2006–2008

BIENNIAL REPORT

LAMONT-DOHERTY
EARTH OBSERVATORY
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

Prevailing winds blow desert dust off North Africa into the Atlantic Ocean, where it settles to the seafloor. By analyzing cores of seafloor sediments collected off West Africa, Lamont-Doherty paleoceanographer Peter deMenocal tested a hypothesis that North Africa's climate shifted abruptly about 5,000 years ago, turning a once wet and vegetated landscape into the Sahara Desert.

LAMONT-DOHERTY EARTH OBSERVATORY IS RENOWNED IN THE INTERNATIONAL SCIENTIFIC COMMUNITY FOR its success and innovation in advancing understanding of the Earth, for its unique geological and climatological archives and state-of-the-art laboratory facilities, and for the outstanding achievement of its graduates. Observatory scientists observe Earth on a global scale, from its deepest interior to the outer reaches of its atmosphere, on every continent and in every ocean. They decipher the long record of the past, monitor the present and seek to foresee Earth's future. From global climate change to earthquakes, volcanoes, nonrenewable resources, environmental hazards and beyond, the Observatory's fundamental challenge is to provide a rational basis for the difficult choices faced by humankind in the stewardship of this fragile planet.

G. Michael Purdy
Director, Lamont-Doherty Earth Observatory

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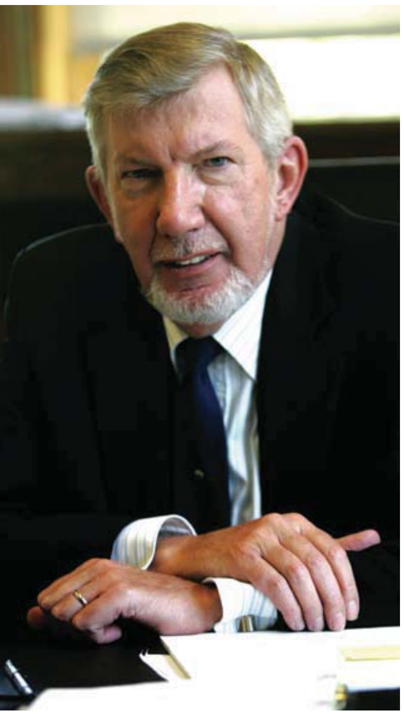
We are building a truly exceptional research portfolio to produce the answers that global leaders need to make sound decisions.



IT IS RARE IN THE HISTORY OF THE OBSERVATORY FOR ANY TWO-YEAR period to encompass the changes that have occurred since 2006. As the 21st century begins, the greatest challenges that society faces are challenges that cannot be met until our understanding of the Earth system is greatly improved. In response to this, we are building a truly exceptional research portfolio to produce the answers that global leaders need to make sound decisions.

Key components of this portfolio depend on the kinds of sophisticated analysis enabled by the new Gary C. Comer Geochemistry Building. This state-of-the-art $45 million facility is the first major Lamont-Doherty research building in more than three decades and represents an important step toward a campus-wide modernization of research infrastructure.

This report also details the first year of operations for the Observatory's new research vessel *Marcus G. Langseth*, which continues our long tradition of leadership in marine geophysical data acquisition. The ship is unique within the U.S. national fleet for its ability to tow multiple seismic streamers and enable the construction of three-dimensional images of structures deep beneath the ocean floor—be they volcanic plumbing systems beneath mid-ocean ridges or seismogenic faults beneath subduction zones.

As the Earth Institute has grown, Lamont-Doherty researchers have taken advantage of many new opportunities to cross boundaries between disciplines—especially into public health and engineering—in order to accelerate the translation of new knowledge about our planet for the benefit of humankind. As the United States welcomes a new administration into the White House, we look forward to an escalation in opportunities for our researchers to work in conjunction with other disciplines and to make even greater progress in advancing a global sustainable development agenda.

It is clear, however, that exclusive reliance upon federal research funding is far less viable today than it was just decades ago. Under the leadership of Quentin Kennedy, chair of Lamont-Doherty's active Advisory Board, we have made important progress in building a development program focused upon raising endowment and infrastructure funding from the private sector and in expanding our base of committed donors.

All the success that the Observatory has enjoyed over the past two years has been due to the quality and dedication of all Lamont-Doherty's employees—researchers and administrators alike. Continued success will require that we be able to recruit and retain the same fine quality of individuals that today populate the Observatory's roster. It is my job as director to make sure this is the case. Only then can I be confident that the report that follows this one in two years will document a set of accomplishments of comparable quality and significance.

G. Michael Purdy
Director

Now, more than ever, the fundamental science carried out by its researchers and students forms the underpinning for all the Earth Institute does.

FOR NEARLY 60 YEARS, THE LAMONT-DOHERTY EARTH OBSERVATORY has been leading research into the workings of Earth on almost every level—beneath and on the surface, in the oceans, and throughout the atmosphere. Much progress has been made at the Observatory in revealing the complex, interconnected dynamics of our planet, but far more remains to be discovered if humanity is to live and develop sustainably in the 21st century. Now, more than ever, the fundamental science carried out by its researchers and students forms the underpinning for all the Earth Institute does.

Lamont-Doherty is particularly famed for its path-breaking climate studies. Nothing made this expertise clearer than when the Intergovernmental Panel on Climate Change (IPCC) shared the 2007 Nobel Peace Prize with former Vice President Al Gore. The IPCC's recent Fourth Assessment Report included no fewer than nine researchers from Lamont-Doherty, along with contributions from dozens of scientists from other parts of the Earth Institute. If we are to successfully address the intricate problem of sustainable development in a changing climate, it must also occur collaboratively, with scientists interacting across virtually every discipline—from research scientists, to political scientists and economists, to engineers. The excellence and global leadership of the Earth Institute rests fundamentally and squarely on the unrivaled wealth of intellectual and creative capital in Lamont-Doherty's faculty and on the faculty's inspiring commitment to link public policy and decision making to cutting-edge and world-changing science.

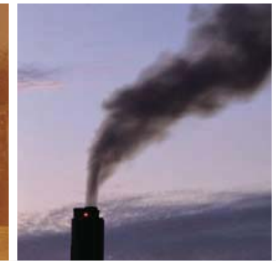
The accomplishments cited throughout this report document Lamont-Doherty's astounding leadership across the earth sciences and also reflect the emphasis these researchers place on educating a new generation of scientists and researchers. Lamont-Doherty's faculty trains and mentors dozens of master's and Ph.D. students each year in state-of-the-art facilities such as the new Gary C. Comer Geochemistry Building, on board the recently launched R/V *Marcus G. Langseth*, and at research sites around the globe. This next generation of researchers will play a vital role in our attempt to anticipate and mitigate future predicaments, surmount environmental obstacles, harness new knowledge, and present solutions to our leaders and global society.

As we try to unravel the complex puzzle called Earth, it is paramount that we decipher the long record of the planet's past, monitor its present, and attempt to foresee its future. I salute Director Mike Purdy and our colleagues at Lamont-Doherty for their inspiring contributions to this critical task and wish them full speed ahead and all success in their quest for new knowledge!

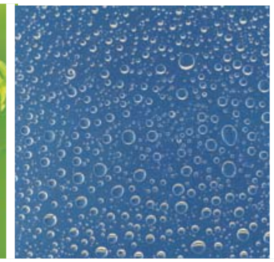
Jeffrey D. Sachs
Director, The Earth Institute at Columbia University







SCIENCE TO SUSTAIN THE PLANET

CONTINUED ECONOMIC DEVELOPMENT IS CHANGING THE RELATIONSHIP BETWEEN HUMANS and the planet. Science can help us understand how we are altering—and how we are affected by—the world's natural systems; it can also help us find a balance between human prosperity and a healthy Earth.

Lamont-Doherty researchers continually advance knowledge of the natural processes that sustain—or threaten—humans around the globe. Whether by investigating the ability of the world's oceans to absorb climate-altering carbon dioxide or learning how and where earthquakes occur, researchers are adding pieces to our understanding of the Earth-system puzzle with every scientific finding. Together, those pieces create a clearer picture of the planet's impacts on humanity and vice versa.

"Almost everything we learn about the Earth informs our ability to live better on the planet," said G. Michael Purdy, director of the Lamont-Doherty Earth Observatory. "Every piece of knowledge can be important." Ultimately, earth science provides fundamental information about the way Earth's climate, oceans, ecosystems and landmasses behave. This, in turn, helps policymakers and all of society determine how much and what kind of human activity our finite planet can tolerate.

To manage changes responsibly and help keep countries on the path of sustainable development, scientists and decision makers need to be able to make accurate predictions of how the planet's natural systems will respond to human actions. "Useful predictions can only be made when we have a basic understanding of the underlying physics, chemistry and biology that govern the evolution of the planet," said Purdy. "Without that knowledge, it is impossible to predict whether any particular human action will adversely affect the lives of generations to come."

Mapping Carbon and the Oceans

Every year, the oceans absorb about a quarter of the 21 billion tons of the heat-trapping greenhouse gas carbon dioxide produced by human activity. Since the world's oceans hold as much as 50 times more carbon dioxide than the atmosphere, slight changes in the rate or pattern of ocean circulation in response to climate changes could drastically alter the absorption of the greenhouse gas.

Lamont-Doherty geochemist Taro Takahashi has spent more than 40 years studying carbon dioxide in the world's oceans. He and colleagues use sampling devices deployed on ocean-going research vessels to calculate how surface waters exchange carbon dioxide with the air above them. For the past two decades now, he has published a map of the oceans—updating it every five years or so—that highlights where the gas is being absorbed and where it is being released.

Recently, he published the fourth in his series of global carbon dioxide maps. The goal, he says, is to provide a baseline from which to view changes in the planet's carbon cycle. "Unless you have a baseline, you can't measure changes," said Takahashi. "Now we can look at changes from the first map. But the big question is: Will the trend change?"

If the oceans continue to take up carbon dioxide, seawater will become more acidic, threatening marine life and ecosystems that provide food and income to millions of people. If the oceans' ability to absorb carbon dioxide weakens, it would exacerbate global warming and lead to accelerated changes to the world's climate.

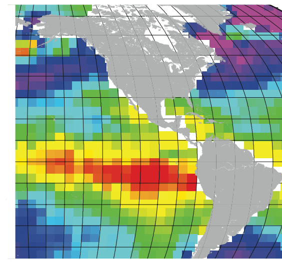
Predicting Precipitation Shifts

As human-induced climate change progresses, we may see a widespread rearrangement of the planet's precipitation patterns. Although populations have successfully adapted to periodic, seasonal fluctuations in the past, many scientists foresee changes in store that could be either too rapid or too widespread for human systems to adjust.

"Climate model projections are good enough to tell us changes in precipitation are going to occur," said Richard Seager, a climate modeler in Lamont-Doherty's Ocean and Climate Physics Division. The models still contain uncertainties about the precise nature of these altered precipitation patterns, but the reality that weather is going to change is clear.

Broadly, many models project that dry areas will get drier and wet areas will get wetter, while the subtropical arid zones expand toward the poles. This will pose challenges for people in both wet and semi-arid climates. Already marginal areas such as southern Africa may no longer be able to sustain agriculture; regions such as Southeast Asia could find that monsoon rains become stronger and lead to deadly flooding.

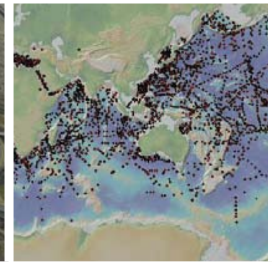
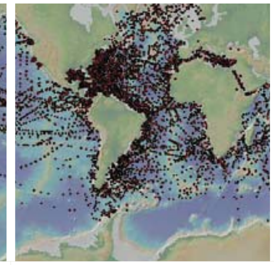
Of the many uncertainties still present in projections, the role that small particles in the atmosphere, known as aerosols, play is one of the most complex. Adding to the complexity is the fact that human activity can influence the amount of aerosols in the atmosphere. Seager recently looked back at the 1930s dust bowl drought in the U.S. Great Plains and concluded that human action may have actually turned an ordinary drying cycle into widespread agricultural collapse. He and a group of colleagues at Lamont-Doherty and the Goddard Institute for Space Studies found that aerosols in the form of dust caused by drought and exacerbated by poor agricultural practices very likely spread and intensified naturally occurring arid conditions in part of the Great Plains.



