to the WHOI Marine Chemistry and Geochemistry Department. Senior Scientist Jim Ledwell has carried out numerous cruises in his "DIMES" project, including some in 2008—during which he releases custom-made chemical tracers into the sea to study how water masses mix in the deep ocean. Also in 2008, Assistant Scientist Rich Camilli finished developing a miniaturized mass spectrometer (a huge room full of equipment in 1964) that measures chemicals in the ocean. It will soon be deployed on small AUVs and gliders to travel the seas detecting oil leaks, unexploded ordinance, telltale chemicals released by seafloor spreading, and other things researchers can discover with a "bloodhound nose" for chemicals.

Bell Systems' exhibit anticipated future communications: In 1964, Dick Tracy's "two way wrist radio" was a science fiction gadget in that comic strip, but now we live in the cell phone era. What about the ocean? Well, we've kept up with the above-water developments. AOP&E's Associate Scientist Jim Preisig and Senior Engineer Lee Freitag are leaders in the art of underwater acoustic communications from moorings, vehicles, and whatever we put in the sea. Sound travels much further than light in water, which helps us communicate over respectable ranges underwater. However, if you need high bandwidth (for sending a LOT of information), then you need to use light. AOP&E is also leading the way in underwater optical transmissions, with Senior Engineer Norm Farr and others building an advanced optical modem. All told, we've met and passed the 1964 predictions for communications.

General Electric's Progressland featured robotics: The "audio-animatronic" Abe Lincoln robot at the '64 Fair astonished everyone with the realism of its words and movements.

AOP&E Department's Ocean Systems Laboratory members Amy Kukulya and Greg Packard deploy a *REMUS 100* vehicle in calm but cold winter waters. (Woods Hole Oceanographic Institution)

Half a century later, robotics is not just an amusing novelty, but a transformational technology, on land and in the sea. Robotic vehicles such as the *REMUS* AUV, the *Sentry* AUV, the *NEREUS* ROV/AUV hybrid, and others developed in the AOP&E Department carry scientific and applications payloads all over the world's oceans. *NEREUS* was in advanced development in 2008, and in 2009 dove to the deepest part of the world's oceans, the Mariana Trench (10,902 m). Also in 2008, a customized *REMUS* vehicle built by AOP&E engineers again examined the water tunnels for the City of New York. Robots are now important research tools, and in the future they may become perhaps our primary tool.

General Motors presented the "City of Tomorrow": In terms of the ocean, next to which the majority of humanity resides, AOP&E is helping to create the technology and science for that City. Our acoustics research helps provide for its defense from enemies from the sea. Our coastal oceanographers study factors that affect the City's water quality, both salt and fresh. Our biologists examine threats from "red tides" (toxic algal blooms), with an eye to understanding and predicting them. The list goes on.

Our science and technology really is as modern as the futuristic displays of 45 years ago, and AOP&E operates at the border of that visionary realm. Forty-five years from now, I hope that scientists and engineers in our Department have the same feeling of "gosh, we DID fulfill those old dreams" that I feel today, looking back at promises made by a World's Fair, most of a career ago.

—James F. Lynch, Department Chair

Biology

In 2008, members of the Biology Department traveled to the poles, the tropics, shallow lagoons and the deep sea. At WHOI, research in biology covers a broad range of life forms from microscopic to some of the largest marine mammals on the planet. Equally broad is the range of sub-disciplines in biology, from the genomic level to large-scale processes and modeling.

An overall goal of research in the Biology Department is to gain a better understanding of the ecology and evolutionary biology of living organisms in the sea. To accomplish this, scientists use a variety of tools to observe, experiment and model interactions among species and between species and their environments.

Among the expeditions undertaken by Biology staff in 2008 were 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.

Biological research benefits from the development of new tools that facilitate observations, analyses and interpretation of phenomena. In 2008, several new tools and approaches in the Biology Department yielded research advances.

Using the Imaging FlowCytobot, biologists Rob Olson, Heidi Sosik, and Lisa Campbell of Texas A & M University were able to detect a bloom of *Dinophysis acuminata* in the Gulf of Mexico, posing a serious health hazard to shellfish harvests. This toxic alga was never before detected in local waters, but its presence alerted Texas health officials to take action before any health hazards occurred.

Mark Baumgartner and colleagues in the Applied Ocean Physics and Engineering Department developed a Realtime Acoustic Tracking system (RATS) to examine the foraging behavior of baleen whales in three dimensions. The system consists of a free-floating array of GPS-linked hydrophone buoys that determine the position of a whale equipped with an acoustic transmitter. The time-of-arrival data are relayed from the buoys to a ship immediately upon receipt of each acoustic pulse from the transmitter. Using these techniques, predator behavior can be monitored in relation to its prey availability.

The Marine Mammal Center for the study and conservation of marine mammals was also formed during 2008. The center combines scientific expertise, state-of-the-art facilities, and technological innovations to address basic questions about marine mammal behavior, physiology and health, as well as potential effects of human activities on marine mammals and the ecosystems on which they depend. The MMC combines scientific expertise with novel applications of technologies and tools such as gliders, sound propagation models, and biomedical and habitat visualizations.

—Judy McDowell, Department Chair

Reef-building corals create habitats for many other organisms. The corals reefs of the Red Sea are highly diverse and unique in the world, providing shelter and sustenance for abundant fishes and other marine life. A research partnership with KAUST (King Abdullah University of Science and Technology) in Saudi Arabia is providing WHOI scientists a rare opportunity to study the Red Sea, including an assessment of pristine coral reef ecosystems near the Saudi Arabia coast. (Photo by Jessie Kneeland, Woods Hole Oceanographic Institution)

Geology & Geophysics

Research in the Department of Geology and Geophysics encompasses earth and ocean processes: from the formation of ocean crust and ocean basins, to the underlying dynamics of plate tectonics and deep earth mantle geochemistry, to climate change and its relation to present and past ocean circulation and coastal environments.

In the last quarter of 2008, Susan Humphris stepped down as Chair of the Geology and Geophysics Department and was succeeded by Maurice Tivey. Former G&G Department Chair Susan Humphris agreed to be interim Vice-President of Marine Operations replacing Bob Detrick, who was appointed Division Director of Earth Sciences (EAR) at the National Science Foundation (NSF). Department member and Senior Scientist Debbie Smith is also currently at NSF, as a Program Director in the Ocean Drilling Program section of Ocean Sciences.

The total Department staff numbered 92, with 39 postdoctoral investigators and Joint Program (JP) graduate students. Our scientific staff decreased by four this year, including Brian Tucholke, who retired after ~30 years at the Institution and was appointed Scientist Emeritus. Promotions included Mark Behn to Associate Scientist and Maurice Tivey to Senior Scientist. There were no new additions to the scientific staff in 2008.

Three Department members received notable awards and recognition in 2008: Scientist Emeritus Stan Hart received the Arthur L. Day award for his lasting contributions to the study of the physics of the Earth; Ralph Stephen was awarded the Edward W. and Betty J. Scripps Chair for Excellence in Oceanography; and Dan Fornari was appointed Chair of the NSF-sponsored RIDGE2000 program with the RIDGE2000 Office moving to WHOI in November 2008 for a 4-year term.

As always, Geology and Geophysics Department members traveled to all corners of the world this year to carry out their research. Staff participated in research cruises to the Pacific, Atlantic, Indian, and Arctic Oceans as well as the Red Sea, aboard vessels from the US, United Kingdom, Japan, China and Saudi Arabia. They conducted land-based fieldwork in Greenland, Romania, Bermuda, Costa Rica, Iceland, Samoa, Australia, Florida, Hawaii, and North Carolina.

A significant area of research in the G&G Department is seismology – the study of earthquakes and the propagation of waves through the Earth – and our scientists use tools that range from seafloor instruments to ships to obtain seismic information. Several important seismology cruises took place this year using the newly commissioned R/V *Marcus Langseth*, an NSF-owned vessel specially equipped for seismology. Dan Lizarralde, Chief Scientist and Co-Chief for the first two such cruises, studied the region beneath the coast of Costa Rica where the Cocos tectonic plate subducts beneath (slides under) the Caribbean plate. The work was part of an NSF-funded research program called the "MARGINS Subduction Factory" initiative. This large project aims to quantify chemical exchanges between Earth's mantle and crust, changes in mantle and crust physical properties, and the role of water and rock alteration in the subduction process.

Another major topic of G&G scientists is the crustal structure of the mid-ocean ridge system, where tectonic plates spread apart. Pablo Canales took part in the first academic "3D seismic reflection" experiment (sending sound through the water to the crust and analyzing the return echoes) aboard the *Langseth*. The objective was to create an accurate 3D image of the oceanic crust at the East Pacific Rise (EPR) at 9° 50' N, and the magma chamber that lies underneath it.

One note about the magnitude of this work: The cruise collected about 3.7 Terabytes (thousands of gigabytes) of data! – the equivalent of 30,256 km of seismic tracklines with 99,888 seismic "shots," or sound bursts, and 186,998,336 seismic traces, which is nearly a trillion data samples.

Pablo and JP student Min Xu will process part of this mass of data, to investigate the structure of the crust and the axial magma chamber at the EPR. In a separate seismic experiment, also on the *Langseth*, Chief Scientist Jeff McGuire and John Collins placed an array of ocean bottom seismometers (OBSs), instruments designed to measure seafloor earthquakes, on three faults along the EPR where tectonic plates slide past each other, called Quebrada, Discovery, and Gofar (also known as the "QDG transform faults.") The QDG transforms, although similar in appearance, have very different levels of seismic activity, with the Quebrada being almost completely quiet, with very few earthquakes. Based on his previous work on earthquake cycles, Jeff predicted that a large quake of magnitude 6.0 should occur on the Gofar or Discovery transforms during the period the OBSs remained on site, and indeed such a quake did occur on Sept. 18th, 2008—a successful result. The OBSs were recovered at the beginning of 2009. These data will be used to help us define the faulting and triggering processes for earthquakes that occur on oceanic transforms.

The year also marked the first field work in the Red Sea as part of a collaborative research program with King Abdullah University of Science and Technology (KAUST), a new world-class, graduate-level scientific research university under development in Saudi Arabia. WHOI research vessel *Oceanus* carried out oceanographic surveys in the Red Sea and geological and geophysical surveys of the very unusual hot brine deeps, including deep-towed camera surveys. Steve Swift led the geological program at sea with

Postdoctoral researcher Justin Ries, working with Anne Cohen and Dan McCorkle in the WHOI Geology and Geophysics Department, grew this tropical pencil urchin (*Eucidaris tribuloides*) and other marine shell-building animals for months in tanks under atmospheres containing high carbon dioxide levels. More carbon dioxide generates greater acidity in the water, which can corrode calcium carbonate, the material many marine animals use for their shells. Ries (now at the University of North Carolina) wanted to test the animals' ability to build their shells under the increasingly high levels of carbon dioxide predicted for the future, if fossil fuel reserves continue to be burned and the resulting CO_2 released. (Photo by Tom Kleindinst, Woods Hole Oceanographic Institution)

WHOI colleagues Dan Fornari, Adam Soule, Mark Behn and Maurice Tivey.

Another aspect of our collaborative work with KAUST was studying the Red Sea's diverse coral reefs. Anne Cohen led a science team with Pat Lohmann, Postdoc Neal Cantin, and JP student Casey Saenger to collect coral samples to investigate the relationships between natural and human-driven environmental changes in coral growth and reef health. The researchers will measure changes in the skeletal and tissue growth of the corals on seasonal through centennial timescales, with longer timescales providing an assessment of the pre-industrial reef, and seasonal timescales allowing correlations between ocean conditions and coral growth. In related work, Dan McCorkle collected water samples from Red Sea reefs and offshore waters to document the balance of carbon compounds and nutrients. This will help to define current environmental conditions on the reefs and improve our ability to anticipate impacts of rising atmospheric CO_2 concentrations on the Red Sea coral reef ecosystems.