Geochemist Taro Takahashi has traveled the world to map the uptake and release of carbon dioxide by oceans [above and opposite page, top left]. *Credit: Taro Takahashi [above] and CDIAC [opposite page]*

Climatologist Richard Seager recently found that dust in the atmosphere caused naturally occurring drought conditions during the dust bowl years [above, top] to worsen and spread. *Credit: Library of Congress, Prints & Photographs Division, FSA/OWI Collection, LC-DIG-ppmsc-00241*




Dorothy Peteet [above] took cores from a marsh in Jamaica Bay, New York, to study human and climate impacts recorded in the sediments.
Credit: Bruce Gilbert

Juerg Matter and colleagues will inject carbon dioxide from the Hellisheidi power plant [top of page] near Reykjavik, Iceland, to test the ability of rock formations beneath to securely hold large amounts of carbon dioxide for long periods of time.
Credit: Sigfús Már Pétursson

Revealing Changes

Another uncertainty in climate projections is how natural ecosystems will respond to natural and human-induced changes. Ecosystem modeling is still in its infancy, but one of the first steps toward understanding the future of Earth's biological systems is to study what has happened in the past. Dorothy Peteet, a research scientist in the Biology and Paleo Environment Division, has turned to Lamont-Doherty's own backyard—the Hudson Valley—for clues.

Her work has documented many previously unknown changes that occurred since the last ice age—and how European settlers changed the face of the region. For example, she has seen how invasive and weedy plant species brought by settlers led to declines of fish species and the loss of wetlands that provide natural water filtration.

On a much larger scale, Peteet has seen how climate can lead to ecosystem changes that can either mitigate or exacerbate global warming. As much as two-thirds of terrestrial carbon is stored in soils, but in the past, warmer and drier conditions have resulted in less carbon being stored away, particularly in marshes and other wetlands, while the relatively cooler, wetter conditions of today permit more carbon to be sequestered. "The question is whether it will stay there and whether the current rate of sequestration can continue," she said.

Trapping Carbon

One of the most troubling aspects of carbon dioxide is how long it remains in the atmosphere. With an average residence time of 500 years, the carbon dioxide emitted today will continue warming the planet for generations to come.

About half of atmospheric carbon dioxide is converted into organic carbon that is taken up by Earth's primary natural carbon sinks—vegetation and the oceans. A group of Lamont-Doherty geochemists and geophysicists are working on the sequestration of carbon in another location—hundreds of feet beneath the ground. Juerg Matter and colleagues are participating in a multinational project in Iceland to study the potential of the nation's vast basalt formations to store carbon. Carbon dioxide injected into the porous basalt reacts chemically with the rock to form solid calcium carbonate and remains safely locked away. In 2009, the team plans to begin a test to inject 30,000 tons of carbon dioxide over six to nine months. Other locations being studied by Lamont-Doherty researchers include geologic formations in Wyoming and Oman and beneath the ocean floor off the Canadian Pacific coast.

"In many ways, the issues of sustainable development and climate change are energy problems," said Matter. "Certainly, we need renewable energy sources, but those need time to scale up. Carbon sequestration offers us a bridge to the future so we can provide energy and food to nine billion people without harming the planet."

In many ways, the issues of sustainable development and climate change are energy problems.

DEEP-SEA SAMPLE REPOSITORY IS LIBRARY OF EARTH HISTORY

NOT LONG AFTER LAMONT WAS CREATED, THE DICTUM CAME DOWN FROM ITS FOUNDER Maurice Ewing: "a core a day." Wherever Lamont's ships traveled and no matter what researchers aboard were doing, he wanted them to collect at least one core of deep seafloor sediments that could contain clues to piece together the history of our planet.

Today, the Lamont-Doherty Deep-Sea Sample Repository holds the largest and most diverse archive of cores anywhere—nearly 19,000 cores from more than 12,000 sites, totaling nearly 75,000 meters (or 50 miles)—as well as more than 3,750 rock and sediment samples dredged from the seafloor. New cores are added every year and have been used by researchers at Lamont-Doherty and around the world to yield exciting new knowledge about ocean currents, marine life, volcanic eruptions, climate changes and many other aspects of our planet.

Lamont-Doherty paleoceanographer Peter deMenocal, for example, collected cores off the west coast of Africa to test a hypothesis that North Africa's climate shifted abruptly about 5,000 years ago, turning a once wet and vegetated landscape into the Sahara Desert. By analyzing geochemical clues in deep-sea cores, deMenocal and colleagues showed that the modern Sahara Desert region was home to numerous large lakes and abundant wetland fauna between 5,000 and 10,000 years ago. The new cores should eventually document variations in the African monsoon over the last 20,000 years and show whether monsoonal rainfall patterns shifted abruptly 5,000 years ago to establish the Sahara's modern hyperarid desert ecology.

In another unfolding research story, Dallas Abbott in Lamont's Marine Geology and Geophysics Division, is exploring a new theory that Earth may have been hit by large comets or asteroids much more frequently in its recent history than previously believed and that those impacts spawned mammoth tsunamis and major climate changes. She recently launched an ambitious program to investigate a vast number of new and old cores to look for evidence of impact craters on the ocean floor. Looking for such evidence in ocean sediments is like looking for needles in a haystack; many students are spending hours taking samples from the cores and searching for microscopic spherules of magnetite, glass and shocked quartz, which are created when asteroids crash into the ocean.

Today, in an effort to make the lab's holdings more widely available to the scientific community, information about many of the cores is available online through the System for Earth Sample Registration (SESAR), GeoMapApp and the National Geophysical Data Center (NGDC). In another ambitious initiative, researchers in the repository lab are analyzing layers of calcium carbonate in hundreds of previously unstudied cores that offer a quick and easy way to determine whether a particular core is likely to contain evidence that can answer scientists' specific questions. The goal is to create a "stratigraphic library" that will allow the research community to home in on the most promising material more quickly and continue Ewing's vision of unlocking more of Earth's secrets from the cores.

An ambitious program has been launched to investigate new and old cores for evidence of impact craters on the seafloor.

Rusty Lotti Bond [right] is curator of Lamont-Doherty's Deep-Sea Sample Repository, which archives nearly 19,000 seafloor sediment cores from more than 12,000 sites around the world [black dots in map at top of page].
Credit: Bruce Gilbert [portrait at right]



Scientists in the Biology and Paleo Environment Division reconstruct how Earth's life and climate have shifted in the past, assess today's environment, and help predict future changes.

Rosanne D'Arrigo
Associate Director,
Biology and Paleo Environment
Credit: Bruce Gilbert

Scientists in the Biology and Paleo Environment (B&PE) Division engage in wide-ranging investigations that greatly improve our understanding of the history and causes of changes in the climate, environment and life on Earth. B&PE researchers reach as far back as hundreds of millions of years ago to reveal natural events that changed the face of the planet and steered the evolution of life on it. Their investigations extend right to the present, when human activities such as agriculture, pollution and fossil fuel burning are having substantial impacts on land, rivers, estuaries, oceans, climate and ecosystems.

To reconstruct the past, B&PE scientists glean information from a variety of sources that preserve records of past environmental and climatic conditions. Ed Cook and other scientists in B&PE's Tree-Ring Laboratory use measurements of annual growth rings in trees in ancient forests across Asia to improve understanding of the ocean and atmospheric conditions that affect the Asian monsoon, whose rains affect the welfare of billions of people (see page 40). Paul Olsen, Dennis Kent and colleagues are examining rock formations, fossils, preserved spores and pollen, iridium deposits, and other evidence to explore one of the greatest mass extinctions in Earth's history (see page 9).

The Lamont-Doherty Deep-Sea Sample Repository, curated by Rusty Lotti, holds the largest and most diverse archive of deep-sea sediment cores on the globe, which are analyzed by scientists around the world for geochemical clues to past conditions. In recent years, for example, B&PE paleoceanographer Peter deMenocal and colleagues have studied cores extracted off the West African coast to learn about climate changes that may have created the Sahara Desert (see page 7).

B&PE scientist Dorothy Peteet and her students take cores from a different source—wetlands bordering the Hudson River. They analyze pollen, spores, and plant and animal macrofossils in them to reconstruct how the watershed changed in response to past environmental changes such as droughts and floods and, more recently, to land-use changes after the arrival of Europeans (see page 35). Meanwhile, B&PE biologists Andy Juhl, Ray Sambrotto and Greg O'Mullan monitor water quality in the Hudson River today, examining conditions and human activities that lead to an abundance of disease-causing microbes (see page 11).

In other studies of recent environmental changes, B&PE scientists such as Natalie Boelman and Kevin Griffin are using field surveys, lab experiments, remote sensing and bioacoustics (the recording and study of animal sounds) to learn about resistance to invasive species in Hawaii, to compare how environmental conditions in rural and urban regions in New York affect the abundance and distribution of trees, and to determine whether shrubs are increasing in the Alaskan tundra in response to climate change. Beate Liepert and Mike Previdi are exploring whether global warming may lead to changes in rainfall (see page 10).

Studies like these help provide a long-term context to help us tease apart the relative influences of human activities and natural processes on our planet. And that understanding helps us improve predictions of future changes.

Massive Volcanic Eruptions and the Rise of the Dinosaurs

For many years, Lamont-Doherty paleontologist Paul Olsen and colleagues have stalked ancient rock formations on both sides of the Atlantic Ocean and coaxed clues out of them to answer some of our planet's biggest mysteries: What caused the mass extinction of life on Earth at the Triassic-Jurassic (Tr-J) boundary about 200 million years ago and set the stage for dinosaurs to dominate? Was it related to extensive volcanic eruptions at roughly the same time? What caused such huge eruptions—an asteroid hitting Earth, perhaps, or the rifting of the supercontinent Pangea into what is now America, Europe and Africa?

The researchers explored the Central Atlantic Magmatic Province (CAMP), rock formations generated from a massive burst of eruptions that occurred sometime around the Tr-J boundary. The eruptions flooded magma over the Pangean landscape near the seams where it was rifting apart. CAMP spans roughly 11 million square kilometers and is one kilometer thick in Brazil, western Africa, Spain and France, and eastern North America.

Olsen and colleagues—including paleomagneticist Dennis Kent, geochemist Sidney Hemming and geologist Mark Anders at Lamont-Doherty; former Columbia graduate students Roy Schlische, Jessica Whiteside and Sarah Fowell; and Mohammed Et-Touhami of Université Mohamed Premier in Morocco—built on previous research dating cores drilled from the Newark Supergroup, rock formations that extend from North Carolina to Nova Scotia. Deposited in ancient lakebeds between 230 million and 199 million years ago, the rocks bookend the Tr-J boundary.

The researchers collected a wide range of evidence to unravel what exactly happened at the boundary. Fossils and footprints showed that a broad range of four-legged crocodile relatives became extinct and were supplanted relatively quickly by a rapidly evolving diversity of more birdlike, bipedal, big-handed reptiles—dinosaurs. Similarly, fossilized pollen and spores showed a spike in ferns at the Tr-J boundary, suggesting they quickly reclaimed a landscape laid barren by a catastrophe. The team also found a localized spike in a largely extraterrestrial element, iridium—a hint (but far from proof) that an asteroid may have struck the planet near the Tr-J boundary.

[top] Paleontologist Paul Olsen examines gray-blue rock strata in Morocco that formed around the Triassic-Jurassic boundary about 200 million years ago. The red layers are older rocks formed in the Triassic. The overlying yellow layers come from lava flows from giant eruptions that occurred sometime near the Tr-J boundary.
Credit: Mohammed Et-Touhami

[bottom] A natural cast of a footprint made by a Jurassic period prosauropod dinosaur. The fossil was found in Nova Scotia, Canada.
Credit: Paul Olsen

Will Global Warming Bring More Rainfall to Our Planet?

It stands to reason that a warming world could lead to more evaporation and more rainfall. How much more? A provocative study published in 2007 by Frank Wentz and colleagues at a research company called Remote Sensing Systems indicated that along with rising greenhouse gases and global temperatures, rainfall over the past two decades also increased—two to three times more than climate models predicted.

The finding raised concerns of a rainier future—but hold on, say Lamont-Doherty scientists Michael Previdi and Beate Liepert. Another factor—aerosol levels in the atmosphere—played a key role in changing global rainfall during the past two decades, they say, and must be included in any predictions for the 21st century. One of the main ways that Earth's surface cools itself is by evaporating water and transferring it to the atmosphere. The water condenses to form clouds and then rain; the process releases heat into the atmosphere that radiates back out to space.

Most climate models indicate that global precipitation increases about 1 to 3 percent per degree Celsius of warming. But Wentz et al. showed that precipitation increased by 7 percent per degree Celsius between 1987 and 2006, suggesting the models may not be reliable.

Previdi and Liepert analyzed the finding in a larger context and, in a study published in May 2008 in the journal *EOS*, they wrote: "We caution against using the observed precipitation response to global warming from 1987 to 2006 to infer longer-term changes."

[top] A sunphotometer on the roof of the Oceanography building measures different wavelengths of sunlight. The data allow scientists to determine levels of ozone, water vapor and particulate matter in the atmosphere. *Credit: Beate Liepert*

[bottom] Storm clouds form over the ocean. A rise in rainfall over the last 20 years may have been caused more by reductions in air pollution than by global warming, Lamont-Doherty researchers say.

Studying eight different climate models, the LDEO scientists found that although the models averaged 1.4 percent precipitation rises per degree Celsius, they also produced some 20-year periods in which precipitation increased by 7 percent. In other words, the models show that some decades can have considerably more or less rainfall. "A period of only 20 years"—including the most recent 20 years—"may not be representative of a longer-term response to warming," the researchers said.

The recent rapid increase in rainfall, Previdi and Liepert say, may be a response to a factor that has an impact similar to greenhouse gases in the atmosphere: aerosols. Besides greenhouse gases, fossil fuel burning also produces sulfate, soot, ash and other particles, collectively called aerosols. So do erupting volcanoes. Aerosols reduce the amount of sunlight reaching Earth's surface, a phenomenon called "global dimming"; this keeps Earth cooler, which, in turn, reduces evaporation and rainfall.

That's what happened between 1960 and 1990, Liepert has shown. Since then, however, the trend has reversed. Pollution controls have reduced aerosol emissions, and, after aerosols from the 1991 eruption of Mount Pinatubo began to settle, global aerosol levels started to decline. We switched into an era of "global brightening," in which more solar radiation reached Earth's surface. Adding sharp reductions in air pollution to continuously rising levels of greenhouse gases may explain the surprisingly large precipitation rise over the past 20 years, and future air pollution levels may influence future rainfall trends, Previdi and Liepert say.

Decreasing air pollution, in addition to rising levels of greenhouse gases, may explain the increase in global rainfall over the past 20 years.

Lamont and Riverkeeper Partner to Keep Track of Hudson River Water Quality

The 1972 federal Clean Water Act mandated one of the clearest benchmarks for waters used by the public: "fishable and swimmable." But assessing water quality isn't so clear-cut.

Take the Hudson River, for example. Each year millions of people spend time in and on the river, but officials still cannot definitively answer whether, where or when the river is safe for swimming, boating and fishing.

To make inroads on this dilemma and help devise better management policies, Lamont-Doherty scientists Gregory O'Mullan, Andrew Juhl and Raymond Sambrotto launched a novel partnership in 2006 with Riverkeeper, the independent watch group "for the health and protection of the Hudson River." On cruises aboard Riverkeeper's patrol boat, the scientists collected monthly water samples for a year in 27 locations, from New York City to Peekskill. In 2008, funding from the Wallace Research Foundation allowed 40 testing locations to be added, extending the study above the confluence of the Mohawk and Hudson Rivers.

The Lamont/Riverkeeper project made the water quality data publicly available on Riverkeeper's Web site within days—in contrast to local, state and federal authorities, which often take months or years to report findings to the public.

The scientists measured salinity, oxygen, temperature, suspended sediment and chlorophyll in the water samples as well as *Enteroccocus*, a bacterium that is abundant in sewage and correlated with other human pathogens. Together, these measurements—collected over a span of time and river geography—painted a picture of ecological conditions in the river and helped identify when and why conditions turn unsafe.

Initial results showed that water quality in the Hudson has improved in recent decades, with long stretches largely free of sewage contamination during dry weather. But the river has received spikes of bacterial counts that exceeded standards for safe swimming—specifically, near shorelines and after heavy rainfalls, when aging street drainage and sewage systems send overflow into the river.

Of the 27 locations sampled, 21 experienced at least one single-day measurement indicating increased risk of illness from swimming in or having direct contact with river water on that day. Even at sites where conditions were generally acceptable, poor water quality existed on individual days, particularly after heavy rains, and high pathogen levels lingered for several days afterward. The data also showed that certain areas—Piermont Pier and Newtown Creek in Brooklyn, for example—chronically experience poor water quality.

Greg O'Mullan processes a river water sample with Lamont-Doherty summer intern Liz Suter. *Credit: Kevin Krajick*

The study spotlighted several ways for environmental and health agencies to improve water quality monitoring and policies to protect the public. Among the report's recommendations:

- Develop a uniform water quality testing system for the entire Hudson River Estuary not based on political boundaries.
- Increase testing after heavy rainstorms and at targeted problem locations.
- Develop testing protocols that can capture short-term and extreme events and localized problems, instead of protocols based merely on averages.
- Require municipalities to provide timely and location-specific monitoring results and develop better public notification systems.

The new Gary C. Comer Geochemistry Building is a dream facility for researchers probing fundamental processes occurring on our planet.

Bob Anderson
Associate Director, Geochemistry
Credit: Bruce Gilbert

Perhaps the most significant event for the Geochemistry Division during the past two years was the completion of the Gary C. Comer Geochemistry Building in 2007. The ribbon cutting took place on November 30, and we began moving offices from the old building the following April. The building currently houses 104 scientists, students and staff and provides world-class facilities for us to conduct our wide-ranging research, much of which focuses on areas that directly relate to sustaining our planet and human societies around the world. These include:

- ***Solid earth dynamics; structure and composition of Earth's crust and mantle.*** A variety of chemicals and isotopes in crustal material as well as materials synthesized in the laboratory at conditions found deep within Earth reveal information about the structure and composition of the mantle and the exchange of material between the planet's core, mantle and crust.
- ***Past and current climate, particularly the ocean's role in Earth's climate.*** Measurements of a variety of stable radioisotopes preserved in ocean sediments can be used to obtain climate records that extend back millions of years (see page 14).
- ***Modern ocean circulation and mixing.*** Anthropogenic tracers such as tritium, carbon-14, chlorofluorocarbons (CFCs) and sulfur hexafluoride (SF_6) enter the ocean from the atmosphere and are carried down into the deep ocean, tracing the pathways of heat transport and the ocean's uptake of gases such as carbon dioxide.
- ***Carbon dioxide in the atmosphere and ocean.*** Exchange of carbon dioxide between the surface ocean and the atmosphere is a primary mechanism controlling the carbon dioxide concentration in the atmosphere, where it is the primary gas responsible for global warming (see pages 4 and 15).
- ***Pollution of air, water and sediments.*** Lamont-Doherty geochemists are investigating a number of serious pollution problems, including particulate matter in urban air, arsenic contamination of groundwater (see page 13) and toxins adsorbed to Hudson River sediments.
- ***Mitigation of global warming by carbon sequestration.*** Efforts to inject carbon dioxide into fractured basalt aquifers, where the carbon dioxide would react chemically with the basalt and be stored permanently underground, are moving forward in several locations around the world with help from Lamont-Doherty geochemists (see page 6).

Our research requires many different analytical techniques, especially mass spectrometry, which provides very precise measurements of isotopic ratios for many elements. The Comer Building has four state-of-the-art laboratories that will eventually house eight to ten mass spectrometers and nine chemistry labs for sample preparation. This superb facility enabled a group of Lamont-Doherty geochemists to obtain funding from the National Science Foundation for three new mass spectrometers.

The second most common analytical tool is the gas chromatograph, which measures CFCs, SF_6 and various organic pollutants. The new building houses two laboratories for these instruments as well as laboratories for high-pressure presses that simulate conditions deep within the planet, coulometers for measuring carbon dioxide in water, and an X-ray probe for a variety of elemental analyses. All the labs also have state-of-the-art temperature control and advanced air-handling systems, making the Comer building a dream facility for researchers probing the fundamental nature of our planet.

Going With the Flow

Arsenic is one of the most insidious and debilitating naturally occurring poisons in the world. It is known to cause a variety of cancers, heart disease, kidney disease, diabetes and reduced IQ in children. In South Asia alone, as many as 100 million people are exposed to high levels of arsenic in the water they cook with and drink every day.

The severity of arsenic poisoning around the world underscores the need to understand what causes the element to occur in places like Bangladesh, where an estimated 50 million people are exposed to arsenic levels that exceed World Health Organization limits. Large-scale surveys in Bangladesh have shown that elevated arsenic concentrations are primarily limited to the upper 300 feet of many aquifers and are distributed in a seemingly patchwork pattern among locations without high arsenic levels. In a study published in 2007, Lamont-Doherty geochemist and Barnard College professor Martin Stute, along with colleagues in the United States and Bangladesh, revealed significant new clues that explain this pattern of contamination and counter prevailing theories.

The patchwork of contamination originally led scientists to believe that the geology of the region, which is known to be similarly variable, along with the geochemical properties of the sediments and the groundwater in aquifers determined where arsenic was released into surrounding aquifers.

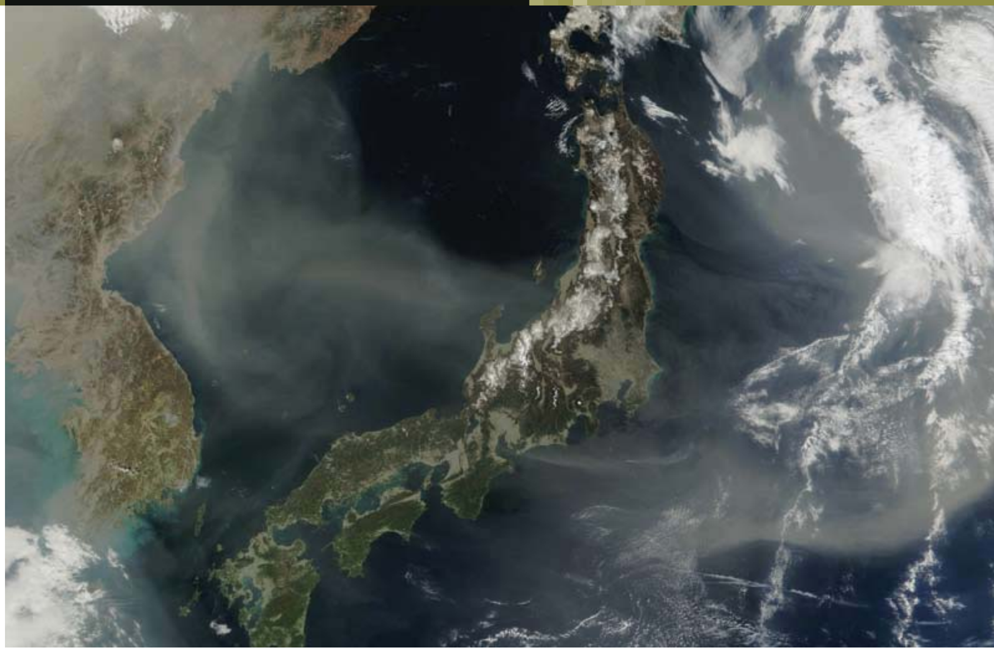
Stute, together with Lamont-Doherty researchers Yan Zheng, Peter Schlosser, Allen Horneman, Ratan Dhar, Saugata Datta and Alexander van Geen, employed a technique known as tritium-helium dating, which allowed them to determine how much time had passed since a groundwater sample entered an aquifer. They found that arsenic levels were lower wherever groundwater was "younger"—essentially wherever water was able to recharge an aquifer more frequently. As a result, they concluded that, rather than being the result of variable geology, lower arsenic levels occurred because arsenic did not have a lot of time to accumulate in the water as it flowed through or because arsenic had been flushed out of the aquifer.

Moreover, their findings contradict the commonly held belief that the rapid rise in irrigation-fed agriculture has contributed to the problem by drawing high-arsenic water (or water high in organic matter that could draw arsenic from the sediments) into previously uncontaminated aquifers. Instead, the results show just the opposite, that water in the aquifers from the 1970s, before the increase in irrigation, contains consistently more arsenic than water that entered the aquifer more recently.

"If pumping was to blame, we'd expect to see more contamination of younger water," said Stute. "Instead of linking arsenic contamination to specific geologic or geochemical factors or to human activity, it means we need to look more carefully at how and where water flows beneath the surface."

[top] Gary C. Comer Geochemistry Building
Credit: Bruce Gilbert

[left] Martin Stute in the field in Bangladesh
Credit: Courtesy of Martin Stute



Dust clouds move from China across Korea and Japan to the Pacific Ocean.
Credit: Jacques Descloitres, MODIS Land Rapid Response Team, NASA/GSFC

Dust in the Wind

Each year, long-distance winds transport as much as 900 million tons of dust from Earth's landmasses and drop it into the oceans. Scientists have known this phenomenon connects to global climate, but exactly how has remained an open question. In 2008, a group of geochemists fit a big piece of the puzzle into place by showing that the amount of dust entering the equatorial Pacific peaks sharply during ice ages, then declines when the climate warms.