—Maurice Tivey, Department Chair

Marine Chemistry & Geochemistry

Scientists in the Marine Chemistry and Geochemistry (MC&G) Department seek to understand processes that drive chemical cycling in the ocean (chemicals moving between air, water, organisms, sediments and rock) and to learn how ocean chemistry influences and responds to biological activity and climate on Earth, now and in the past.

Ocean chemists increasingly work at the interfaces with other disciplines, because important new questions arise at these boundaries — questions that bridge not only seawater chemistry, but also processes that influence ocean life, geology and climate.

For example, novel techniques have revealed the remarkable diversity of single-celled microbes in the ocean and their powerful role in biogeochemical processes (processes involving organisms interacting with their physical and chemical environments). This is a vibrant area of interaction between chemists and biologists, including many Department members. In 2008, Assistant Scientist Tracy Mincer – who has expertise in both natural products chemistry and molecular biology – joined the MC&G staff to further strengthen such interactions.

MC&G scientists Scott Doney, Dan Repeta and Mak Saito participate in another research program at the biology-chemistry interface – a large, on-going NSF-sponsored, multi-investigator, multi-institutional program coordinated from Hawaii. Called "C-MORE" (Center for Microbial Oceanography: Research and Education) the program investigates biological and ecological diversity of marine microbes and their role in global processes.

2008 also marked the culmination of a major research program called "VERTIGO" (VERtical Transport In the Global Ocean) spearheaded by MC&G scientist Ken Buesseler, to understand processes in the middle depths of the ocean (approximately 100 to 1000 meters). This "mesopelagic" region is also called the "Twilight Zone" [Figure 1] – because of its location below the sunlit surface and above deep abyssal waters, and because of its enigmatic biological, chemical and physical processes.

Despite its mysteries, understanding this region is critical for assessing the ocean's ability to remove CO_2 from the atmosphere via a "biological pump" – whereby photosynthetic organisms convert CO_2 into organic matter in surface waters, and sinking dead cell debris and fecal material remove this carbon to the deep ocean, sequestering it. The VERTIGO program used innovative sampling [Figure 2] and measurement technologies, developed with WHOI engineers and including contributions from MC&G scientists Karen Casciotti, Phoebe Lam, Carl Lamborg, and Ben Van Mooy. VERTIGO shed important new light on the Twilight Zone, and the findings were highlighted in a special issue of *Deep-Sea Research* that was published this year.

Department members continue to make discoveries about processes at the bottom of the ocean. Postdoctoral investigator Giora Proskurowski – working with MC&G scientist Jeff Seewald and colleagues at the University of Washington and ETH Zurich in Switzerland – has been studying geochemical processes at the "Lost City" hydrothermal vent system on the Mid-Atlantic Ridge [Figure 3]. They found evidence for *non-biological* reactions that result in the synthesis of small organic (hydrocarbon) molecules under the geochemical and thermal conditions at Lost City. These findings, which have important implications for the origin of life on Earth, were reported in 2008 in the journal Science.

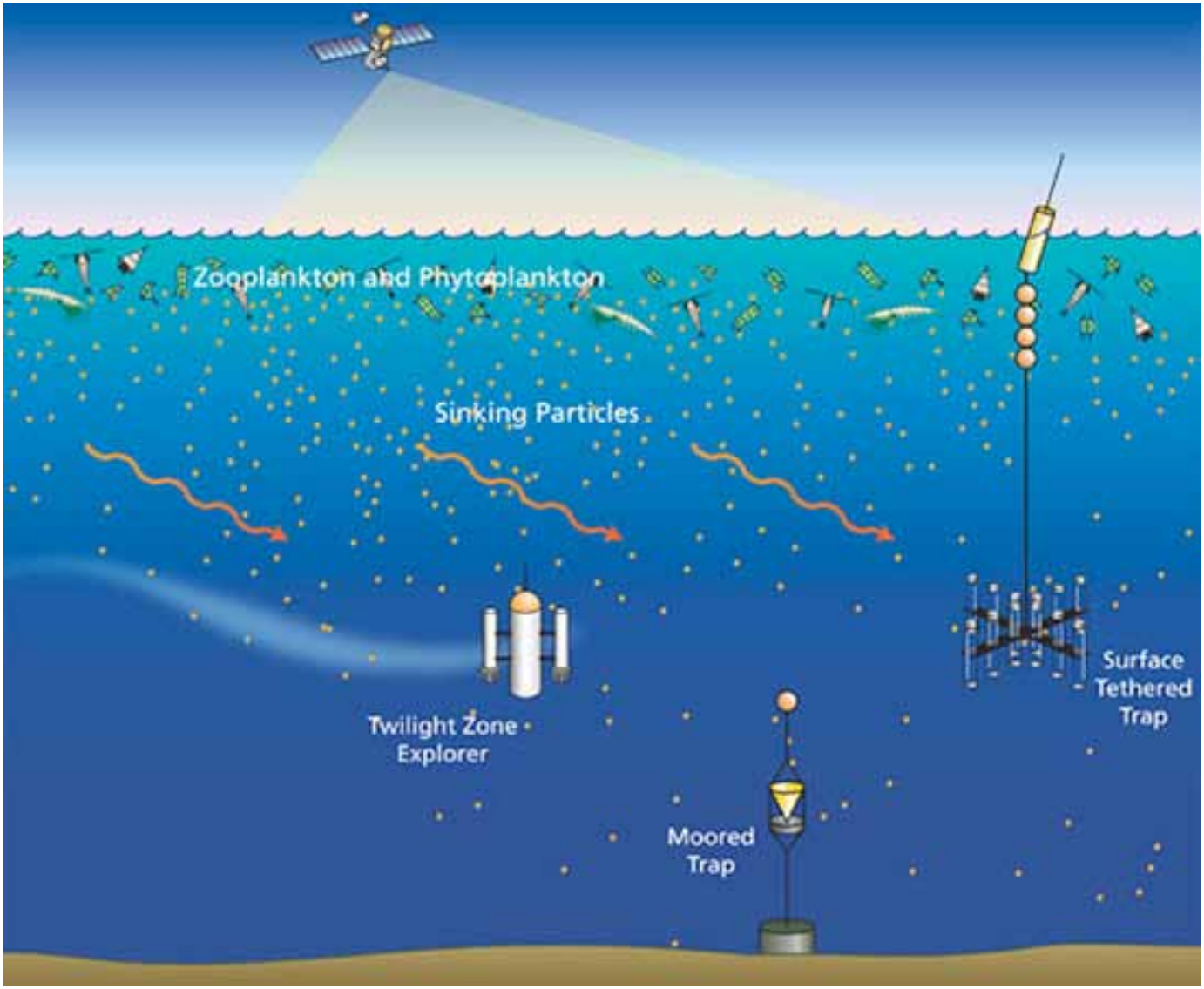
Scientists in MC&G study not only chemical "species" (elements, organic compounds, isotopes) resulting from natural processes; they also investigate the types, sources, concentrations and impact of chemicals stemming from human activity. Much research has focused on the fate and impact of such chemicals after their release into the environment, but chemists at WHOI are trying to head off effects of potentially harmful chemicals even before they are produced.

For example, one of the most rapidly growing areas of technological innovation is nanotechnology. An important aspect of this involves carbon nanotubes –tubular arrangements of carbon molecules that exhibit remarkable mechanical properties. MIT/WHOI Joint Program student Desiree Plata, with MC&G scientist Chris Reddy and Dr. Phil Gschwend at MIT, has examined nanotubes' chemical properties and potentially harmful by-products from their manufacture. They found that some commercially available carbon nanotubes contain large amounts of toxic metal and carbon-containing impurities. These distinct chemical signatures may serve as 'fingerprints' to trace the sources of carbon nanotubes released into the environment [Figure 4].

In one regard, 2008 was no exception: MC&G scientists traveled extensively to undertake fieldwork in remote corners of the globe and under challenging conditions.

In April-May 2008 Laura Robinson and several colleagues participated in a research cruise on the ice breaker *Nathaniel B. Palmer* to study cold-water corals in the Drake Passage between Antarctica and the southernmost tip of South America - some of the most inhospitable waters in the world! [Figure 5]

Corals inhabit many areas of the world's ocean, some living more than 3 miles deep. Deep-living corals' calcareous skeletons may hold important clues about past deep ocean variability and climate history, but their distributions, ecology and life histories are poorly known. The cruise brought together experts in coral ecology and habitats, seafloor mapping, and paleoclimate (Earth's past climate), to start building a coherent picture of temporal and spatial distributions of deep-sea corals in the Southern Ocean. Researchers used multibeam sonar and WHOI's TowCam camera system



An array of sampling technologies were utilized in the VERTIGO program to follow the fate of particles sinking from sunlit surface waters through the ocean's dimly lit twilight zone. In particular, Ken Buesseler and engineer Jim Valdes designed a new-generation neutrally buoyant untethered vehicle called the Twilight Zone Explorer, that is swept along with the currents and surfaces periodically to relay data via satellite. (Illustration by Jack Cook, Woods Hole Oceanographic Institution)

to document cold-water coral habitats, and used research trawls [Figure #6] and dredges to collect living and long-dead ("fossil") corals [Figure #7]. These samples are now being dated to determine how long they have been living in the Southern Ocean, and to select corals to use for paleoclimate estimates.

In the Arctic, MC&G scientists Elizabeth Kujawinski and Matt Charette joined Joint Program student Maya Bhatia and scientists from WHOI's Geology & Geophysics Department on the coast of Greenland, to examine the biogeochemical significance of materials transported in meltwater from the adjacent ice sheet. The WHOI Ocean and Climate Change Institute's Arctic Research Initiative funds supported this work. And in the tropics, Phoebe Lam transited the Atlantic from Barbados to the Cape Verde Islands and then onto the Canary Islands aboard R/V *Oceanus* to explore the sources of iron emanating from the African continent, and its role in ocean biological productivity.

Finally, in addition to their activities in the field and in the laboratory, MC&G scientists also helped to shape science policy and scientific programs through service on panels, in working groups and at conferences. Overall, it was a busy and highly successful year for the Department!

—Timothy Eglinton, Department Chair

Physical Oceanography

On a calm day, ocean waters may look featureless and smooth at the surface. Beneath, currents and variations in the water's temperature, salinity, density and other features create structure within the ocean that affects sea, land, and atmosphere. Researchers in the Physical Oceanography (PO) Department seek to describe and understand the physical structure and variability of the ocean and the processes that create that structure and variability.

They investigate physical properties of the ocean using laboratory experiments, analytical and numerical modeling (creating mathematical descriptions and computer simulations of the ocean to test against real-world observations), analysis and synthesis of existing data, and new observations at sea. A strong heritage and expertise in observing the ocean and in developing new observational methods plays a defining role in work done by members of the PO Department, in 2008 as in other years.

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

• Glen Gawarkiewicz, Frank Bahr, and Craig Marquette participated in an international experiment to study oceanographic processes that contribute to uncertainty in predictions of ocean currents and how sound travels in the East China Sea. In September 2008, these scientists conducted a pilot experiment for this project, jointly with scientists from National Central University, National Taiwan University, and National Taiwan Ocean University.

• In this pilot project northeast of Taiwan, WHOI and National Taiwan University team members used a "SeaSoar"—a towed vehicle that undulates up and down through the water, measuring water properties as it moves forward— to identify water from the strong Kuroshio Current forcefully intruding over the continental shelf. The Kuroshio is the northward-flowing current that is the Pacific counterpart to the Gulf Stream in the western north Atlantic. The main fieldwork for this international project will take place in August and September 2009, with four different ships measuring ocean currents, temperature, salt content, and density, as well as how sound propagates in an oceanographically complex region.