Lamont-Doherty geochemists Gisela Winckler, Bob Anderson, Martin Fleisher and David McGee, along with Natalie Mahowald from Cornell University, carried out the research. Their conclusions, published in the journal *Science*, cement the theory that atmospheric moisture, and thus dust, move in close step with temperature on a global scale, a finding that will be incorporated into and improve global climate models. In the past decade, scientists have identified layers of dust in ice cores from Greenland and Antarctica and in sediment cores from the Atlantic and Indian Oceans that coincide with cold, dry periods in Earth's climate. Records from the Pacific, however, have been inconclusive.

The researchers studied cores of seafloor sediment representing 500,000 years of deposition from sites spanning 6,000 miles of the Pacific equator—nearly a quarter of the globe's circumference. In each core, they found the same thing: At the height of each of five known ice ages, accumulation of the isotope thorium-232, a tracer for terrestrial dust, shot up 2.5 times over the level of warmer "interglacial" periods. The peaks appear about every 100,000 years, with the last one appearing 20,000 years ago—the culmination of the last glacial age.

Through other isotopes, the scientists traced the dust in the western Pacific to Asia and in the eastern Pacific to South America. The reasons for the lockstep peaks are probably complex; but, the scientists said, colder air generally holds less moisture than warmer air, and cold periods tend to be windier. Some dust transported at high altitudes would have reflected sunlight, thus reducing the solar radiation reaching the planet's surface and making the climate even colder.

With this study, all the records have been shown to tell the same story. Moreover, because changes in the atmosphere over the Pacific and the tropics in general are known to affect huge areas of the world, the work also highlights a stark connection between atmospheric dust and human welfare. "It suggests that the whole world's hydrologic cycle varies in unison, on a pretty rapid time scale," said Winckler, lead author of the paper.

The Air We Breathe

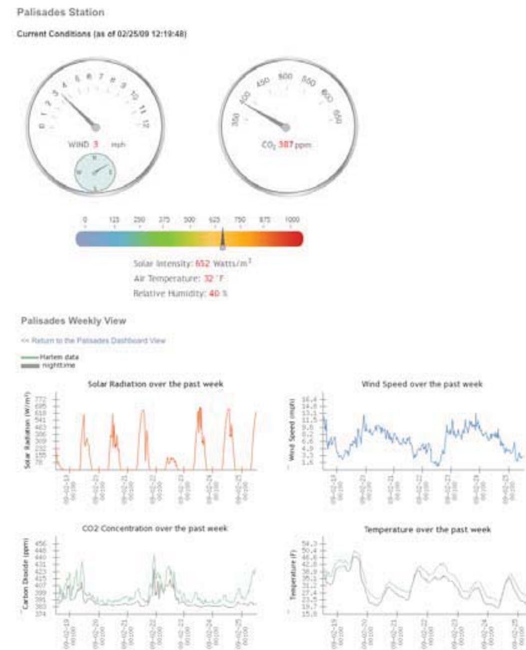
Carbon dioxide, it seems, is on everyone's mind these days, but few people actually know how much CO_2 is in the air they breathe or how and why the amount differs from place to place. A new monitoring network, spearheaded by Lamont-Doherty geochemist Wade McGillis, aims to raise awareness among residents of the New York City metropolitan area of their local CO_2 levels and, at the same time, help researchers better understand the basic physics, biology and chemistry of carbon dioxide in the environment.

The Lamont Atmospheric Carbon Observation Project (LACOP) grew out of an environmental engineering class McGillis taught, during which he tried to impress on his students the need for more extensive urban environmental monitoring to support better, more sustainable decisions and designs. McGillis and his students installed the first monitoring site at the Future Leaders Institute Elementary School in Harlem to measure a combination of meteorological and environmental data, including carbon dioxide. Currently, there are six stations that extend from Harlem to the eastern end of Long Island to Ashokan, New York, 100 miles north of the city.

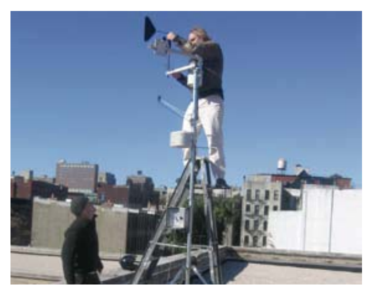
The monitoring stations have produced the first detailed measurements of carbon dioxide levels in Manhattan and surrounding rural areas showing that the city's elevated carbon levels extend out at least 20 miles, although the magnitude of the city's reach is not as bad as most U.S. urban areas. This is likely because the Atlantic Ocean produces winds almost daily that help flush carbon dioxide out of the city, McGillis said. In addition, the researchers found that forested rural areas in upstate New York and northern New Jersey provide the city with a constant stream of low-carbon air.

During daylight hours, trees take carbon dioxide out of the air and use it for photosynthesis. At night, however, trees actually emit carbon dioxide, as they burn stored sugars to keep their systems running in the absence of light. Carbon dioxide levels in the air in rural environments clearly show this daily cycle. Manhattan's carbon dioxide levels follow a similar but more subtle daily pattern, with a time lag showing that wind from adjacent rural environments is a significant factor in cleaning Manhattan air.

"While New York is one of the most carbon-neutral cities in America, we still can and should strive to do better," said McGillis. "One thing we can do is ensure that we keep the forests outside of Manhattan in good condition and keep what trees we have here safe and healthy, while also encouraging developers to add trees to their designs." Real-time carbon dioxide levels and historic trends are available from the LACOP network at www.ldeo.columbia.edu/outr/LACOP.



The instrument display on Wade McGillis' motorcycle inspired his design for the current conditions diagrams on the LACOP Web site [above, top]. Visitors to the site can also view historical data for each of the stations [above, bottom].



Wade McGillis and John Bent install a weather station with a CO_2 monitor on top of the Future Leaders Institute Elementary School in Harlem.
Credit: Future Leaders Institute

Our goal is to learn about how the planet in its entirety works—and how humans can live more sustainably on it.

Roger Buck
Associate Director,
Marine Geology and
Geophysics Division
Credit: Bruce Gilbert

The ocean basins are among some of the most remote places on Earth. They also happen to be the best places to study many of the fundamental processes changing the face of our planet. That is why scientists in the Marine Geology and Geophysics (MG&G) Division spend so much time plumbing the depths, so to speak, for answers to some basic geologic questions. But because our goal is to learn about how the planet in its entirety works—and how humans can live more sustainably on it—many of us also collect or analyze data from considerably dryer places. In some cases, we are able to do this because techniques developed to collect or analyze marine data can be applied to terrestrial-based questions.

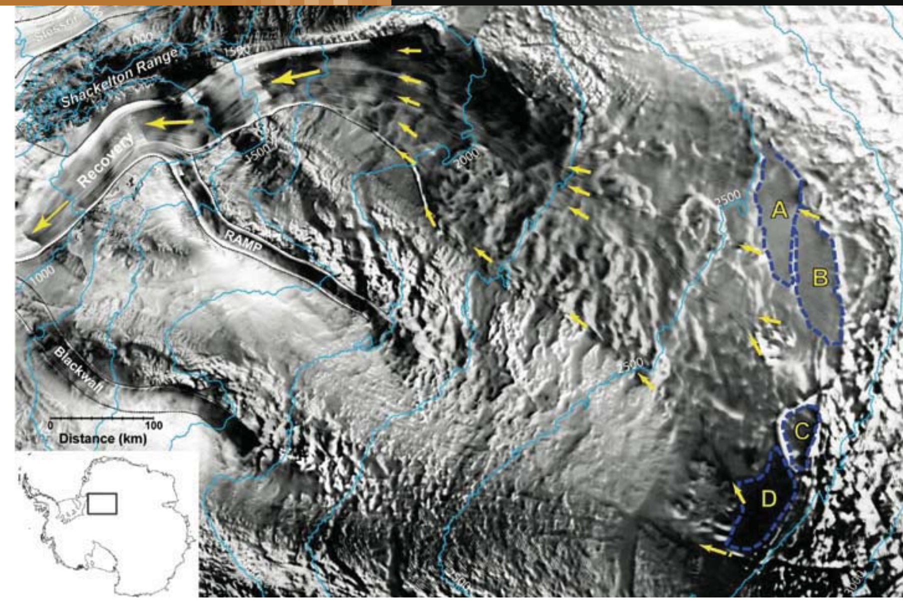
There are many examples of projects that have in some way "spun off" marine geological research, several of which came to completion or showed significant gains over the past two fiscal years. The challenge of measuring fine-scale variations in gravity from a moving, rolling ship to study the seafloor has recently been applied to making measurements from airplanes that "see" through polar ice to the bedrock (see page 17). Likewise, experience gained from shipboard studies of how island loads bend the seafloor is allowing Michael Steckler and Chris Small to study the strength of Earth's continental crust using the more subtle loads put on land by monsoon floods. Another case that crosses the shoreline is Dallas Abbott's work to look for evidence of impact craters on the seafloor—work that recently turned her attention to land to look for deposits laid down by the tsunamis that would result from such impacts.

In keeping with our history (and our name), however, many of the largest projects involving MG&G scientists focus on marine work. One such effort is to study the processes of magma movement, partly because most magma flows out of Earth's interior at submarine spreading centers. The ocean-bottom seismometer array deployed by Maya Tolstoy and seismologist Felix Waldhauser on the East Pacific Rise (EPR) captured the seismic pattern leading up to a major eruption in January 2006. Earlier data from the EPR showed that the system of water circulating through the crust at mid-ocean ridges is much different than previously believed (see page 19).

Other ongoing programs with significant MG&G leadership include the Integrated Ocean Drilling Program, where MG&G researchers, including Gerry Iturrino, Mary Reagan and Dave Goldberg, are helping supervise the reconstruction of the deep-ocean drilling vessel *JOIDES Resolution*. Suzanne Carbotte, Kerstin Lehnert, Dan Quoidbach and Bill Ryan are also leading a national effort to collect, store and make useable decades of priceless data collected by marine scientists from around the world; they recently succeeded in linking it to the free, Java-based Internet application GeoMapApp.

In all, MG&G efforts on land and at sea are helping deepen our understanding of this remarkable planet that we share.

Magnetometers and gravimeters—instruments more commonly used to study the seafloor from ships—together with ice-penetrating radar and laser altimeters are being used by Michael Studinger and Robin Bell to peer beneath miles of ice from an airplane [shown above Greenland].
Credit: Michael Studinger



In their 2007 *Nature* paper, Bell and Studinger combined satellite images to reveal the Recovery Ice Stream [arrows] and location of four new subglacial lakes [A, B, C and D] that lie at the head of the stream.
Credit: Chris Shuman and Vijay Suchdeo, NASA

Getting to the Bottom of Things

The featureless expanses of the ice sheets on Greenland and Antarctica belie a surprisingly complex world hidden deep beneath the surface—a world that may have a direct bearing on how much or how quickly sea level rises due to global warming. There's only one problem with studying the bottom of an ice sheet: It's covered with ice.

Lamont-Doherty geophysicists Michael Studinger and Robin Bell are working to peel back that layer of ice, so to speak, a layer that can be as much as two miles thick. In 2006, the two MG&G geophysicists received nearly $2 million from the National Science Foundation to deploy an airborne sensor array capable of revealing the bedrock beneath the ice. Nick Fearson, an engineer on sabbatical from the British Antarctic Survey, helped design and build the system. In June 2008, the team traveled to Greenland for the first tests of the sensor array in conditions similar to those they expect to encounter in Antarctica.

In 2007, Bell and Studinger reported in the journal *Nature* that meltwater lakes deep beneath the Antarctic ice sheet appear to contribute to the movement of ice at the surface. They made the discovery by examining satellite radar images and high-resolution laser altimeter profiles of a region in East Antarctica, where both ice streams and surface features indicated the presence of subglacial lakes. Not only did they find four new lakes beneath the ice sheet, but they also discovered that the lakes coincide with the origin of tributaries of the massive Recovery Glacier. Bell and Studinger concluded that the lakes provide a reservoir of water that lubricates the bed of the sheet and facilitates the flow of some 35 billion tons of ice into the Weddell Sea each year. In a warming climate, increased meltwater could accelerate the entire continent's flow of ice to the surrounding ocean and, consequently, increase the pace of sea level rise.

With their new airborne sensors, which include a gravimeter, ice-penetrating radar, laser topography scanner and two magnetometers, Studinger, Bell and Fearson expect to be able to map surface and subsurface features such as these in greater detail than ever possible. In the process, they intend to explore the last unexplored mountain range on Earth—Antarctica's Gamburtsev Range. The mountains are estimated to be as large as the European Alps, but because they are entirely covered by snow and ice, they were only discovered during the 1957–1958 International Geophysical Year. The expedition to return to the mountains, which are believed to be the birthplace of the Antarctic ice sheet, is a flagship project of the International Polar Year.

The Gamburtsev Mountains are estimated to be as large as the European Alps, but because they are entirely covered by snow and ice, they have never been explored.