• Closer to home Richard Limeburner, Bob Beardsley, and Will Ostrom deployed an array of three moorings from the R/V *Tioga* to measure and record temperature, salinity, and currents at the three main openings to Nantucket Sound – between Woods Hole and Martha's Vineyard, between Martha's Vineyard and Nantucket, and between Nantucket and Monomoy Island on Cape Cod. The moorings were recovered in November 2008, refurbished and re-deployed December, and their final recovery will be in June 2009.

• The moorings' collected measurements will be used to improve computer models of ocean circulation for the waters around Cape Cod and the larger-scale coastal ocean in this region. One of these is the Northeast Coastal Ocean Forecast System (NECOFS) – a coupled atmosphere/ocean model for the New England and Gulf of Maine region, recently developed by PO's Bob Beardsley and Changsheng Chen of the University of Massachusetts Dartmouth.

• Work at high latitudes continues as a research focus. In August-September 2008, a WHOI PO Department team led by Richard Krishfield (see www.whoi.edu/beaufortgyre for details) returned to the Beaufort Gyre in the Canadian Arctic Ocean, to make field observations, re-deploy moorings, and install instrument systems including Ice-Tethered Profilers (ITPs), Ice Mass Balance Buoys (IMBs)) and Autonomous Ocean Flux Buoys (AOSBs) – all designed to measure properties of the ice-covered ocean. Scientists will observe variability over years to decades, observe changes in fresh water and heat content, and aim to understand processes involved in Arctic climate change. Since 2004, 31 of these systems—developed and constructed at WHOI, placed by WHOI and by international teams of scientists—have operated throughout the Arctic Ocean in all seasons, recording conditions from the seafloor to just below the ice cover (approximately 7 to 760 meters.)

• Fiamma Straneo continued fieldwork in Canada's Hudson Strait, to quantify the transport of freshwater southward through the strait, part of the overall export of freshwater from the polar region, a process that markedly affects ocean circulation. Straneo also began doing innovative measurements from a small local vessel in a glacial fjord in East Greenland, that showed a thick layer of warm, salty subtropical waters rapidly intruding deep into the fjord, which may contribute to the acceleration of Greenland's outlet glaciers (and loss of ice) that researchers observe.

• PO Department members continue to do research in the Red Sea under a research partnership with KAUST (King Abdullah University of Science and Technology) highlighted elsewhere in this annual report. Planning for the National Science Foundation's Ocean Observatory Initiative (OOI) advanced this year as well.

• Terry Joyce and many in the Department have been studying the formation of a persistent layer of constant-temperature seawater in the north Atlantic called "18°C mode water" that may influence climate – part of a project called CLIMODE ("CLIVAR Mode Water Dynamics Experiment.") Shipboard research for this project finished in 2007, and scientists are following up this year with data analysis and publication.

• Members of the Department continue making long-term observations of the ocean – both with long-term "Ocean Reference Station" moorings (off northern Chile, north of Hawaii, and in the North Atlantic trade winds region) and with ongoing deployments of ARGO profiling floats that drift throughout the global ocean automatically

The Taiwanese/U.S. "Sea Soar" team on the fantail of the research vessel *Ocean Researcher #1*. The team used the towed vehicle to measure ocean properties and identify water from the Kuroshio Current over the continental shelf.

measuring temperature and salinity from the surface to great depth.

• Claudia Cenedese is interested in improving our understanding of how buoyant (less-dense) waters in the ocean transport pollution and sediments along coastlines, particularly when multiple buoyant sources are present. Using a combination of analytical calculations and laboratory simulations, she is studying the interaction and stability of two buoyant coastal currents having different densities. Using calculations, she predicted different scenarios for where the currents would be, along the coastline. Then, doing laboratory experiments with a rotating tank designed to mimic Earth's rotation, she confirmed her analytical predictions. Furthermore, she discovered that the two current fronts (edges) became unstable, as shown in the accompanying image. This result – the two currents' coupled frontal instability – is different from previous results on the instability of a single current, a difference that is unexpected and interesting, and could yield insight into real-ocean situations.

• Members of the PO Department also continued numerical and analytical modeling and theoretical studies through 2008. Joe Pedlosky's contributions were acknowledged when he was invited to deliver the Haurwitz Lecture at the January 2009 American Meteorological Society annual meeting, presenting a talk entitled "Kelvin's Theorem, the Tunneling of Rossby Waves and the Circulation around Planetary Islands." And Senior Scientist Ray Schmitt participated in a large study on climate change by the National Academy of Sciences, serving on a panel on the science of climate change.

—Robert Weller, Department Chair

Coastal Ocean Institute

The Coastal Ocean Institute (COI) promotes scientific inquiry into phenomena that shape our coastal waters and ecosystems. Through research grants, scientific gatherings, and the development of state-of-the-art facilities, COI encourages interdisciplinary research and innovative technology development. COI strives to translate the results of this basic research for citizens and policymakers, providing a solid information base for better resource management.

COI's research themes focus on examining threats to and abuses of coastal waters; observing and analyzing the biological, physical, geological, and chemical processes at work where air, sea, and land meet; and developing instruments to better measure, monitor, and analyze the fundamental processes shaping the coastal region.

To support these themes, COI funded six research projects and one new initiative in 2008. We also initiated support for one new COI Fellow: Karen Casciotti (MC&G) whose research focuses on how nitrogen and nitrogen-containing compounds cycle in coastal waters, including the greenhouse gas nitrous oxide (N_2O). The COI fellowship will allow her to explore emerging areas of research, such as the mechanisms of N_2O production and nitrogen inputs to the coastal ocean from human activity.

COI continues its support of four other Fellows. Rob Evans (G&G) is using marine electromagnetics to study groundwater discharge and to characterize the sedimentary environment on the continental shelf. Becky Gast (BIO) is studying the epidemiology of infectious diseases in coastal areas. Andone Lavery (AOP&E) is using high-frequency sonar to learn more about how turbulence and mixing affect the biology of coastal waters. Claudia Cenedese (PO) is using laboratory experiments and analytical models to simulate the dynamics of eddies and buoyant coastal currents.

The Institute supported several postdoctoral scholars and Joint Program graduate students in various ways in 2008. Postdoc Anthony Kirincich is using the Martha's Vineyard Coastal Observatory to examine the vertical structure of the water column and the effects of waves on sub-tidal circulation, while postdoc Juliette Smith is studying the ecophysiology of a recently cultivated marine dinoflagellate, *Dinophysis* spp., focusing on its production of Diarrhetic Shellfish Poisoning (DSP) toxins.

COI-sponsored graduate student Dan Rogers is using molecular biology and stable isotopic techniques to examine the distribution, abundance, and activity of nitrogen-cycling microbes in the subterranean estuary in Waquoit Bay, Mass. Graduate student Erin Banning is also using Waquoit Bay as a research base where he is exploring the potential importance of bacterial predation on biogeochemical processes.

—Christopher Reddy, Institute Director

Biogeochemist Karen Casciotti, a COI fellow, is working to understand how microorganisms affect the exchange of excess nutrients (principally nitrate) between groundwater and the coastal ocean. Casciotti and colleagues are using microbiological, molecular, and chemical techniques to understand which nitrogen-metabolizing microbes are present in the Waquoit Bay (Falmouth, Mass.) subterranean estuary and at what rate they are removing nitrogen from the system. (Photo by Tom Kleindinst, Woods Hole Oceanographic Institution)

Deep Ocean Exploration Institute

Vast areas of Earth's seafloor have yet to be explored, from dynamic areas near subduction zones where tectonic plates slide under other plates, in back-arc basins (behind subduction zones,) and along the mid-ocean ridge system, to more quiescent areas dominated by deep sediments that have accumulated over millions of years. The Deep Ocean Exploration Institute (DOEI) fosters multi-disciplinary study of physical, chemical, geological, and biological processes in all these areas and in the planet's interior, and development of the technology needed to access environments at and below the seafloor.

In 2008, DOEI funded twelve new research projects, many with co-investigators from different departments, to explore questions related to the Institute's three thematic areas: seafloor observatory science and instrumentation, Earth's deep biosphere (organisms living deep below the Earth's surface), and fluid flow in geologic systems. Highlights of some of these are below.

• Rob Reves-Sohn (G&G, the Geology and Geophysics Department) and Andy Solow (the Marine Policy Center) are applying statistical modeling techniques to existing data to identify and quantify the relationships between seismic (earthquake) activity and temperatures of heated fluids exiting hydrothermal vents at the TAG hydrothermal mound.

• Mark Behn and Brian Tucholke (both in G&G) study a very different type of fluid flow—magma. They use numerical modeling (mathematical representations of processes with equations and variables) to investigate factors affecting magma flow and its interactions with tectonic plates at mid-ocean ridges.

• Virginia Edgcomb (G&G) and Rebecca Gast (Biology Department) are considering another distinct environment, investigating whether single celled eukaryotic organisms (protists) are present and active in deep-sea sediments by analyzing material from four existing deep subsurface sediment cores. Their project includes developing RNA extraction protocols to help identify genetic signatures of these organisms.

• Greg Ventura and Chris Reddy (both in MC&G, the Marine Chemistry and Geochemistry Department) are also searching for evidence of organisms in sediments, specifically the molecular lipid remains of organisms, but in young, shallow sediments from another hydrothermal area, the Guaymas Basin off Mexico's coast, that are subject to rapid changes in temperature.

• And Ray Schmitt (in the Physical Oceanography Department) and Robert Petitt (in the Applied Ocean Physics and Engineering Department) are developing new instruments for use in the unusual hot brine pools deep in the Red Sea. Their high-range CTD (conductivity-temperature-depth recorder), designed to work in these very warm and salty waters, allows documentation of the detailed thermal and physical structure of these layered regions and provides estimates of heat and salt exchanges with adjacent water.

Other projects span a range of environments and topics, including the impact of hydrothermal plumes on the deep ocean, volcanism away from the central mid ocean ridge axis, the heterogeneity of the mantle, sulfur cycling (moving of sulfur-containing compounds) through subduction zones, sources of hydrothermal CO_2 in the Lau Basin in Tonga's waters, and the biology and geology of deep-sea brine areas of the Red Sea.

DOEI supported three Fellows in 2008: Jeff McGuire (G&G) uses recordings of seismic waves and ground deformation to investigate rupture processes and faulting, and is working to develop a real-time earthquake early warning system for the Pacific Northwest. Tim Shank (Biology Department) combines multiple genetic approaches to examine ecological and evolutionary factors that affect populations of deep-sea species, incuding deep-sea corals and hydrothermal vent fauna. Maurice Tivey (G&G) uses magnetic imaging to learn about the subsurface structure of hydrothermal vents.

As part of his 2008 Fellowship activities, Maurice Tivey planned the MORSS Colloquium on "Precious Metals from Deep-Sea Vents," with keynote speakers from the Rule of the Law Committee for the Oceans, the International Seabed Authority, Colorado School of Mines, and WHOI. A one and a half day workshop preceded the April 2009 colloquium; 98 people from 20 nations participated, including students from Papua New Guinea, Mauritius and Djibouti. The aim of the colloquium and workshop was to discuss issues related to deep-sea mining of seafloor massive sulfide deposits, a topic connected to society, the global economy, and the conservation of unique marine ecosystems. Media representatives attended, and the Associated Press bulletin was broadcast on more than three thousand web pages around the globe.

In addition to these research and fellow activities, an important new endeavor was launched in 2008 – the Ocean Ridge Initiative. Its purpose is to explore the largest continuous geologic feature on Earth – the mid-ocean ridge system. The Initiative acknowledges the value of the many unanticipated discoveries that have been made in the past along this system, such as the presence of unusual chemosynthesis-based biological communities at areas of hydrothermal venting.