Beneath the Marmara Sea

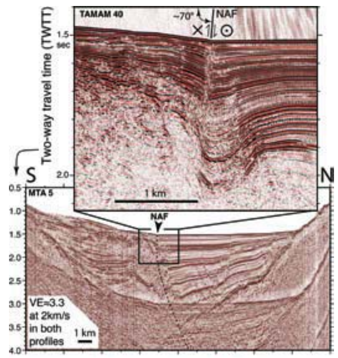
In 1999, two earthquakes, one with a magnitude of 7.4, ruptured a 100-mile segment of the North Anatolian continental transform fault (NAF). The event devastated the Turkish town of Izmit, caused extensive damage to nearby Istanbul, and killed more than 15,000 people. It was the first major earthquake along the fault segment in nearly two centuries and underscored the risk faced by Istanbul and its 11 million residents.

In 2008, MG&G geophysicist Michael Steckler, together with Lamont-Doherty colleagues Leonardo Seeber, John Diebold and Donna Shillington and researchers from the United States and Turkey, created the first high-resolution, multichannel seismic images of the NAF beneath the Marmara Sea, a necessary first step in efforts to clarify the seismic hazard posed by the fault. The NAF marks the 1,000-mile boundary between the westward-moving Anatolian tectonic platelet and the much larger Eurasian Plate. The plates' movement relative to one another results in repeated, large earthquakes every few decades. The section of the fault beneath the Marmara Sea, however, has been largely silent, and presumably accumulating strain, for nearly three centuries. But without an accurate picture of the fault and its many branches, scientists are uncertain how much of the strain is borne by the NAF's main segment or by nearby faults beneath the Marmara Sea.

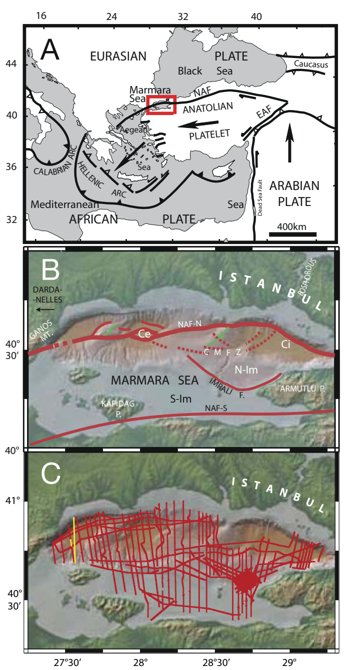
Understanding how this strain is distributed is critical for estimating how large an earthquake is expected and where it might be located. Fortunately, sediments deposited on the floor of the Marmara Sea display patterns that indicate changes to the shape of the ocean basin caused by past seismic activity, much as tree rings record the conditions in which a tree grew.

For nearly three weeks, the research team crisscrossed the Marmara Sea gathering acoustic data from the Turkish research vessel *K. Piri Reis*. They then processed these data into the most detailed images to date of the sediment layers as much as two miles beneath the seafloor. As with tree rings, however, scientists also need markers to assign ages to sediment layers. Fortunately, Steckler and his colleagues discovered in their images the remains of several old deltas and other features buried beneath the seafloor that, they concluded, were formed as water levels in the sea fell during the last several ice ages. Because the timing of the ice ages is well known, the features can be used to date nearby layers.

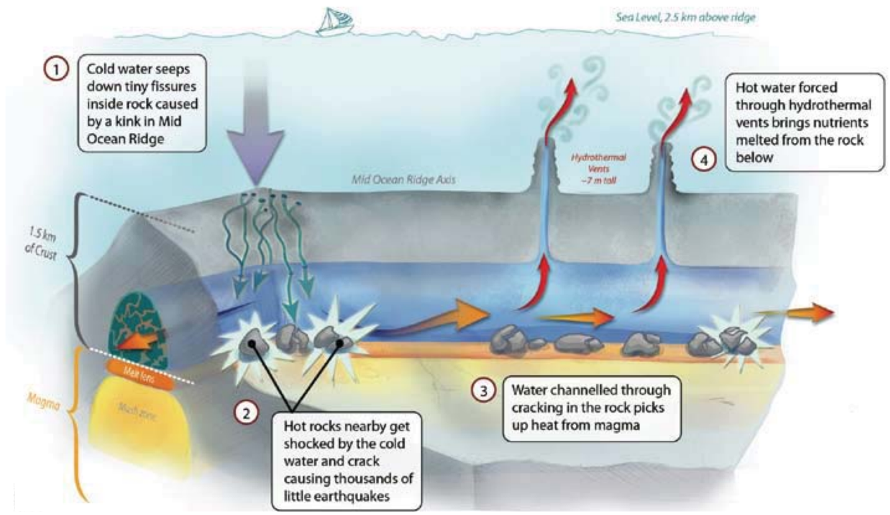
Steckler hopes he and others can now begin to piece together the complex tectonics of the NAF and its branches beneath the Marmara Sea. Only then will they be able to reveal the history—and possibly future—of Istanbul and the region.



[top right] High-resolution seismic images recorded by Steckler and colleagues clearly show the NAF running through sediments beneath the Marmara Sea, a marked improvement over earlier, low-resolution imagery. *Credit: Steckler et al.*



[near right] The Marmara Sea [box in A] is situated along the North Anatolian continental transform fault (NAF), where the Anatolian platelet meets the Eurasian Plate. The bottom of the sea is marked by several major faults and other features [B] that Michael Steckler and his colleagues explored on the R/V *K. Piri Reis* [C]. *Credit: Steckler et al.*



Plumbing the Earth's Plumbing

Zigzagging more than 35,000 miles across ocean floors, a system of mid-ocean ridges is Earth's single largest topographic feature. Scattered along the ridges are places where ocean water circulates down into the crust and back to the seafloor. These hydrothermal vent systems play a crucial role in the movement of tectonic plates, in the transfer of heat from the interior of the planet, and in regulating the chemistry of the oceans and atmosphere. Unique life forms also feed off the chemical-laden fluids emitted from the vents, and valuable minerals often accumulate nearby.

Despite the importance of hydrothermal circulation to the planet's inner—and outer—workings, it was not until the late 1970s that scientists discovered the existence of these vast, planet-girdling plumbing systems. In January 2008, a group of Lamont-Doherty researchers examined the East Pacific Rise (EPR), 565 miles southwest of Acapulco, Mexico, and created the first images of one of these systems—and it does not look the way most scientists had assumed.

The prevailing wisdom held that water was forced down through large faults and cracks along the sides of a ridge. That water would then be heated by a shallow magma chamber and rise toward the middle of the ridge where vents (often called "black smokers" for the clouds of particulate-filled fluids they exude) are often found in clusters. The new data, however, showed the water takes a very different path.

Using new techniques developed by Lamont-Doherty seismologist Felix Waldhauser, Tolstoy and her colleagues located more than 7,000 small earthquakes with great precision and found the quakes clustered neatly around zones of down-flowing cold ocean water that were located on the axis, rather than the sides, of the ridge.

They were also able to trace the water straight down through the ridge where it fanned out into a horizontal band before bottoming out at depths approaching one mile, just above the magma. The heated water then appeared to rise back up through a series of vents further along the ridge.

The researchers interpreted the small quakes to be caused by cold water passing through hot rocks, a process that shrinks and cracks the rocks and creates the small quakes. Tolstoy and her co-authors also believe the water travels, not through large faults in the rock as in the model previously favored by some scientists, but through systems of tiny cracks. Furthermore, their calculations suggest that the water moves faster than previously thought and that as much as one billion gallons pass through this part of the EPR each year.

[top] Artist's conception of a hydrothermal system beneath the seafloor *Credit: National Science Foundation*

[bottom] Water that descends through the seafloor re-emerges at hydrothermal vents—sometimes known as black smokers for the dark, super-heated, chemical-rich fluids that billow out. *Credit: Woods Hole Oceanographic Institution*

There's growing urgency to better predict how climate changes are going to play out and growing debate on what actions to take to mitigate the impacts of change.

Arnold L. Gordon
Professor of Earth and Environmental Sciences, Associate Director, Ocean and Climate Physics Division
Credit: Bruce Gilbert

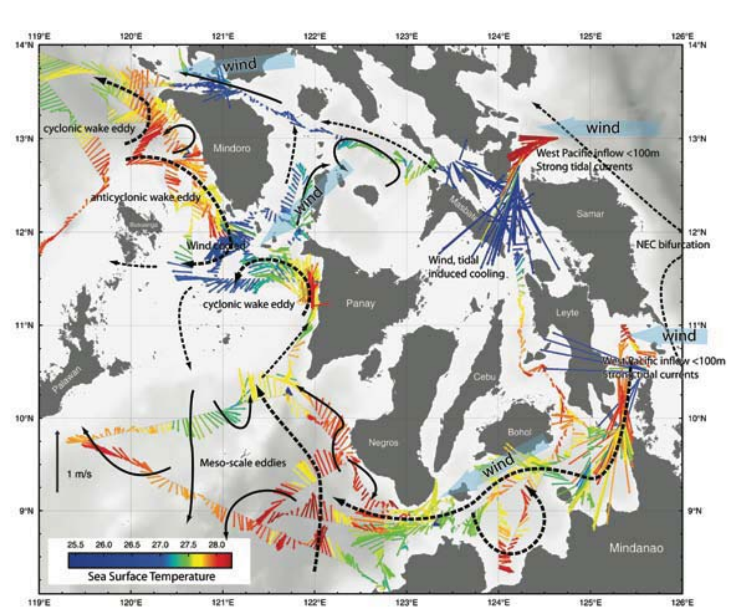
Earth's air and water, so familiar to humans, provide an amiable climate and make possible the terrestrial and marine ecosystems on which we depend. Now environmental changes influenced by human activities are becoming increasingly apparent. Arctic sea ice is dramatically reduced in summer; alpine glaciers are melting; the ice sheets of Greenland and Antarctica are changing; the oceans are slowly acidifying, threatening corals and other marine life critical to the food web; extreme droughts and floods are disrupting food supplies and displacing populations; tropical storms are becoming more frequent and severe; and sea levels are rising, threatening to inundate coastal areas. There's a growing urgency to better predict how these changes are going to play out: How rapidly, gradually or abruptly will they happen? And there is a growing debate on what actions to take to mitigate the impacts of change.

Scientists in the Ocean and Climate Physics (OCP) Division strive to understand the forces driving our climate. They investigate patterns of climate change that occur over time and across geography, using data obtained over the past 160 years or so by meteorological and oceanographic instruments and, more recently, by Earth-orbiting satellites. They employ reconstructions of past climate gleaned with information from cores of deep-sea sediments and glacial ice and from the growth rings of trees and corals.

OCP oceanographers also undertake seagoing expeditions to explore the ocean's role in the climate system, examining the processes that govern how heat, fresh water and gases (including greenhouse gases such as carbon dioxide) are stored and transported across the ocean, mixed into deeper layers, and exchanged between air and sea. Expeditions range from local estuaries and coastal waters to the broad sweep of the tropical ocean. Two recent expeditions focused on dramatic warming in the frozen sea off western Antarctica and taking critical measurements of ocean circulation through the balmy seas of Southeast Asia (see pages 21 and 22).

OCP climate modelers use both direct observations and past climate records to test and improve their climate-simulation models, often finding that small phenomena can have large-scale repercussions. Understanding the natural variability of Earth's climate is complicated enough; but now, more than ever, humankind is superimposing additional, powerful stresses on our planet's delicately balanced climate system. Efforts to distinguish the various forces acting on our climate—such as a project highlighted on page 24—will help develop more reliable predictions of global and regional climate change, which we will need as we plan strategies to adapt to change.

Scientists in the Ocean and Climate Physics Division strive to understand the forces driving our climate.



The Philippine Islands create a maze of seas and passages that add complexity to small-scale ocean circulation. Dashed black arrows show general flow patterns, but the color-coded vectors expose complicated swirls of ocean flow. Blue arrows indicate places where strong winds funneled between mountainous islands probably cool sea surface waters and set up strong wakes and eddies. Cool surface water in the passages to the western Pacific Ocean, both north and south of Samar Island, are likely the result of mixing by tidal currents.
Credit: Arnold L. Gordon

Exploring Exotic Seas

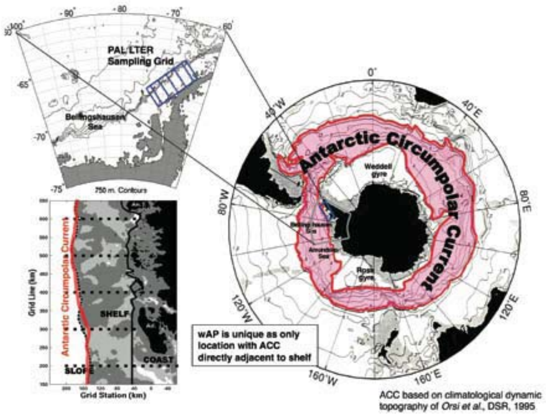
The oceans flow like a vast watery highway, circulating heat and water around the planet and interacting with the atmosphere to create our global climate and regional temperatures and rainfall patterns. Unlike the globally enveloping atmosphere, however, the world ocean is segmented by continents with passages between them.