A major focus of the Initiative will be development of new technologies for efficient surveying, sensing, and sampling of areas along and beneath the ridge, and for information exchange. A workshop held to identify the overarching vision of this initiative, needed technological advances, and specific projects to be carried out, drew thirty-six scientists and engineers from all of the five WHOI departments, as well as eight participants from communications and development.

As in years past, DOEI continued to promote WHOI educational and outreach opportunities. In 2008, DOEI provided support for two post-doctoral scholars, two graduate students, and the annual multi-disciplinary Geodynamics Program.

—Margaret K. Tivey, Institute Director

Ocean & Climate Change Institute

In 2008, the Ocean and Climate Change Institute (OCCI) concentrated most of its research activities and resources on changes in North Atlantic and Arctic Ocean climate. The institute distributed about $1.3M for the Arctic Research Initiative (ARI), our five-year focused research program, supported by the Sealark Foundation, to study changes in Arctic climate and their impacts on the marine and surrounding terrestrial ecosystems.

Combined with our research activities funded by the Comer Science and Education Foundation, the two year funding total for the Arctic Research Initiative is now about $5M, supporting more than 30 research projects and significantly enhancing WHOI participation in International Polar Year research. ARI supports diverse research activities, including studies of the transport and fate of terrestrial carbon to the Arctic Ocean, the effects of changing sea ice cover on marine ecosystems and organisms, and the effects of changing ocean circulation on sea ice extent.

OCCI also supported research in other areas and regions, including several studies of the ocean's biological pump and the possibility of ocean iron fertilization to enhance ocean productivity and uptake of atmospheric CO_2.

Katherine Silverthorne (Joint Program student in Physical Oceanography) was supported by OCCI and her research was highlighted in an article in the January 2009 OCCI report. Katie studies the development of the "18 degree water" in the North Atlantic, a persistent water layer of consistent temperature and salinity characteristics that may play a role in climate).

Jong Jin Park (PO) was the 2008 OCCI Postdoctoral Fellow, working with Ray Schmitt, examining global drifter and float-collected measurements of ocean properties, to study inertial oscillations in the mixed layers of the oceans. Delia Oppo (G&G) and Ruth Curry (PO) finished three-year OCCI fellowships in 2008. Delia works on the past history of earth's climate. Ruth studies the modern ocean circulation and climate-driven changes in ocean properties such as salinity and temperature.

Last year OCCI also participated in notable outreach to individuals from industry and government. In February, we participated in CERA Week 2008, an important annual meeting of the energy industry, at the invitation of WHOI Corporation Member James Rosenfield. At this meeting we had the opportunity to showcase WHOI research and under-ice technology for the Arctic, a region of much interest to energy companies because of its future resource potential.

In July, OCCI participated in a "Climate War Game" hosted by The Center for a New American Security, an independent and nonpartisan defense think tank, which is headed by WHOI Corporation Member Kurt Campbell. The "war game" was a simulation of future international negotiations to reduce greenhouse gas emissions and stabilize climate. Individuals played the roles of future government leaders participating in the negotiations. Our role was to help produce a future climate scenario that would be both realistic and also severe enough to prompt cooperative action by future world leaders. Several of the participants in this war game are now serving in the new administration, including Kurt Campbell, the new Assistant Secretary of State for East Asian Affairs.

(from left) Joint Program student Camilo Ponton, Tim Eglinton (MCG department chair), Liviu Giosan (G&G), and Daniel Montlucon (MCG) load the helicopter to return from sampling remote lakes in the Canadian Arctic. Supported by the Arctic Research Initiative, the team took lake-bottom sediment cores in the Mackenzie River delta to analyze for baseline data on river flow and transport of organic matter from soils, from pre-industrial times to the present. (Photo courtesy of Liviu Giosan, Woods Hole Oceanographic Institution)

With the help of Mary Louise Timmermans (Assistant Scientist in Physical Oceanography), OCCI hosted the International Symposium on Arctic Sea Ice and Climate at WHOI in November. This symposium convened a group of leading Arctic researchers to discuss the recent, rapid melting in the Arctic and to present preliminary observations from the 2008 field season.

As part of OCCI's outreach efforts, one of the Symposium participants, Jean Claude Gascard, an oceanographer at the Université Pierre et Marie Curie in Paris, France, presented a public lecture at Redfield Auditorium in Woods Hole. The lecture, entitled "Arctic Changes, Global Warming, Global Warning", was well attended and stimulated much discussion.

— *William Curry, Institute Director*

Ocean Life Institute

Life in the ocean is threatened on many fronts, from global warming to pollution to over-fishing. Basic research sponsored by the Ocean Life Institute (OLI) during the past year has addressed several key issues related to ocean health and biodiversity. This research included studies of how ocean physics and chemistry affect ocean life, and was supported through OLI fellowships, postdoctoral and graduate student awards, and research grants.

New research grants funded by OLI during 2008 covered a variety of topics. The research involved studies of reef fish genetics and connectivity, chemical communication among bacteria, how marine animals respond genetically to environmental stress, and toxic algae that cause diuretic shellfish poisoning.

The Tropical Research Initiative within OLI supported five new grants, including hormone transfer between corals, geological analysis of ancient ocean circulation patterns, physics of equatorial waves, bacterial cycling of nutrients in the Pacific, and the importance of nitrogen-fixing bacteria (bacteria that can take nitrogen from the air and incorporate it into organic compounds) in tropical estuaries.

OLI supports several studies at the Liquid Jungle Laboratory, Panama. We are developing a new initiative on the oceanography of coral reefs that will tie together several WHOI projects around the globe. We also are pursuing a new study off Taiwan, to examine the impact of climate, ocean currents, and plankton on coral reef ecosystems and fisheries.

This year OLI continued to promote research in the area of ecosystem-based management and worked to develop a new modeling-observing system in support of fisheries along the northeast US coast. A new multi-institutional proposal was submitted to NOAA (the National Oceanographic and Atmospheric Administration) with WHOI as the lead, to establish the framework for such a system. The OLI also supported the use of a state-of-the-art computer model of ocean physics and biology to aid in the design of an ocean observing system in the Gulf of Maine-Georges Bank region.

Highlights of 2008 include the research projects of two OLI Fellows, a grantee, and a student. Fellow Marco Coolen from the Marine Chemistry and Geochemistry Department has developed new tools for analyzing DNA of ancient plankton communities, archived in layers of marine sediments, providing a glimpse into the past that was never before possible. Fellow Mac Saito (also MC&G) is studying the proteins produced by microbes and their importance in ocean ecology and global nutrient cycling.

With an OLI grant, Gareth Lawson, in the Biology Department, is using new acoustic methods – sending sound into the water, then analyzing sound reflected back from objects – to study krill populations in the Gulf of Maine. Finally, MIT-WHOI Joint Program student Carter Esch (also Biology) is studying the distribution patterns of whales' prey organisms in the Arctic Ocean.

I would like to express my deepest appreciation for all who have supported the OLI.

—Cabell Davis, Institute Director

With funding from the OLI, WHOI researchers Gareth Lawson, Andone Lavery and Peter Wiebe are analyzing data collected from a suite of advanced sensing technologies, to understand krill distribution in the deep basins of the Gulf of Maine. In the Gulf of Maine, there is evidence, based on limited observations that krill can be locally abundant and important members of the food web. (Photo by Øystein Paulsen)

Marine Policy Center

Research at the Institution's Marine Policy Center (MPC) involves the application of economics and other social sciences to public policy issues connected to the world's oceans and coastal areas. Some recent MPC studies have concentrated on estimating the costs to society of marine hazards and identifying and evaluating public policy responses aimed at avoiding or reducing these costs.

One example is a recently completed study of human respiratory disease caused by harmful algal blooms (HABs) off the Gulf coast of Florida. This study was led by Senior Research Specialist Porter Hoagland, Senior Scientist Di Jin, and 2007 Summer Student Fellow Lara Polansky, and included collaborators at the University of Miami, the Mote Marine Laboratory in Sarasota, the Florida Department of Health, and the US Centers for Disease Control and Prevention. The results of the first part of the study, which was funded by the Centers for Ocean and Human Health at WHOI and the University of Miami and the State of Florida, have been published in the journal *Environmental Health Perspectives*.

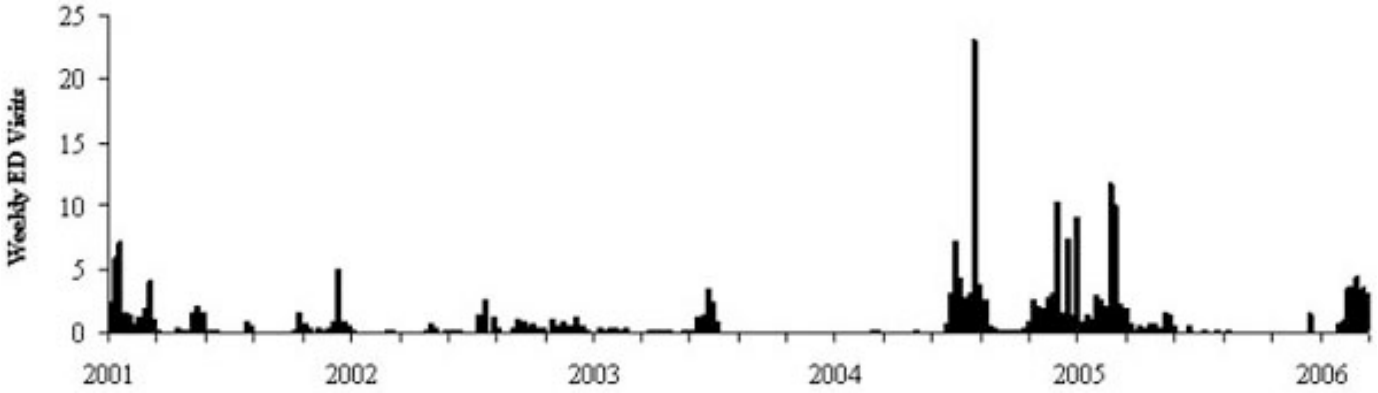
Annual blooms of the algal species *Karenia brevis* produce substances known as brevetoxins that can be aerosolized and transported from marine waters to the coast. Although it is known that aerosolized brevetoxins can cause serious respiratory problems in humans, the magnitude of the problem has not been well understood, and the first step in the study was to develop a quantitative measure.

In the first phase of this study, researchers used 5 years of data to estimate the relationship between *K. brevis* cell counts in the ocean and non-asthma respiratory cases at a single hospital in Sarasota. The number of emergency room visits for respiratory cases at this hospital averaged around 70 per week. The analysis found that, depending on the severity of the bloom, up to 20% of these could be attributed to brevetoxins. An interesting sidelight of the analysis was the inability to detect a significant relationship between *K. brevis* blooms and emergency room visits for asthma attacks. One hypothesis is that asthma sufferers are more experienced with respiratory distress and do not require treatment in the emergency room.

The second phase of the study focused on the economic cost of emergency hospitalization for HAB-related respiratory illness. A conservative estimate of the costs of cases treated at this hospital alone is on the order of $200,000 per year.

A number of measures are being used to mitigate the brevetoxin problem in Florida. These include efforts to reduce the frequency and severity of the blooms themselves, through restrictions on the use of fertilizers, development of a capability to predict blooms through the use of satellite measurements of chlorophyll in surface waters, and the use of a warning system once blooms occur. In the third phase of this project, these and other policy options will be analyzed in terms of their cost effectiveness.

—Andrew Solow, Center Director



Estimated number of emergency room visits at Sarasota Memorial Hospital for respiratory distress caused by blooms of the harmful algal species *Karenia brevis* blooms.