In 2006, Lamont-Doherty physical oceanographer Arnold L. Gordon and researchers Dwi Susanto and Amy Ffield completed a landmark three-year project with scientists from five nations to measure the flow between the Pacific and Indian Oceans—through a complicated maze of islands, narrow passages and seas (with exotic names such as Java and Sunda) that stretches 2,500 miles from Southeast Asia to Australia.

How heat and water are exchanged through this crucial bottleneck, known as the Indonesian Throughflow (ITF), plays a big role in two oscillating patterns of winds and water temperatures that have big impacts on climate: the well-known El Niño–Southern Oscillation and the similar, but lesser known, Indian Ocean Dipole. Both of these, in turn, influence the strength of the Asian monsoons, which govern the rainfall that waters crops or causes droughts and floods that affect billions of people.

For the first time, the scientists simultaneously measured the flows through all the principal ITF pathways—from the Pacific into the Makassar Strait and Lifamatola Passage and out to the Indian Ocean through the Ombai and Lombok Straits and Timor Passage. Previously, these major corridors had been monitored in different years and over varying lengths of time, making it impossible to assemble a reliable, complete picture of the ITF inter-ocean exchange. In May 2008, several climate and ocean modeling groups convened at Lamont-Doherty to see how the new data could improve their models' ability to predict future ocean and climate changes.

In June 2007, Gordon launched another program, with U.S. and Philippine scientists, to unravel the forces that govern how water flows through another complex network of seas and straits around the Philippine Islands. This time, the focus is to determine what happens over tens and hundreds rather than thousands of miles, and over days and seasons rather than years and decades. On such scales, winds, tides and seafloor topography as small as coral reefs take on larger roles, creating oceanographic phenomena useful to know to clean up oil spills, manage fishing and ecosystems, and for search-and-rescue missions and naval operations.



A Hotspot in a Cold Spot: West Antarctic Ice Is Melting

Call this one "The Mystery of the Melting Ice." Since the 1960s, the fastest-warming area on Earth during winter has been one of the coldest places on Earth—the western coast of the Antarctic Peninsula. In this region, which points like a mammoth ice-covered finger to the southern tip of South America, wintertime temperatures increased more than five times the global average. Before the 1970s, sea ice clogged the peninsula's coastline year-round; now the ice appears for an average of only four months in winter.

A whopping 87 percent of the peninsula's glaciers are now retreating, turning ice into water that raises global sea levels. The disappearing ice also has dramatic impacts on Adélie penguins whose lifestyles depend on it. In 1974, a colony on the peninsula included 15,200 breeding pairs of penguins; in 2007, there were only 3,500 pairs.

In Antarctic winters, with no sunlight or warm air masses, what could be warming up the region? The answer, says Lamont-Doherty physical oceanographer Douglas Martinson, is the ocean.

Since 1999, Martinson has been part of a project to examine the ecology off the western Antarctic Peninsula each summer. His contribution has been to measure ocean conditions that affect the peninsula's ecosystem by deploying moorings in 2007 and 2008—for the first time collecting oceanographic data in the region year-round. The evidence he and his team collected led to the Antarctic Circumpolar Current (ACC), the huge current that circulates uninterruptedly around the continent.

"The ACC is the world's Mixmaster of ocean water," Martinson said. The ACC transports water that contains enough heat to melt any ice it comes in contact with. "The heat contained in water one degree Celsius above freezing contains more than 4,000 times the amount of heat in the same volume and temperature of air," he said.

Around most of Antarctica's coastline, cold ocean gyres circulating near the coast act as buffers that keep the ACC offshore. But on the west side of the Antarctic Peninsula, the ACC's path takes it on a collision course with the coast.

In winter, storms striking the peninsula from the west drive surface waters offshore. To replace those waters, deeper, warmer waters—brought in by the ACC—are pulled right to the surface, where they flood over the continental shelf and vent heat into the atmosphere. "This effectively puts glacier ice into a warm bath," Martinson said. Since the 1990s, that warm bath has gotten stronger—mainly because winter storms (and winds) have grown stronger, bringing more warm ACC water up to the surface, but also because the ACC waters have become slightly warmer.

"The ACC is a freight train full of hot coals that it delivers right to the doorstep of the west Antarctic Peninsula and onto the ice shelf," Martinson said. This newly documented mechanism, he said, should be factored into estimates of how much and how fast this crucial area will respond to future climate changes.

With moorings deployed off the western coast of the Antarctic Peninsula [dotted lines in map at top], Doug Martinson and colleagues learned that the Antarctic Circumpolar Current was likely delivering warm water and heat that is melting glacial ice in the region [opposite page]. The disappearing ice has dramatic impacts on colonies of Adélie penguins [left] whose lifestyles depend on it.

A stunning 87 percent of glaciers on the western coast of the Antarctic Peninsula are retreating.
Credit: Jacques Descloitres, MODIS Land Rapid Response Team, NASA/GSFC

What Is Causing Climate Change—Nature or People?

Surface temperatures in the North Atlantic Ocean have increased sharply in recent years. This has raised concerns that human activities will spur more ocean warming, which in turn could change rainfall patterns, generate more frequent and more severe hurricanes, and diminish the Greenland ice sheet more rapidly.

Unfortunately, predicting future ocean and climate conditions is not straightforward. Recent ocean-monitoring instruments—as well as records of past climate extracted from tree rings and ice cores—have shown evidence that North Atlantic surface temperatures naturally fluctuate in warmer and cooler phases that last several decades—a phenomenon called the Atlantic Multidecadal Oscillation, or AMO.

Scientists have not been able to directly monitor the AMO long enough to understand its workings or predict its pattern. Moreover, because temperature changes caused by the AMO and by human activities are superimposed on each other, scientists have been debating the degree to which nature or people have caused recent ocean temperature changes and will influence future ones.

To help answer this question, Lamont-Doherty scientists Mingfang Ting, Yochanan Kushnir, Richard Seager and Cuihua Li undertook a study to deconstruct the records of North Atlantic surface temperatures over the 20th century into their human activity-related and natural components.

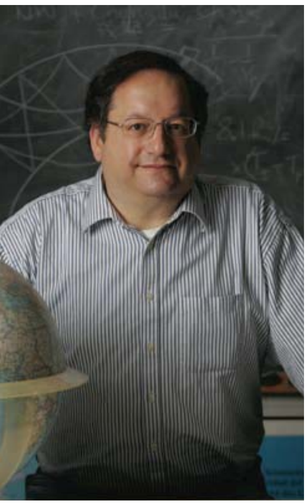
They used six different ocean and climate models—computer simulations that mathematically incorporate the myriad physical factors and processes that combine to generate ocean circulation and create our climate. Each computer simulation was integrated with real input from factors and forces that were clearly caused by humans, such as greenhouse gases and aerosols released into the atmosphere by human activities in the 20th century, but also allowed for the variability generated by natural causes.

They then averaged the results of multiple runs of each model and applied special statistical techniques to determine the best estimate of sea surface temperature changes caused by human influence. Subtracting that from the full, observed record, they extracted the variability in North Atlantic surface temperatures caused by natural oscillations.

The Lamont-Doherty team found that natural oscillations played more of a role in the early part of the century, particularly during the 1920s and 1930s, when a rapid warming in the North Atlantic Ocean led to an increase in Atlantic tropical storms and Greenland temperatures. In the 1960s, an ocean cooling, most likely due to natural causes, temporarily offset local impacts resulting from human-induced global warming and led to a temporary decrease in tropical Atlantic storms. This changed in the mid-1990s, when nature reversed direction and ocean temperatures began to warm again, thus enhancing human-induced warming.

The results show that natural variations could shape future climate change in and around the North Atlantic region, acting either to counter or accentuate human-caused warming. In future research, the team will explore whether such natural variations can be predicted.

The questions that drive us are not answered by individual tools, but by bringing together observations, theories and methods from diverse perspectives.



Art Lerner-Lam
Lamont-Doherty Senior Scientist, Associate Director, Seismology, Geology and Tectonophysics Division
Credit: Bruce Gilbert

Modern studies of the solid Earth demand integrated, multidisciplinary research. The questions that drive us are not answered by individual tools, but by bringing together observations, theories and methods from diverse perspectives. Indeed, over the past two years, researchers in the Seismology, Geology and Tectonophysics (SG&T) Division have demonstrated this outlook by developing new insights into the planet's dynamic processes that blend traditional seismology, geology and tectonics with petrology, fluid dynamics, mineral physics, rock mechanics and geodesy.

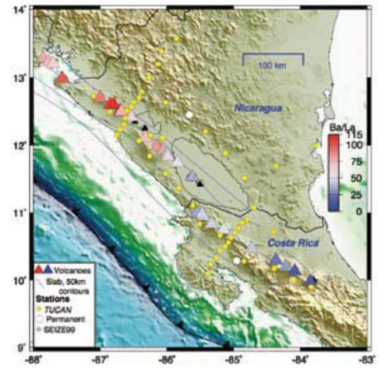
This is not a new mode of thinking in our division, where the enthusiasm and fresh perspective of a new group of students, post-docs and young and midcareer scientists are energizing collaborations with scientists across the other divisions. For example, the arrival of Geoffrey Abers early in 2008 also brought to Lamont-Doherty the National Science Foundation's MARGINS Office, which Abers heads. MARGINS provides support for interdisciplinary initiatives to study active and passive continental margins. Lamont-Doherty scientists participate in several MARGINS programs, including a major investigation of subduction zones (see page 25). In many ways, this is a continuation of the pioneering work done in the 1960s by Lamont seismologists, which showed the relationship between earthquakes and subduction during the early days of plate tectonics. The new programs, however, involve many more disciplines and perspectives.

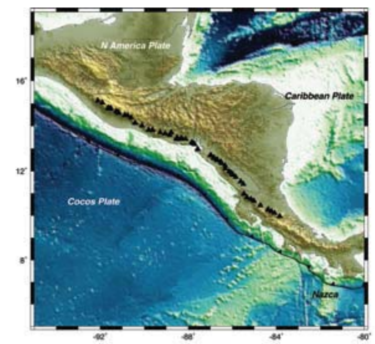
Seismology, geology and tectonophysics are also the cornerstones of geodynamics, providing structural constraints on the core, mantle and crust and on the energy released by earthquakes. Göran Ekström and Meredith Nettles, along with post-doc Vala Hjörleifsdóttir, continue to provide earthquake source characterizations through the Global Centroid Moment Tensor (GCMT) project (see page 27). The information the GCMT project generates has become the standard product used by many to do further studies, and their methods, as well as the hyper-accurate location techniques developed by Felix Waldhauser and David Schaff, are part of the tools used by agencies around the world to provide greater detail about seismic events as quickly as possible.

Seismology can only help describe mantle flow and plate dynamics if seismic observations can be accurately related to composition, temperature and mineral structure. Ben Holtzman is one who is combining experimental studies in rock mechanics, modeling and theoretical knowledge to derive relationships between seismological observation and geological and petrological features (see page 26). Work such as this is the glue that brings the disciplines together and gives us a window to dynamic aspects of the solid Earth.

Several notable personnel changes occurred over the last two years. Lynn Sykes and Paul Richards formally retired, though both continue path-breaking research. New research engineers David Gassier and Scott Pugsley joined Andrew Barclay in the Ocean Bottom Seismology Lab and are helping develop new instruments for *in situ* seafloor observations. We also welcomed new post-docs Collen Dalton, Po Chen, Vala Hjörleifsdóttir, Josh Calkins and Jeremy Zechar in addition to two new classes of talented graduate students.

[far right] University of Maine glaciologist Gordon Hamilton works on a seismic station in Greenland, part of Meredith Nettles' ongoing work to study the movement of glaciers in the region.
Credit: Meredith Nettles





Location of seismic monitoring stations in Nicaragua and Costa Rica [left, top] along the region known as the Central American Subduction Factory that Abers and his colleagues used to study why many of the world's most explosive volcanoes form in subduction zones [left, bottom]
Credit: Syracuse and Abers

Very little is known about the amount of water carried down by subducting crust, where or how it is released, and how it moves beneath the surface.