Woods Hole Sea Grant Program

The Woods Hole Sea Grant Program is part of the National Oceanic and Atmospheric Administration's national Sea Grant network of 32 programs. Collectively, Sea Grant promotes 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 2008, Sea Grant-supported nine projects at WHOI and other institutions that focused on topics ranging from understanding alternative nitrogen cycling pathways and their relationship to eutrophication (overloading with nutrients and algal growth,) to studies of mercury sources and cycling in the local estuary Waquoit Bay. Jesús Pineda and colleagues are examining the accumulation of zooplankton in internal waves in the sea, 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, a parasitic infection in quahog populations.

More than one-third of Woods Hole Sea Grant's budget is dedicated to research translation, outreach, and education. Sea Grant reaches its audience through one-on-one advice, training programs, publications, Web sites, workshops, and lectures. Collaboration with the Cape Cod Cooperative Extension Service brings outreach and demonstration projects to local communities in fisheries and aquaculture and coastal processes.

As a partner with the Massachusetts Coastal Zone Management Program and the Waquoit Bay National Estuarine Research Reserve, Woods Hole Sea Grant participates in the Massachusetts Coastal Training Program, designed to enable communities to better manage their coastal resources. With funding from the National Sea Grant Law Center, Woods Hole Sea Grant collaborated with the Massachusetts Association of Conservation Commissions to develop a coastal training module for conservation commissioners in coastal communities. With this course, all conservation commissioners will have access to up-to-date information for making scientifically sound and regulatory-based decisions.

Volunteers empty bags of juvenile oysters into the wild as part of a "remote set" restoration project. During a remote set, oyster seed attaches to old shell that has been bagged in mesh and placed into hatchery tanks. Once viable, the bags of old shell are moved to the area where oyster restoration is most needed and released. With the support of Woods Hole Sea Grant, natural resource managers are increasingly turning to remote set to improve their restoration efforts. (Photo by Diane Murphy, WHSG and Cape Cod Cooperative Extension)

In the ocean science education field, Woods Hole Sea Grant has developed workshops for K-12 teachers and has 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. For more than a decade, Woods Hole Sea Grant has partnered with colleagues at New Hampshire Sea Grant to provide marine career information to students. Woods Hole Sea Grant is also participating in a WHOI effort to promote effective research–outreach partnerships and is initiating efforts aimed at reducing marine debris and plastics in the ocean.

—Judith E. McDowell, Program Director

Center for Ocean, Seafloor, and Marine Observing Systems

In 2008 the Center for Ocean, Seafloor, and Marine Observing Systems (COSMOS), under the direction of John Trowbridge, has been active in overseeing and promoting observing systems in the coastal oceans. Ultimately, observatories will improve our ability to monitor changes in coastal systems, enable scientific advances, and promote engineering development that will increase our understanding of the oceans. The present goal of COSMOS is to establish, off the Northeast US, an ocean observing system capable of achieving WHOI's scientific objectives in the region.

Ocean observing systems

"Observing systems" are installations of multi-use instrument arrays on physical platforms ("observatories") including both moored buoys and coastal observatory towers connected to land by power and data cables. These platforms carry a variety of attached instruments measuring a range of ocean properties – primarily water current velocity, temperature, salinity, water level and chemical nutrients. Observatories also use other means of making ocean measurements: autonomous underwater vehicles (AUVs), remote sensors such as underwater gliders, satellite images, and data from shipboard surveys.

Ocean observatories collect data continuously, providing a complete spatial and temporal picture of changing conditions in the coastal ocean – something that was not possible to achieve using widely-spaced shipboard measurements or isolated moorings. Researchers can now couple observing system data with computer models to produce forecasts of ocean conditions and "hindcasts" – predictions of current conditions based on past data that test the models' accuracy. In addition to furthering scientific research, ocean observatory data are available for weather forecasting, emergency management planning, policy and land-use planning in federal, state and local government agencies, and private industry.

The Massachusetts Technology Collaborative John Adams Innovation Institute

An opportunity for WHOI to promote ocean observatories through COSMOS came via a matching-fund contribution from the Massachusetts Technology Collaborative through the John Adams Innovation Institute. COSMOS will administer the funds to stimulate development of the next generation of ocean observing technology and products by promoting academic-industry partnerships and providing access to an ocean test-bed.

The first phase of this five-year project includes upgrades and enhancements of the Martha's Vineyard Coastal Observatory (see below), establishment of an Underwater Acoustic Communication Network Test-Bed at MVCO, and addition of advanced meteorological sensors to existing weather buoys off the coast of Massachusetts – enhancements that will make WHOI a showcase for coastal observing capabilities.

Martha's Vineyard Coastal Observatory

A COSMOS activity that supports the goal of achieving WHOI's scientific objectives in the Northeast is managing WHOI's ocean observatory, the Martha's Vineyard Coastal Observatory (MVCO) on Martha's Vineyard's southern shore. Through COSMOS, MVCO's chief scientist Heidi Sosik and operations manager Janet Fredericks work with Jay Sisson, Andy Girard and other WHOI engineers and technicians to operate and maintain the MVCO.

MVCO, a cabled observatory, connects an undersea power node, plus a tower carrying instruments, to an onshore "meteorological mast" monitoring weather, and an onshore laboratory. The MVCO provides laboratory-quality power and communications in a nearby ocean setting exposed to forcing from the open North Atlantic. For seven years MVCO has sent oceanographic and atmospheric data to scientists via continuous high-speed two-way communications, for dozens of projects funded by the National Science Foundation (NSF), the Office of Naval Research (ONR), the National Aeronautics and Space Administration (NASA) and private funds.

Among projects using MVCO data and facilities (its capability to provide power and bandwidth to modern instrumentation) in 2008:

• Heidi Sosik is comparing satellite data with data from instruments above and below the water at MVCO, in work sponsored by NASA, to determine the atmosphere's effect on satellite-retrieved data on ocean color (a proxy for the amount of phytoplankton present.)

• Sosik and Rob Olson use MVCO to test the "Imaging Flowcytobot," a robotic device Olson developed that measures chlorophyll and takes images of plankton cells sized between 10 and 100 micrometers (about 4 to 40 ten-thousandths of an inch) in seawater. It counts, measures, and identifies the organisms that bloom (have population explosions) in coastal waters and are critical parts of the marine food chain.

• MVCO's continuous record of ocean conditions and data from the Imaging FlowCytobot have made it possible to test ecological hypotheses about seasonal blooms of specific organisms. For instance, with NASA funding, Sosik, Steve Lentz and John Trowbridge, are using measurements from MVCO and models to characterize processes of water mixing, to study winter and autumn phytoplankton blooms.

• Instruments (seafloor and profiling sensors) at MVCO have determined the distribution of particles and optical and acoustical properties near the seabed. In a collaborative project funded by ONR, John Trowbridge and researchers from University of Maine, Dalhousie University and Bedford Institute of Oceanography, using advanced sensors that use the MVCO power and communications infrastructure, are collecting data and using those data to evaluate and improve

computer models of the links between water physics, particle concentration and size, and optical and acoustical properties near the seabed.

• NSF supported Steve Lentz in a project to develop computer models of wave-driven water circulation over the inner continental shelf, using new data from a cross-inner shelf array of instruments at MVCO, plus past measurements from other coastal observatories and MVCO. The MVCO measurements were a central element of MIT-WHOI Joint Program student Melanie Fewings' doctoral thesis.

• ONR funded Jim Preisig to study the performance of underwater acoustics at MVCO to determine how to transmit data underwater, reliably and efficiently.

• ONR also supported the "Ripples DRI" project at MVCO: Peter Traykovski with colleagues from Dalhousie University, the US Geological Survey (USGS) and Naval Post-Graduate School deployed an array of high resolution, sidescan (side-looking) sonars for months, to measure changes in sea-bottom fine and coarse sand formations with wave and current conditions.

• The US Geological Survey conducted large-scale surveys with advanced sonar equipment to produce accurate measurements of the ocean bottom –and several very high- resolution surveys using an autonomous (robotic) vehicle, the *REMUS-100* AUV.

The NOAA Integrated Ocean Observing System

NERACOOS's region, from Nova Scotia to New York City, includes bays, estuaries, and the coastal ocean to the western continental shelf. Issues of concern here include harmful algal blooms, nearshore and estuarine water quality, ecosystem and fishery sustainability, safety and efficiency of marine operations, and coastal flooding and inundation. Ocean observatories will help us address all these.

IOOS-supported projects within NERACOOS include:

• A grant led by WHOI that supports infrastructure throughout the entire NERACOOS region, including in particular buoys in the Gulf of Maine and Long Island Sound, data management and communications activities, development and test deployment of advanced sensors to obtain continuous time-series measurements of nutrient concentrations, and development and demonstration of advanced capabilities for simulation of storm surge and inundation.

• A grant led by WHOI that supports long-range planning for NERACOOS.

• The Northeast Benthic Observing System, which takes images of the seafloor with "HABCAM", a towed optical imaging system developed by Scott Gallager and others. The system automatically processes images of the seafloor so researchers can characterize the habitat of sea scallops and measure scallop abundance and sizes on George's Bank, a historically rich fishing area. This information will help regulators of the scallop fishing industry.

• Hauke Kite-Powell is developing economic models to maximize the economic impact of NERACOOS.

• Funding went to Janet Fredericks to work on the "Open-Geospatial Consortium Sensor Web Enablement" program and to participate in the Global Earth Observations System of Systems (GEOSS) sensor web project to develop standards to allow "interoperability" between sensor data and data consumers. The important goal of this work is to create a standard framework for describing the capabilities of *in-situ* observatory instruments, how they take measurements, how data are processed, and how to implement data quality control. Such a framework will allow future users to better understand the observatory data they request and process.

One of COSMOS activities is managing WHOI's ocean observatory, the Martha's Vineyard Coastal Observatory (MVCO) on Martha's Vineyard's southern shore. MVCO, a cabled observatory, connects an undersea power node, plus a tower carrying instruments, to an onshore "meteorological mast" monitoring weather, and an onshore laboratory. The MVCO provides laboratory-quality power and communications in a nearby ocean setting exposed to forcing from the open North Atlantic. (Photo by Jayne Doucette, Woods Hole Oceanographic Institution)

Other national and international programs

COSMOS is also involved with international observatory systems. Jian Lin is working with scientists at Tongji University in Shanghai, China to define scientific objectives and plan a deep-sea cabled observatory in the South China Sea. Scott Gallager and Janet Fredericks were invited guests at the International Workshop on SeaFloor Observatories in Shanghai.

Finally, COSMOS has been working in parallel with the ongoing development of the "Pioneer Array," a new observatory system to be installed south of Martha's Vineyard – part of a major program at NSF, the Ocean Observatory Initiative. WHOI is the implementing organization for the coastal- and global-scale components of this program: Principal investigator Bob Weller, project manager Libby Signell, project scientist Al Plueddemann and their colleagues at Scripps Institution of Oceanography, Oregon State University and Raytheon's Integrated Defense Systems Division were granted infrastructure funds over five years and additional operating funds for the first 10 years.

—John Trowbridge, Center Director

Cooperative Institute for Climate and Ocean Research (CICOR)

A 1998 agreement between WHOI and NOAA (the National Oceanographic and Atmospheric Administration) established at WHOI a unique center 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, in service of NOAA's mission and goals.

With its founding agreement renewed in 2001, CICOR has been a global and national resource for scientists and has 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 has come to be known as a catalyst and incubator of ideas for collaborative climate, coastal and ecosystems research.

As NOAA's focus on regional activity has increased, so too has CICOR's role in regional and planning efforts. In 2008 CICOR supported 82 projects, totaling nearly $8.5 million in funding. Since 1998, CICOR has supported more than 188 research, education, outreach and program development projects, bringing its ten-year activity to more than $46.8 million.

2008 was a decisive year programmatically for CICOR. Anticipated a competition for a regional Cooperative Institute (CI), NOAA extended the CICOR agreement an additional year until June 2009, and in October 2008 requested proposals for a new cooperative institute in the Northeast region. With a focus on regional ecosystems and a call for multiple partners, the model of the new CI will look significantly different than CICOR, so CICOR itself has entered a transition stage.

To support some continuing projects, NOAA has extended the cooperative agreement through June 2010, and we anticipate a further no-cost extension until June 2011. In addition to maintaining certain research and educational activities, the office has continued to bring together regional and international investigators. CICOR principal investigators 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 this region and around the globe.

CICOR continued to make strong contributions to WHOI academic programming in 2008: CICOR supported three summer student undergraduate fellows, one in each of the theme areas, and was instrumental in placing NOAA Hollings Scholars with WHOI and NOAA PIs for summer internships. Ricardo De Pol Holz completed his research as a Post Doctoral Investigator with Lloyd Keigwin (Geology and Geophysics Department), studying paleoceanography and the role of the ocean in global climate change. CICOR also supported Post Doctoral Investigator Tobias Kukulka who, together with Albert J. Plueddemann from the Physical Oceanography (PO) Department and John Trowbridge from the Applied Ocean Physics and Engineering (AOPE) Department, investigated the influence of surface waves on the oceanic boundary layer. Post Doctoral Investigator Philip Wallhead is investigating phytoplankton population dynamics on Georges Bank by testing models with *in situ* observations from the GLOBEC (GLobal Ocean ECosystems Dynamics) program, with advisor Dennis McGillicuddy (AOPhysicsEngineering.)

Through technological developments in observations and modeling and through collaborative planning in the region, CICOR has forged advances toward many of NOAA's goals, including these highlights:

• CICOR contributions to major elements of the global ocean climate observing system – including profiling ocean floats (ARGO), ocean gliders, ocean reference stations, and collection of high quality surface meteorology from Volunteer Observing Ships (VOS) – are improving the quality and quantity of climate observation.

• CICOR is proud of its scientists and data managers who partner with NOAA to build NOAA's Integrated Ocean Observing System (IOOS.) The IOOS marks a major shift in the traditional approach to ocean observing, drawing together many networks of disparate, Federal and non-Federal observing systems to produce data, information, and products at the scales needed to support decision making.

• CICOR Fellow, Dr. Bob Beardsley and his UMASS Dartmouth colleague Dr. Changsheng Chen continue their cutting edge collaborative work on coastal modeling that brings climate and weather data to the shoreline. In 2008 they set up the Northeast Coastal Forecast System (NECOFS), which provides 3-day forecasts (and hindcasts) of the surface weather and ocean currents and water properties for the New England/Gulf of Maine coastal region – now being posted on the NECOFS website. The regional Taunton, Mass. NOAA National Weather Service Weather Forecast Office is using NECOFS forecast data for winter icing warnings and inundation due to storm and hurricane activity. Beardsley and Chen are working with the Boston U.S. Coast Guard Station to provide NECOFS forecast data in formats useful in their search and research planning efforts. The Massachusetts Water Resource Authority and Massachusetts Coastal Zone Management Office are other government users of NECOFS forecast information.

• In 2008 CICOR Fellow Andrey Proshutinsky coordinated a CICOR Distinguished Lecture Series on "The Arctic future under the influence of an ice-free summer ocean," consisting of four lectures:

~ "Implications for Globalization and Access Change in the Maritime Arctic," by Lawson W. Brigham, PhD Deputy Director, U.S. Arctic Research Commission Chair, Arctic

Marine Shipping Assessment of the Arctic Council.

~ "Penetration of wind energy into the Arctic Ocean: impact of a changing ice cover" by Harper Simmons.

~ "State of Fate of Permafrost on a Changing Planet" by Vladimir Romanovsky, Geophysical Institute, University of Alaska Fairbanks.

~ "The forcings and feedbacks of rapid Arctic sea ice loss" by Marika Holland, Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, CO.

Also in 2008, the CICOR office sponsored events including:

• An April workshop, informal talks and round table discussion moderated by Ray Schmitt (WHOI PO Department) on "Change in the Global Freshwater Cycle: The Ocean's Role," with Graeme Stephens (Department of Atmospheric Science, Colorado State University) and Lisan Yu (WHOI PO Department) participating.

• The October 2008 Connecticut River Science Workshop at the Connecticut River Museum in Essex, CT provided a forum for over 50 scientists active in the Connecticut River basin to share their work and ideas and to foster collaborations for future research on the Connecticut River and its drainage basin.

Finally, WHOI biologist Don Anderson and modelers Dennis McGuillicuddy and Ruoying He conducted computer simulations of the spread of harmful algal blooms along New England's coast, providing useful data to NOAA Fisheries and coastal managers. In 2008 they successfully predicted a widespread bloom that materialized in New England coastal waters. The forecasting method offers officials and shellfish harvesters a new early-warning tool to help minimize health risks and economic losses caused by shellfish tainted by the toxic algae, *Alexandrium fundyens*.

—Robert Weller, CICOR Director

WHOI biologist Don Anderson (left) and oceanographer Dennis McGillicuddy review the results of a computer simulation of the 2008 harmful algae season in New England waters. The model predicted a large regional outbreak of harmful algae that materialized later in the spring. (Photo by Tom Kleindinst, Woods Hole Oceanographic Institution)

Marine Mammal Center

The new WHOI Marine Mammal Center was funded in May 2008 by a generous gift from *Pete and Ginny Nicholas and family.* The focus of the WHOI Marine Mammal Center (MMC) is to develop strength in basic research and technology, concentrating on conservation applications through strategic partnerships and interdisciplinary approaches.

This focus 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 generate intense popular and scientific interest and have a special conservation status in the US. Many populations are threatened or endangered because of past whaling and current fishing and shipping industries. As fewer marine mammals are killed intentionally by humans, the focus in conservation has switched to accidental deaths (for example, in fishing gear) and to the degradation of their habitats.

Many of today's threats are less obvious than whaling, but may endanger the health of marine mammal populations even more. Fisheries compete with marine mammals for food; chemical and noise pollution threatens them. 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, applied to understanding the issues and to developing innovative conservation solutions. Careful, objective assessment of where the major negative human impacts on marine mammal populations occur in time and space allow the most focussed mitigation measures, that in turn minimize the impacts on associated industrial and defense activities.

The Woods Hole Oceanographic Institution has been a pioneer in marine mammal research since WHOI researchers founded the field of marine mammal bioacoustics in the late 1940s. Research on marine mammals has faced a bias, particularly from terrestrial scientists, as being too difficult for scientific breakthroughs. Yet researchers at WHOI have developed advanced technologies enabling them to make important discoveries about how marine mammals specialize in using sound to communicate, to feed, and to orient in the ocean. Discoveries and methods developed through basic research at WHOI and elsewhere have turned out to be essential to understanding and managing risks to marine mammals, especially risks of ocean noise pollution.

Understanding the distribution and abundance of marine mammals, the demography of their populations, the ecological factors that affect their movements, and their behavior and physiology at sea are all areas of basic research that are essential for conserving marine mammal populations. Also important are computer models, tools that let researchers make predictions about what will happen to populations in the future. The WHOI MMC has a commitment to support both field and modeling work, bringing scientists together across disciplines.

Just as vital to our understanding of marine mammals is the hands-on study of marine mammals on land. Over the past 8 years, an average of 220 marine mammals stranded (beached and injured or dying) on Cape Cod each year, a remarkably high number for such a small area. While the causes of strandings are not fully understood, research on strandings is urgent.

The WHOI Marine Mammal Center partners with many organizations working with strandings on the Cape, in order to improve the welfare of live stranded animals, gather scientific information from strandings, and communicate this information to inform conservation methods. Among groups the MMC works with are the Research Division of the International Fund for Animal Welfare and the National Marine Life Center.

WHOI maintains, and the MMC uses, a state-of-the-art necropsy and imaging facility where researchers help to identify factors contributing to mortality from strandings, entanglement in fishing gear, and other causes. This work is critical for understanding persistent threats to marine mammal populations. The WHOI Marine Mammal Center helps support these critical research facilities and bring experts from many disciplines to work here.

Scientists using the MMC facilities are making new discoveries about the basic biology, physiology and anatomy of marine mammals, as well as information about toxic contaminants and pathogens, some of human origin. Using cutting edge techniques to diagnose the health status and causes of mortality of wild marine mammals is yielding surprising new findings that are exciting science and potentially important for maintaining the health of the populations. For example, WHOI biologists Michael Moore, Rebecca Gast and Andrea Bogolmoni, with colleagues at Tufts University's Cummings School of Veterinary Medicine, the International Fund for Animal Welfare, and the National Marine Fisheries Service recently reported, based on work done the MMC necropsy facility, that numerous species of marine mammals and birds harbored disease organisms, some capable of being transmitted to humans and some resistant to antibiotics. These results are important for human health as well as maintaining healthy populations of marine mammals.

In 2008 the MMC completed its first call for proposals, receiving eight proposals from the WHOI Biology, Chemistry, and AOPE Department and the Marine Policy Center. The MMC sponsored talks at WHOI – Prof. Hal Whitehead,

Marine mammal specialist Michael Moore and WHOI guest student Colby Moore (from the College of the Atlantic) prepare to examine a white-sided dolphin that had stranded and died on a beach in Wellfleet, Massachusetts. Researchers from around the world come to the Marine Mammal Center's specialized facilities at WHOI to perform necropsies and other post-mortem studies of marine creatures. (Photo by Tom Kleindinst, Woods Hole Oceanographic Institution)

(Dalhousie University) on "Cultures of the Open Ocean: the Sperm Whale," and Prof. Christopher Clark (Cornell University) on "Acoustic Ecology of Whales in the Waters around Cape Cod" – and hosted its first workshop, on "Gulf of Maine Seals - populations, problems and priorities" in May 2009.

The MIT/WHOI Joint Program and WHOI postdoctoral programs offer world-class opportunities for training and research, and 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.

In addition to activities at WHOI, MMC is developing other outreach efforts, including web sites and databases for open access to critical data and projects, and funds to scientists for interacting with media, providing testimony and expert advice on marine mammal research and conservation issues. A look at the number of marine mammal-related stories in "WHOI in the News" on the WHOI web site (20 articles in just the second half of 2008,) or *Oceanus* magazine, emphasizes the importance of public outreach about our efforts.

— Peter Tyack, Center Director

Woods Hole Center for Oceans and Human Health

Mission

To improve the public health through enhancing our understanding of how oceanic processes affect the distribution and persistence of human pathogens and toxin-producing organisms in marine and coastal environments.

Theme

The Woods Hole Center for Oceans and Human Health (WH-COHH) addresses the distribution of biological agents with potential human health consequences in the temperate coastal ocean, including bays, harbors and estuaries. Within this geographic theme, research projects in the Center concentrate on harmful algal blooms, bacterial human pathogens, and parasitic protists, with complementary studies of physical oceanographic conditions and biology of the organisms. The conceptual foundation for the WH-COHH lies at the interface between advanced genomics, population biology, and coastal hydrodynamics.

Background

Established in 2004 through a novel partnership between the National Science Foundation (NSF) and National Institute of Environmental Health Sciences (NIEHS), the WH-COHH brings together researchers with expertise in biomedical, genomic, and oceanographic sciences at Woods Hole Oceanographic Institution (WHOI), the Marine Biological Laboratory (MBL), and the Massachusetts Institute of Technology (MIT). Scientists funded by WH-COHH have been leading studies of harmful algal blooms and of human pathogens in marine systems, addressing the current and future needs of a growing human population.