Subduction Zones

Continental margins, particularly subduction zones, are among the most physically dynamic places on Earth. Places where tectonic plates collide and one is forced beneath the other are often where hydrocarbon and metal resources form; where earthquakes, tsunamis, volcanoes and landslides are common; and where some of the world's largest population centers are found. It only makes sense they would be the focus of intense study.

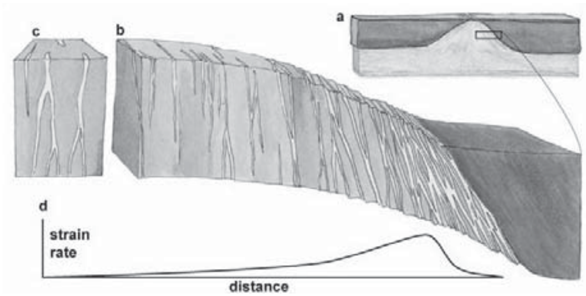
Now, geodynamicists, seismic imaging specialists and geochemists are converging on the planet's subduction zones, bringing a combination of observation, laboratory experiment and theoretical studies. Leading this multidisciplinary effort is the National Science Foundation's MARGINS program. In 2008, geophysicist Geoff Abers came to Lamont-Doherty from Boston University and brought with him the MARGINS Office, which provides support for scientists and their research around the world.

Among the questions that MARGINS scientists address are how volatiles, such as water and carbon dioxide, cycle between the surface and Earth's deep interior; how and where melt material forms to create volcanic arcs; the nature of the planet's thermal structure and the relationship between plate motions and flow; and the origin and evolution of continents. "These are not simple questions," said Abers. "Despite much conjecture and much effort, very little is still known about something as seemingly straightforward as the amount of water carried down by subducting crust, where or how it is released, and how it moves beneath the surface."

In addition to heading MARGINS, Abers has also been active in leading studies of subduction zones beneath Costa Rica and Nicaragua, Alaska, and western Washington. A recent paper he co-authored with colleagues from Boston, Rhode Island, Germany, Nicaragua and Costa Rica found that fluids move laterally beneath the surface, parallel to the volcanic arcs that are common to subduction zones, and not just vertically as previously thought. This affects how magma is generated to form the arcs. A related study with this group used seismic imaging to map out fluids ascending from plates 100 miles deep up to volcanoes.

"These sorts of observations, combined with ongoing modeling efforts, are illuminating the full cycle of volatiles from surface through the subducting plate and back out at arcs," said Abers. In addition to controlling the amount of water on the surface and in the atmosphere, such processes also regulate the carbon dioxide in Earth's atmosphere over geologic time.

In another recent paper, Abers and Boston University graduate student Ellen Syracuse published an analysis of 839 volcanic centers along more than 20,000 miles of volcanic arcs. Their findings challenged a long-held view that magma is formed at a fairly consistent depth beneath the surface and generally coincides with the point at which water is removed from the subducting plate. Instead, Syracuse and Abers found that other characteristics, such as plate geometry and motion, appear to control magma formation and, therefore, the appearance of volcanoes along arcs, including most explosive volcanoes on Earth.



Ben Holtzman's depiction of how strain may relate to melt distribution along plate boundaries
Credit: Ben Holtzman

Straining the Edges

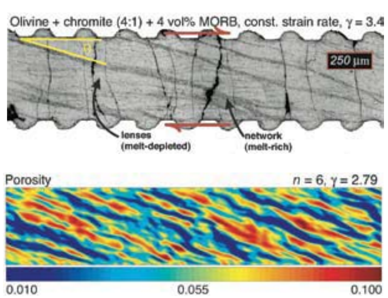
Scientists have known for decades that the planet's massive tectonic plates are in constant motion. What is less well understood is why Earth's rigid outer layer is constructed of discrete, moving plates and exactly how they are able to move past each other while maintaining relatively unchanged interiors. Lamont-Doherty geodynamicist Ben Holtzman recently provided new insight into the problem by combining seismology and materials science.

It is generally understood that the plates move along their boundaries by creeping slowly at depth and at the same time lurching closer to the surface—something we feel as earthquakes. For the deformation and, therefore, the earthquakes to remain localized, the plate boundaries must be much weaker than the interiors. Scientists believe that small amounts of melted material in the boundaries and the organization of that melt during deformation may be important in creating such weakness. Moreover, these channels may also be important in allowing the melt to escape the mantle and form new crust. However, because these processes occur deep within the planet, the formation and movement of melt in plates is not easily studied and is poorly understood.

In 2007, Holtzman reported the results of an experiment he carried out with David Kohlstedt at the University of Minnesota in which they placed thin (0.5 millimeter) sections of rock from the planet's mantle into a high-pressure and high-temperature vessel that simulates conditions deep beneath the surface. After deforming these samples, the researchers discovered that they contained an organized pattern of melt-rich bands interlaced through regions of melt-free rock. They were able to show that these distinctly segregated networks of melt-rich material formed as a result of a feedback involving strength, melt fraction and pressure; small areas with slightly more melt are weaker and have lower pressure than their surroundings, thus drawing in more melt and becoming even weaker. These weak, melt-rich areas eventually connect and organize into the observed networks. Holtzman concluded that rocks in plate margins under similar conditions could produce similarly segregated and organized networks of melt, though on much larger scales.

The researchers are currently working with seismologists to look for signs of organized melt deep in the planet. If found, these patterns could help answer a long-standing question about how the plate boundaries can become weak and remain localized though time. It would also help geodynamic modelers refine their work—including these feedback processes in models may significantly improve their ability to simulate tectonics as observed on Earth.

A section of upper mantle material subjected to conditions found in Earth's interior [right, top] in an experimental deformation apparatus, shows melt segregated into dark bands. A simulation [right, bottom] conducted by Lamont-Doherty colleagues Richard Katz and Marc Spiegelman closely resembles the experimental observations.
Credit: Katz, Spiegelman and Holtzman



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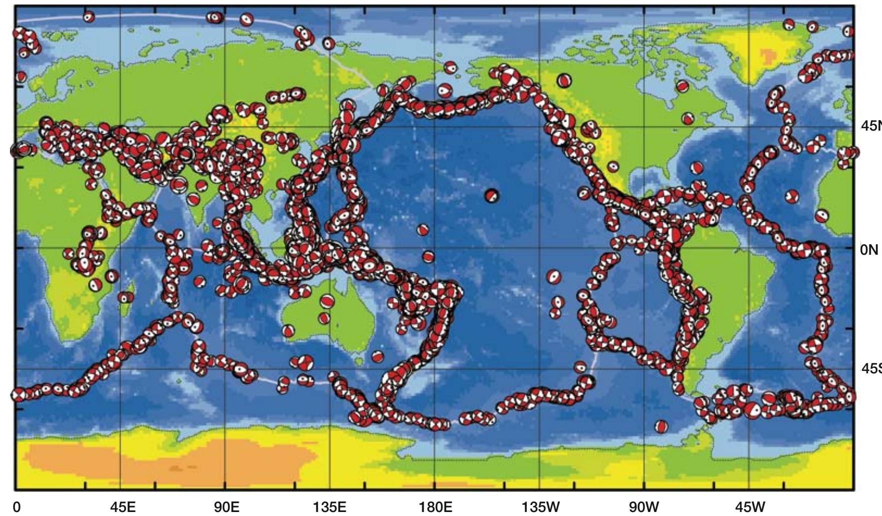


The Global Centroid Moment Tensor catalog contains detailed information about more than 25,000 earthquakes that have occurred since 1976.
Credit: GCMT

Mapping Earthquakes

Each year, more than 2,000 seismic events of magnitude 5 or greater occur worldwide. Many of these have been recorded for decades, but it has only been in the past 20 years that the development of digital seismometers has permitted them to be studied in large numbers and in great detail—and only in the past few years has this record been combed to reveal a wealth of insight into the workings of the planet.

In the summer of 2006, seismologist Göran Ekström relocated to Lamont-Doherty from Harvard University and brought with him the Global Centroid Moment Tensor (GCMT) Project, an NSF-funded initiative to describe every major earthquake recorded by the Global Seismographic Network that today offers the most comprehensive catalog of earthquake characteristics available. It includes not just the location, depth and magnitude of each event, but also the centroid moment tensor solution, a description of the orientation and motion of the fault that generated the earthquake critical to understanding the mechanics of the fault.

Prior to the 1980s, the primary tool used to record earthquakes was the analog seismometer, which generated individual paper records and was primarily useful for analyzing earthquakes with magnitudes greater than 6. With the advent of high-fidelity digital instruments, scientists could detect and study much smaller earthquakes in much greater detail. The concurrent growth of a global network of seismometers meant they could study earthquakes that occurred virtually anywhere on the globe.

Today, Ekström and his colleagues—Adam Dziewonski at Harvard University and Lamont-Doherty seismologist Meredith Nettles—analyze signals from as many as 100 seismometers to determine an earthquake's characteristics and have published the centroid moment tensor solutions for earthquakes between 1976 and the present day. Recently, they have also begun to apply a new earthquake detection method to the data from the global network. In doing so, they have discovered many earthquakes that had never before been cataloged—more than 1,200 between 1993 and 2003 alone—as well as several events that do not correspond to any previously known pattern of earthquake activity.

Among these was a cluster of long-duration earthquakes located along the coast of Greenland. Additional study revealed that these were caused by the movement of glaciers linking the Greenland ice sheet and the surrounding ocean waters. The discovery prompted an ongoing field study, led by Nettles, to study these so-called glacial earthquakes and determine whether warming in and around Greenland could be behind a recent increase in the frequency of the events.

The R/V *Marcus G. Langseth* is off to a great start that is in keeping with the highest traditions of scientific research as set by the Lamont-Doherty research vessels.

Paul Ljunggren
Senior Staff Associate,
Marine Superintendent
Credit: Bruce Gilbert

The past two years have seen many changes in the Office of Marine Operations at Lamont-Doherty. We went from having a vessel in dry dock completing conversion, through the complicated reflagging process and the transfer of the ship's title to the National Science Foundation, to, finally, the start of science operations for the R/V *Marcus G. Langseth*.

With the conversion work completed in early 2007, the ship, named after one of Lamont-Doherty's most famous geophysicists, sailed from Nova Scotia to Galveston, Texas, where much of the seismic equipment acquired with the ship from the *Langseth*'s former owner, Western GECO, was in storage. Because the Houston area is also a hub of the geophysical industry, Galveston proved to be an excellent location for final outfitting and sea trials. At the same time, there were regulatory issues to address, inspections to complete and equipment to test. The ship's new dynamic positioning system alone required several days of underway testing and calibration, as did the new multibeam bathymetric mapping system.

On November 12, 2007, we held a dedication ceremony hosted by Lamont-Doherty Director G. Michael Purdy and attended by Marcus Langseth's wife Lillian and many family members as well as NSF Program Director Emma Dieter. Less than two weeks later, we commenced science operations with the first of two shakedown cruises to test the ship's new linear seismic arrays in both two-dimensional and three-dimensional acquisition configurations. These arrays offer the scientific community new abilities to obtain more finely detailed images of the seafloor and geological structures beneath it than ever before. Interspersed among shakedown cruises were two calibrations to characterize the vessel's sound source—used to create images of the seafloor—in shallow, deep and intermediate water depths. Results from these cruises will also help us refine our enhanced sound mitigation practices and improve our understanding of source characteristics in geophysical research.

In early February 2008, the *Langseth* departed for the first of two seismic cruises that also employed ocean-bottom seismometers and land-based instruments on the Caribbean and Pacific sides of Costa Rica and Nicaragua. During this cruise, a Lamont-Doherty ship for the first time deployed an eight-kilometer hydrophone array and linear sound source arrays to conduct two-dimensional imaging in support of science.

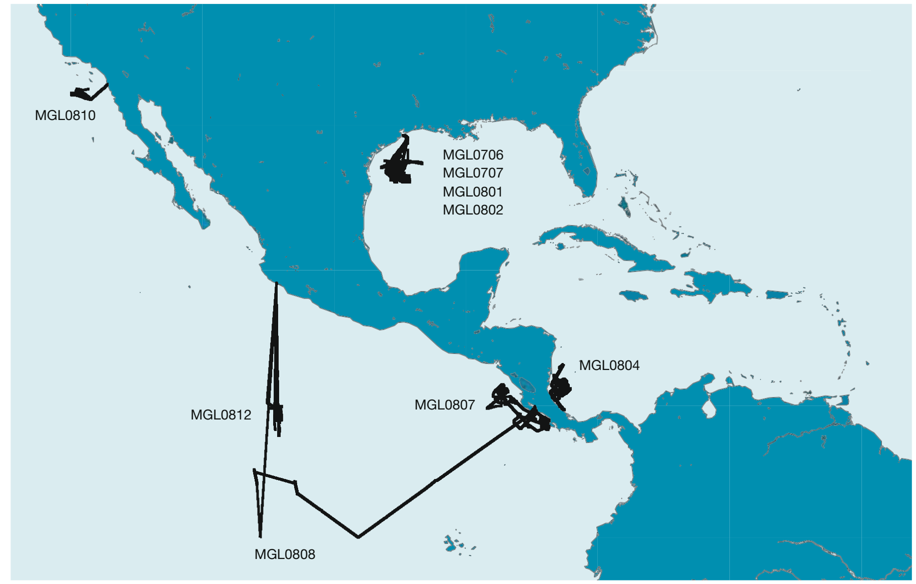
The *Langseth*'s next cruise—to an area of the East Pacific Rise mid-ocean ridge with several large transform faults—explored a theory that foreshocks, or small shocks around magnitude 3, occur in the last hour before a major rupture on a large fault. If correct, these foreshocks could one day be used to provide early warning in places such as the Pacific Northwest, which have similar geology.