Center Administration and Research Projects

The Center includes an Administrative Core that ensures integration of the elements of the Center, a Genomics Core Facility that provides state-of –the-art DNA sequencing for the projects, and a Pilot Project Program of small grants for new research ideas. The standing research projects in the Center focus on combining population dynamics and genetics with hydrodynamic (water movement) transport and discovering the refuges within the environments of harmful algal species and human pathogens. The current projects and researchers are:

1. *Alexandrium* population biology in the Gulf of Maine: Don Anderson (WHOI) and Deana Erdner (University of Texas Marine Science Institute)
2. Hydrodynamic forcing of *Alexandrium* population biology: Dennis McGillicuddy (WHOI)
3. Human pathogens and coastal ocean processes: Rebecca Gast (WHOI) and Linda Amaral-Zettler (MBL)
4. Microecology and evolution of two marine pathogens: Martin Polz (MIT) and James Lerczak (College of Oceanic and Atmospheric Sciences, Oregon State University)

Recent Highlights

Harmful algal blooms

Drs. Anderson and McGillicuddy successfully forecast the 2008 outbreak of *Alexandrium*, the algae that produce the toxin that causes paralytic shellfish poisoning, using a computer model combined with intensive seafloor surveys for the algae's dormant stage cysts. This is a major breakthrough – the first seasonal prediction of a red tide or HAB (harmful algal bloom) on a regional scale – and validates our understanding of the A. *fundyense* bloom dynamics in the Gulf of Maine, and the sophistication and accuracy of our numerical model. McGillicuddy and Anderson have begun discussions with NOAA officials to use this model in NOAA's Harmful Algal Bloom Forecasting System.

Pathogens

Environmental pathogens pose serious threats to human health, but we lack the means to effectively detect or predict their occurrence. This aspect of the program seeks reasons why virulent variants of these organisms co-occur with non-virulent forms of the same organisms. Pathogenic forms can arise as adaptations to non-human hosts or niches, but we know little about underlying mechanisms.

Drs. Mitchell Sogin and Hilary Morrison at MBL oversee the Core Facility, which provides genetic sequencing for the Center's projects and carries out research to enhance sequencing capability. Detecting microorganisms, including human pathogens, present at low abundance – maybe only a few cells in a milliliter of seawater – demands molecular sampling efforts much greater than those routinely done by laboratories. To address this, we developed a "massively parallel sequencing strategy" that allows us to sample many tens of thousands of hypervariable regions from specific genes (rRNA genes) at a fraction of the cost of other methods. We anticipate that this technology has the capacity to distinguish between different sources of fecal pollution, and provide a tool for tracking the fate and transport of pathogens in temperate recreational waters and sands (such as beaches.)

Drs. Gast and Amaral-zettler have detected a diverse set of gene sequences from the bacterial genus *Legionella*, including the disease-causing *Legionella pneumophila*, in several marine environments. They also have detected the presence of other human parasites including *Giardia* in Mt. Hope Bay, Mass.

Dr. Polz detected significant populations of *Vibrio cholerae* (the bacterium responsible for cholera) in coastal waters of Massachusetts – including a novel, closely related potential pathogen group with the collective working name "*V. pseudocholerae*." Recently the Centers for Disease Control and Prevention also isolated organisms from this new group, suggesting that V. pseudocholerae could be a new potential pathogen. In the environment, *V. cholerae* and *V. pseudocholerae* co-occur but our field observations and preliminary laboratory growth experiments suggest that the two groups grow best at distinct temperatures and salinities. And Maine, New Hampshire, and Massachusetts are considering providing funds for cyst surveys in 2009 and 2010, to be matched with federal funds for ship time. This is strong evidence for the value of the Center's forecasting and outreach efforts.

Pilot Projects

Since the beginning of WHCOHH we have funded Pilot Projects, to broaden the scope and impact of the center. Current pilot projects include:

• Hydrodynamics and Transport Pathways for Fecal Microbial Populations in a Salt Marsh and Barrier Beach System" David Ralston (WHOI),

• Using signature tagged mutagenesis to investigate how pandemic *Vibrio parahaemolyticus* persists in the bacterioplankton" Janelle Thompson (MIT), and

• BMAA, a cyanobacterial neurotoxin, in marine food webs" Carl Lamborg, and Mak Saito (WHOI).

• Pilot project awardees Hauke Kite-Powell and Porter Hoagland (both of the WHOI Marine Policy Center) have been collaborating with the Miami Center to assess economic impact of brevetoxins (neurotoxins from harmful algae) in Florida waters.

Conference

A Gordon Research Conference on Oceans and Human Health was held in summer 2008, co-chaired by WH-COHH Director Dr. John Stegeman, and Miami COHH Director Dr. Lora Fleming. The conference was regarded by many as a significant milestone in establishment of the interdisciplinary field of oceans and human health.

—John Stegeman, Center Director

Elizabeth Halliday, a graduate student in the MIT-WHOI Joint Program, takes samples of sand at Wood Neck Beach in Falmouth, Mass., to analyze in the laboratory. Bacteria that are indicators of fecal contamination can live and grow in beach sand, and the DNA from microbes living within this sand will be used to find out how many indicator bacteria are present. Halliday works in Rebecca Gast's laboratory, and her research is supported by the Woods Hole Center for Oceans and Human Health. (Courtesy of Elizabeth Halliday, Woods Hole Oceanographic Institution)

Ocean Observatory Initiative

In 2008, Staff from WHOI's Physical Oceanography and Applied Ocean Physics and Engineering Departments continued to develop a major component of the National Science Foundation's (NSF's) new ocean observatory infrastructure program, the "Ocean Observatories Initiative" (OOI).

In August 2007, the NSF announced that it had awarded WHOI and its partners at Oregon State University and Scripps Institution of Oceanography the contract to design and deploy the coastal and global observatories that are to be designed, built, and deployed under this initiative. Thus, WHOI took the lead on these OOI "Coastal and Global Scale Nodes" or CGSN component. The planned start for the effort is September 1, 2009.

Coastal and Global Scale Nodes

The CGSN component will consist of two coastal and four global "arrays" (Fig 1) – constellations of instruments measuring a variety of ocean properties – placed in specific locations in the ocean. The designs for the CGSN arrays matured in 2008 and were presented at a Final Design Review in November. Additional changes directed by the NSF lead to the present plan.

All the CGSN sites use a combination of fixed sampling platforms (moorings), and mobile platforms (gliders and, when possible, AUVs) to carry the instruments and sample across space and time scales of interest. Observations will be made from the sea surface to the sea floor using vertical profilers – assemblies of sensors, or instruments that measure specific properties while moving up and down along a wire or winching themselves up and down.

Key to this new observing initiative is an emphasis on fielding multidisciplinary sensors, making data available to all as quickly as possible – often in real time by various telemetry methods, increasing the power available to the sensors and the power for data communication, and involving the community as users of the sampling infrastructure and as providers of additional sensors and instruments. WHOI engineers are already working to develop new power systems for surface buoys that combine fuel cells, solar panels, and wind-driven generators.

OOI Arrays

Closest to WHOI is the coastal array in the mid-Atlantic Bight known as the Pioneer Array (Fig. 2); this array will be operated for about 5 years and then, as guided by community input, be deployed at a new location. The Pioneer Array includes moorings, ocean gliders, and AUVs. Power generated by surface buoys in the Pioneer Array will be available to recharge the AUVs at docking stations on the sea floor; the AUVs will also be able to download their data at these docking stations for transmission to shore by telemetry systems on the surface buoys.

The Endurance Array (Fig 3), in the Pacific Northwest, will have a line of three moorings off Newport, Oregon. The subsurface moorings will be attached to a seafloor cable providing power and data communication, a line of mooring off Grays Harbor, Washington, and ocean gliders.

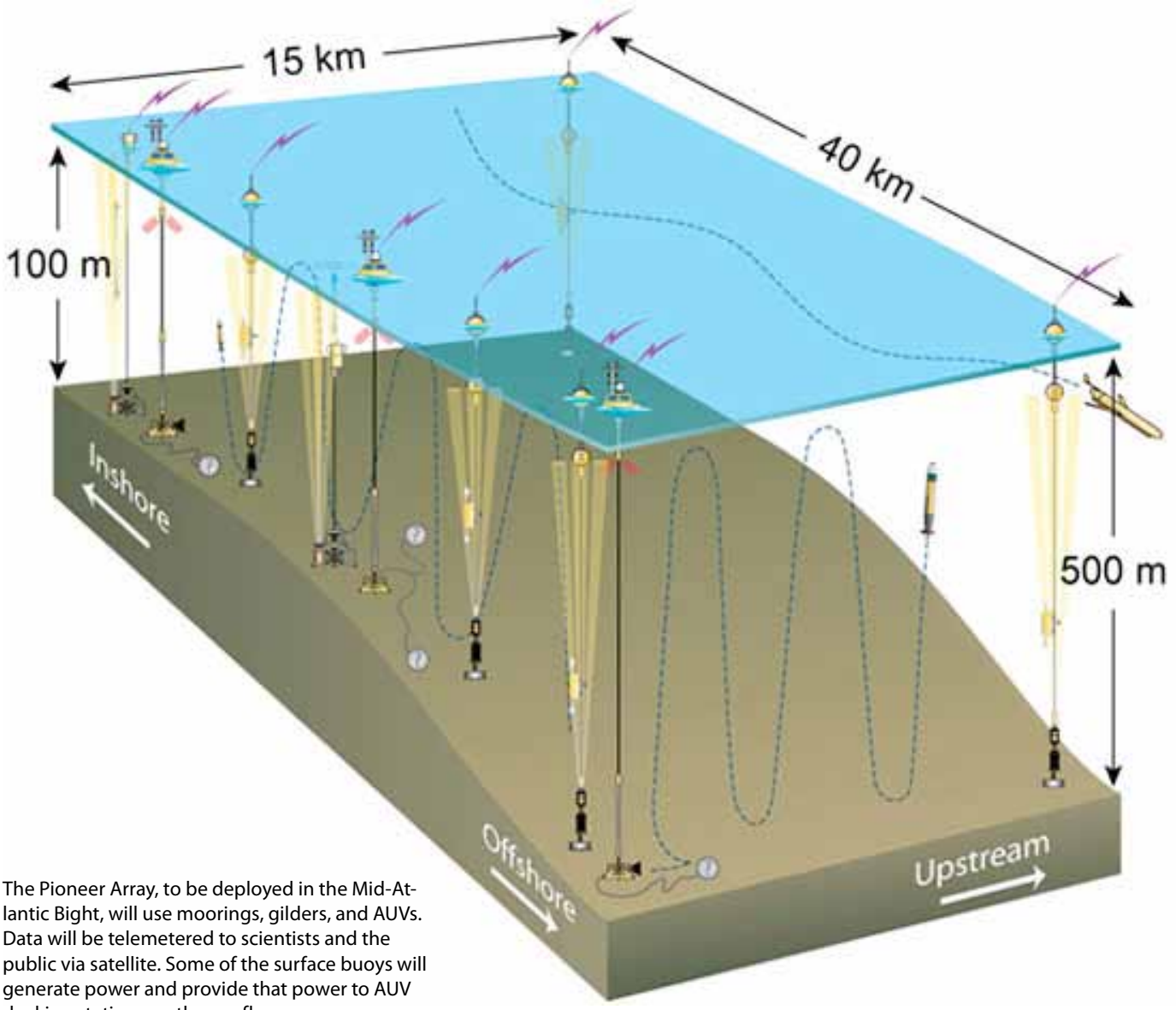
The four global arrays will each use four moorings to define a triangular array together with three ocean gliders to sample in and around the array (Fig. 4). They will be located in the Gulf of Alaska (50°N, 145°W), in the Irminger Sea (60°N, 39°W), off the southwestern tip of Chile (55°S, 90°W), and in the Argentine Basin (42°S, 42°W).

Initial work on arrays has already begun under pilot funding. Full funding is anticipated in late 2009. The first part of the effort will focus on design and construction. Deployments of the arrays would begin in 2013 and continue through 2015. NSF plans for 25 to 30 years of operation for each of the sites, with periodic competition forthe contract to carry out the operation and maintenance. WHOI's initial contract will cover the design and build period as well as the first two years of operations and maintenance.

Other OOI Components

In addition to the CGSN component, there will be a seafloor cabled observatory off Washington under a Regional Scale Node (RSN) led by the University of Washington, and a Cyberinfrastructure or CI component led by the University of California at San Diego. The Consortium for Ocean Leadership in Washington DC directs the program under contract to the NSF.

—Robert Weller, OOI Principal Investigator



The Pioneer Array, to be deployed in the Mid-Atlantic Bight, will use moorings, gilders, and AUVs. Data will be telemetered to scientists and the public via satellite. Some of the surface buoys will generate power and provide that power to AUV docking stations on the sea floor.

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

The shore of Thuwal, Saudi Arabia, a small fishing village north of Jeddah, is also the location of King Abdullah University of Science and Technology (KAUST), a new, international graduate-level research university providing opportunities for study and research in engineering, marine science and in chemical, material and mathematical sciences.

Even before the foundation for the University was poured in Thuwal, SA, KAUST established its first scientific partnership, funding a range of projects with WHOI as part of its Special Academic Partnership program, which is part of KAUST's Global Collaborative Research initiative. The objective of the partnership was for WHOI scientists to begin research projects in the Red Sea that would result in sharing scientific knowledge and the research experience between scientists, technicians, engineers and students of the two institutions.

The ensuing 14 multi-year projects include studies on the ecology and chemistry of coral reefs and fishes, coral health and growth, nutrient and carbonate chemistry of the Red Sea, air-sea dynamics, currents, large-scale circulation in the Red Sea and the development of a bio-economic model for Red Sea fisheries. As KAUST buildings emerged on shoreline, the breadth of expertise amongst WHOI's scientific and technical staffs, and the strength of WHOI's research infrastructure (ship operations and shipping) allowed researchers to start fieldwork quickly, with an impressive suite of modern oceanographic tools to study the Red Sea firsthand.

Hydrography

Heat exchange between the air and the ocean is an important component of atmospheric and oceanic dynamics. To measure heat exchange in the Red Sea, Tom Farrar led the first WHOI KAUST Red Sea cruise on the R/V *Oceanus* in October 2008, accompanied by Susan Avery, Larry Madin, other scientists, technicians and engineers and KAUST staff. About 55 km (34 miles) offshore of the KAUST campus, Farrar and the engineering team deployed a metrological mooring carrying instruments that send real time measurements of surface meteorology, radiation, surface waves and ocean temperature, and salinity. Results thus far indicate that the strong land-sea breeze may contribute to the large evaporation rate (1.3 m or 4.3 feet of water in 6 months) near the coast. Larry Pratt, Houshuo Jiang and collaborators at UMass Dartmouth have created high-resolution atmospheric simulation models for environmental prediction. Houshuo's model identifies two types of coastal mountain-gap wind jets. A daily summer wind jet blows eastward from the Tokar Gap on the Sudanese Red Sea coast, and in winter, every 10-20 days for several days, wind jet bands blow along the northwestern Saudi Arabian coast. These wind jets may generate unusual coastal circulation patterns.

Hydrographic and modeling efforts incorporate data from pressure, temperature and salinity gauges that record sea height differences over seasons, placed by Richard Limeburner in shallow water in Rabigh, Thuwal and Jeddah. Measured differences in sea surface elevation across and along the Red Sea can help explain the movement of wind driven currents and regional water circulation. To examine water flow from the shelf onto the reefs, Steve Lentz and Jim Churchill deployed instruments on moorings across the shelf during the first leg of the *Oceanus* cruise, and on and around coral reefs.

Physical oceanographer Amy Bower led the second leg of the R/V *Oceanus* Red Sea research cruise with WHOI engineers and technicians, KAUST partner scientists from Hong Kong and Cairo, and observers from KAUST, to the "Atlantis II Deep Brine pool," an unusual type of deep water formation in the Red Sea. The first water temperature measurements of the brine pool in 10 years indicate that temperature continues to increase (now at 68.3o C, or 155o F), but the rate of temperature rise over the past 20 years seems to be slowing. In addition to sampling temperature and salinity of the waters around the brine pools, samples were taken for nutrient and carbonate chemistry analysis for Dan McCorkle's project, and cores were taken for biological and geological analysis.

KAUST also sponsored a research cruise led by Dave Fratantoni in the Caribbean test the *Towfish*, a multi-sensor instrument that measures physical variables while taking plankton images with a laser video recorder. Scientists hope to characterize the circulation, water temperature, salinity and chlorophyll variability from the continental shelf to the deep basin on future Red Sea cruises.

Coral Reefs

Coral reefs are ecologically sensitive habitats that undoubtedly will be affected by global climate change. KAUST offers WHOI researchers a chance to study Red Sea corals, fish, and reef hydrography with the overall goal of having a better understanding of reef ecosystems. In the first of two field surveys of diverse fish and coral communities, Simon Thorrold, Konrad Hughen, postdoctoral scholar Michael Berumen (now at KAUST) and at team of coral and fish experts from Australia found 269 reef fish species, 158 scleratinian (hard) coral species, and 14 soft coral genera. Scarcity of a commercially important fish, nagil, and the reduced abundances of grouper and snapper near Jeddah and fishing areas suggests that reefs may be experiencing fishing pressure. Using isotopic chemistry of fish "otoliths" (ear bone), which reveal the fish's lifetime movements, WHOI/MIT graduate student Kelton McMahon has found that snapper utilize mangroves, patch reefs and mains reefs at different times in their life cycle, so all habitats are important to pres-

Through a research agreement with King Abdullah University of Science and Technology, WHOI scientists are studying coral reef ecosystems, fisheries, and water circulation along Saudi Arabia's Red Sea coast. WHOI scientists – including MIT-WHOI Joint Program student Jessie Kneeland, shown measuring a large coral – are assessing the health of extensive coral reefs and identifying environmental factors affecting them. (Photo by Konrad Hughen, Woods Hole Oceanographic Institution)

ervation of coral reef fish diversity.

The distribution and movements of large fishes are not well documented for the Red Sea. As a first step, Simon Thorrold and Michael Berumen successfully tagged 4 whale sharks with data-recording archiving tags, and more tagging is planned. In six months, tags will send back data on the depth, temperature and movements of the sharks.

Anne Cohen, Ann Tarrant and WHOI postdoctoral investigator Neal Cantin are using computed tomography (CT) scans of coral cores to study annual growth bands to document the response of historical calcification rates to periods of high seawater temperature stress. Seasonal patterns in lipid energy stores and photosynthetic pigments within coral tissues are being measured to investigate the link between colony energetic reserves and coral calcification. Dan McCorkle is determining nutrient and carbonate seawater chemistry at reefs where carbonate production rates are being monitored in two species of dominant massive reef building coral.

Konrad Hughen and his students have collected coral samples from 100s of miles of coastline north and south of KAUST to examine large-scale sources of stress to corals. Using trace elements and organic molecular markers in coral tissues and skeleton, they are looking for evidence of stress due to factors such as high temperature, salinity, pollution and disease. They have successfully obtained long coral cores to reconstruct environmental stress and coral health over the past several centuries.

Data collected at several reefs by Steve Lentz and Jim Churchill and by Jesús Pineda indicate that shallow platforms of coral reefs experience large water temperature fluctuations over a 24-hour cycle. In a field experiment to transplant of colonies of the common coral *Sylophora pistillata* from the exposed (seaward) side to the protected side of a reef, Jesús Pineda is determining the impact on corals of small-scale water movement and temperature differences over reef platforms. Molecular analysis in Ann Tarrant's laboratory of transplanted coral will tell us if coral's symbiotic algae – which corals need to grow – respond to these different environmental conditions.

Fisheries stock assessment and bioeconomic models

Hauke Kite-Powell, Porter Hoagland, Andy Solow and Michael Neubert are investigating the health of fish stocks along the Red Sea using historical data from the Saudi Fisheries Department. They have estimated the degree of overfishing and changes in fish stock size from data provided on the amount of fish and species caught, number of fishermen, boats, and fishing trips. Working together with Saudi authorities, they hope to protect the Red Sea fish stocks and coral reefs so that these resources are available for future generations.

KAUST

The inauguration of KAUST will be September 23, 2009. At this time, WHOI and KAUST will share results from ocean and atmosphere models, corals and fish studies, water chemistry analyses, and hydrography measurements from the shoreline, in various coral reefs, out to the continental shelf, and from the deep-sea brines. The KAUST-WHOI partnership is creating a valuable database of information on the Red Sea that will be used by scientists at KAUST and elsewhere for years to come to develop new questions and experiments about the Red Sea.

Academic Programs

The education program achieved some major milestones in 2008. The MIT-WHOI Joint Program celebrated its 40th birthday with two events: a reception at the Ocean Sciences meeting in Orlando, Florida in the spring, and a science symposium at MIT in the fall. Both events attracted many WHOI scientists, MIT faculty, JP students and alumni. Joint Program alums presenting scientific papers at the symposium were Alex Techet (MIT), Peter Franks (Scripps), Eli Tziperman (Harvard), Dan Sigman (Princeton), and Carol Arnosti (UNC). Dr. Howard Johnson, former MIT President, who along with former WHOI Director Paul Fye signed the original MOU creating the Joint Program in 1968, gave opening remarks. Joint Program alum Jay Cohen, Undersecretary for Science and Technology of the U.S. Department of Homeland Security, gave the closing remarks. Both the spring reception and fall symposium were very successful and proved to be a fine way to celebrate the 40th.

We celebrated another important anniversary in 2008 as the Geophysical Fluid Dynamics (GFD) Program marked its 50th year. To mark this important occasion, WHOI hosted a reception in Woods Hole Village, which was attended by six of the seven GFD Program founders and many past and present fellows and staff. We were honored to see GFD founders selected by their peers as the 2008 recipients of the American Geophysical Union's Excellence in Geophysical Education Award.

During the 2007-2008 academic year, the MIT-WHOI Joint Program awarded 28 masters and doctoral degrees in ocean science and engineering. As of fall 2008, the Joint Program has awarded 813 degrees. Twenty new students enrolled in the program in 2008, and the total fall enrollment was 134.

Thirteen Postdoctoral Scholar Fellow awards were made (7 women and 6 men) which includes one postdoc who also received an external NOAA/UCAR award. In addition to the WHOI- and USGS-funded scholars, fellows arrived with support from: the European Union, Brazilian National Council for Scientific and Technological Development, Organization of American States, Office of Naval Research, Greek Secretary of Research and Technology, National Institutes of Health, National Science Foundation, NOAA/UCAR Climate and Global Change Office, Norwegian Research Council, Bjerknes Centre for Climate Research, Portuguese Foundation for Science and Technology, Spanish Ministry of Education and Sciences, the Fulbright Program, Swiss National Science Foundation, and the University of Potsdam - Liebnitz.

The topic for the 2008 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), 8 guest students, 72 staff members and 5 guest lecturers participated in the program.

Maya Bhatia, a doctoral student at WHOI, took hundreds of water samples the summer of 2008 to learn about water chemistry during seven weeks of research in western Greenland. Bhatia, who works with WHOI scientists Sarah Das and Liz Kujawinski, camped on the edge of a glacier that flows into a fjord. This remote area is uninhabited by people, but does have plenty of swarming insects. "It was stunning, absolutely gorgeous," Bhatia said. "But oh my gosh, the bugs. Terrible." (Photo courtesy of Maya Bhatia, Woods Hole Oceanographic Institution)

Twenty-seven Summer Student Fellows (SSF) representing 25 colleges and universities were chosen from a record high 241 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 SSF students later apply for graduate school in the Joint Program.

Students and postdocs bring energy, enthusiasm and new ideas to WHOI's research portfolio and help us move in new directions. It's a privilege to oversee these fine education and training programs.

—James Yoder,
Vice President for Academic Programs & Dean