The *Langseth* then laid over in San Diego for a brief maintenance period before sailing on our first three-dimensional cruise, led by Lamont-Doherty geophysicists John Mutter and Suzanne Carbotte. The cruise acquired nearly 3,800 kilometers of sail-line data during which the sound source was triggered almost 100,000 times, generating more than 950,000,000,000 data samples. "Virtually every survey line is visible in real time and is showing us something quite new or is providing significantly improved resolution over images from previous surveys," Mutter wrote as the data was still coming in.

As just these first few months show, the R/V *Marcus G. Langseth* is off to a great start that is in keeping with the highest traditions of scientific research as set by the Lamont-Doherty research vessels: the *Vema*, the *Conrad* and the *Ewing*. The next two years promise even more.

[left] Lillian Langseth prepares to dedicate the research vessel named after her husband.
Credit: Doug Brusa

R/V *EWING* CRUISE SCHEDULE (2007–2008)					
CRUISE	**2007**	**PORTS**	**AREA**	**PURPOSE**	**PIS**
EW0706	21 Nov–6 Dec	Galveston, TX - Galveston	Northern Gulf of Mexico	Seismic shakedown I	Diebold, LDEO
EW0707	17 Dec–21 Dec	Galveston - Galveston	Northern Gulf of Mexico	Source characterization I	Tolstoy, Diebold, Webb; LDEO
	2008				
EW0801	3 Jan–24 Jan	Galveston - Galveston	Northern Gulf of Mexico	Seismic shakedown II	Diebold, LDEO
EW0802	27 Jan–5 Feb	Galveston - Galveston	Northern Gulf of Mexico	Source characterization II	Tolstoy, Diebold, Webb; LDEO
EW0803	9 Feb–15 Feb	Galveston - Puerto Limon, Costa Rica		Transit	
EW0804	16 Feb–9 Mar	Puerto Limon - Puerto Limon	Western Caribbean	Costa Rica Subduction Factory	Holbrook, Univ. Wyoming
EW0805 EW0806	11 Mar–19 Mar	Puerto Limon - Puerta Caldera, Costa Rica		Transit	
EW0807	19 Mar–16 Apr	Puerta Caldera - Puerta Caldera	Offshore Costa Rica, Pacific	Costa Rica Subduction Factory and site survey	Holbrook, Univ. Wyoming; Breuckman
EW0808	24 Apr–11 May	Puerta Caldera - Manzanillo, Mexico	GOFAR fracture zone	Crustal response	McGuire, Woods Hole Oceanographic Institution
EW0809	12 May–17 May	Manzanillo - San Diego, CA		Transit	
EW0810	27 May–2 Jun	San Diego - San Diego	Offshore San Diego	Seismic shakedown III	Diebold, LDEO
EW0811	22 Jun–27 Jun	San Diego - Manzanillo		Transit	
EW0812	29 Jun–10 Jul	Manzanillo - Manzanillo	East Pacific Rise	3D seismic survey	Mutter, Carbotte; LDEO








[above, left to right] Former Lamont-Doherty Director Manik Talwani, Anni Talwani, Lillian Langseth and G. Michael Purdy *Credit: Doug Brusa*

[right] Lillian Langseth dedicates the research vessel named after her husband by breaking a bottle of champagne across its bow. *Credit: Doug Brusa*

Virtually every survey line is visible in real time and is showing us something quite new or is providing significantly improved resolution over images from previous surveys.




[top] R/V *Marcus G. Langseth* calibration, testing and research cruises, 2007–2008 *Credit: Jay Johnstone*

New young faculty members have come aboard to continue our tradition of excellence, and our students continue to inspire us with their achievements.

During this reporting period, Mark Cane [left] was chair of the Department of Earth and Environmental Sciences. Steven Goldstein [right] was vice chair during this period and succeeded Mark Cane as chair in July 2008.
Credit: Bruce Gilbert

The years 2006 to 2008 represented a changing of the guard for the Department of Earth and Environmental Sciences (DEES). Five faculty members, whose outstanding research careers added distinction to our scientific reputation, retired. To fill their shoes, six new faculty came aboard to continue our tradition of excellence.

The list of retirees included: Professor Dennis Hayes, a marine geophysicist and a major figure in mapping the ocean floor; Professor James Simpson, who worked extensively on the geochemistry of natural waters around the world; Adjunct Professor David Rind of NASA's Goddard Institute for Space Studies, a leading climate modeler, who focused on potential climate change associated with increasing atmospheric greenhouse gases; Adjunct Professor William B.F. Ryan, a marine geologist and geophysicist who developed advanced oceanographic instrumentation, discovered how the Mediterranean Sea dried up, and advanced the theory that the Black Sea flooded at the end of the last ice age; and Paul Richards, Mellon Professor of the Natural Sciences, a leading theoretical seismologist who played an instrumental role in the seismological verification of underground nuclear test-ban treaties.

Among his many achievements, Richards—along with postdoctoral researcher Xiaodong Song—showed that Earth's inner core is rotating slightly faster than the rest of the planet.

The losses have been compensated by the arrivals of Assistant Professor Bärbel Hönisch (paleoceanography), Professor Terry Plank (petrology), Adjunct Professor Geoff Abers and Assistant Professor Meredith Nettles (seismology), and Adjunct Professor Mingfang Ting and Adjunct Associate Professor Lisa Goddard (climate studies).

Abers, from Boston University, was previously a postdoctoral research scientist and an associate research scientist at the Lamont-Doherty Earth Observatory. He studies earthquakes, Earth's structure and active tectonic processes.

Hönisch, a former LDEO post-doc, comes from the Alfred Wegener Institute for Polar and Marine Research. She studies the role of the ocean and marine carbonate chemistry in global climate change. Originally trained as a marine biologist, she focuses on applying boron isotopes as a proxy for past seawater pH.

Nettles came to Lamont as a post-doc after she received her Ph.D. from Harvard. Her research focuses on tomographic imaging of Earth's upper mantle and studies of earthquake sources. She has been working to constrain the source characteristics of glacial earthquakes and the processes that lead to them. From this, she developed a nascent interest in glaciology and spends much of her time working on a geophysical observing campaign at Helheim Glacier in East Greenland.

Plank, who received her Ph.D. at Lamont-Doherty and comes from Boston University, is an expert on magma formation, focusing on the water content of magma and its effects on magma evolution, source composition, and explosivity of eruptions.

Goddard, whose main affiliation is the International Research Institute for Climate and Society on the Lamont campus, teaches in the Master of Arts Program in Climate and Society. Her research focuses on climate dynamics and climate predictability, with special interests in El Niño and climate change and decadal variability.

Ting comes from the University of Illinois at Champaign-Urbana. Her main research interests include the impacts of global climate change at regional scales, the impact of sea surface temperatures on global climate, as well as the dynamics of droughts and floods due to both natural and anthropogenic causes. She, too, teaches in the Master of Arts Program in Climate and Society, as well as in our flagship climate course for undergraduate DEES majors.

Among the awards received by DEES faculty from 2006 to 2008, Paul Olsen, Storke Memorial Professor of Earth and Environmental Sciences, was inducted into the National Academy of Sciences. Richards was elected to membership in the American Academy of Arts and Sciences. Plank and Peter Schlosser, Vinton Professor of Earth and Environmental Engineering, became Fellows of the American Geophysical Union. Wally Broecker received the Crafoord Prize in Geosciences from the Royal Swedish Academy of Sciences—widely regarded as our discipline's equivalent of the Nobel Prize—for his pioneering research on the operation of the global carbon cycle.

DEES continues to invest in undergraduate majors and concentrators and, more broadly, in students fulfilling Columbia's science requirement. In the present academic year, we have 29 majors and concentrators in Environmental Science and Earth Science, up from 19 only five years ago, and we look to continue on that upward trend. We attribute some of this increase to our focus on the changing environment, which has attracted students. Also important are our expanding research opportunities for undergraduates, our spring-break Death Valley geological excursions, and the Frontiers of Science initiative.

An expanded summer intern program has allowed many more Columbia and Barnard students to become involved than had been possible with just the long-running Research Experience for Undergraduates program, which was aimed primarily at bringing in students attending other institutions.

The annual Death Valley excursion took place for a sixth time in the spring of 2008. It is immensely popular with first- and second-year undergraduates and highlights the importance of field-based experiences in earth and environmental sciences. Focusing on vignettes drawn from both the contemporary environment and the geological record, the course encourages students to develop their own observations. With five nights at a bare-bones field station and two nights camping in Death Valley, each trip has also proven to be a bonding experience for the students.

The objective of *Frontiers of Science*, launched in 2004 as Columbia's latest addition to its famed Core Curriculum, is to communicate the philosophy and intellectual habits of science in the context of selected topics at the forefront of research. The course has a large lecture attended by all students and small discussion groups of about 20 students. DEES continues to take responsibility for 25 percent of the course, focusing on the theme of global climate, and accounts for the largest contingent of discussion-group instructors from any one department. Because Frontiers of Science is a requirement of every Columbia College undergraduate, it makes students aware of DEES and draws attention to the excitement and societal relevance of earth and environmental science.

Frontiers of Science, Columbia's latest addition to its famed Core Curriculum, draws attention to the excitement and societal relevance of earth and environmental science.

The year-long DEES Master of Arts Program in Climate and Society, headed by Mark Cane, the G. Unger Vetlesen Professor of Earth and Climate Sciences, has grown from 18 students when it was launched in 2004 to 26 in the 2007–2008 academic year (and to a new high of 39 for 2008–2009, as we went to press). The program trains professionals and academics from all over the world how to study the workings of Earth's climate system, assess its socioeconomic impacts, and make climate information usable for policymakers. They study with Columbia faculty across the University and researchers at Earth Institute units, especially the International Research Institute for Climate and Society.

Our Earth and Environmental Science Journalism Program, led by Adjunct Professor Kim Kastens, is a unique two-year program in which students must be admitted to both DEES and the Columbia School of Journalism, thereby producing graduates with a rare blend of scientific knowledge and journalistic skills. EESJ alumni have found positions at science-oriented publications (*Scientific American, EOS, Geotimes*), environment-oriented publications (*On Earth, Plenty*), mainstream media (*The New York Times, Houston Chronicle, The Wall Street Journal*), and as science writers for university research labs and museums.

The achievements of our students, like the two profiled in this section, continue to inspire us.

The Department of Earth and Environmental Sciences administrative staff [right to left]: Carol Mountain, program coordinator; Mia Leo, department administrator; Jean Leotte, administrative assistant; and Missy Pinckert, administrative aide
Credit: Bruce Gilbert

Exploring Microbe Communities to Protect Human Communities

Eli Dueker spent his initial years after college working for organizations to protect the environment, first in the Pacific Northwest and then as executive director for Project Underground.

"We worked with indigenous communities all over the world who were fighting against oil and mining companies for environmental justice and the rights to their own lands," he said. "The corporations had the money and resources to come up with documents that misused science at the communities' expense. For us, it was tough to find scientists who had the time, energy and wherewithal to respond to the corporations and were willing to step up politically. So I decided the best way to help bridge that gap was to become a scientist myself."

He decided to study at Lamont-Doherty because it was beginning new forays into applying oceanography to the urban environment. In addition, it had just launched the Earth Microbiology Initiative to explore the myriad unseen and interacting microbial communities, both beneficial and pathogenic, that mediate the chemistry of ocean and river ecosystems as they grow, eat, get eaten and decompose.

Dueker started on a project to assess water quality in the Hudson River, with the goal of scientifically modeling microbial dynamics for future management purposes under the guidance of his Ph.D. adviser, Assistant Professor Maria Uriarte in the Department of Ecology, Evolution and Environmental Biology. "That had immediate relevance to communities," he said. Soon he had his own research focus: Newtown Creek, an East River tributary separating Queens and Brooklyn that is bordered by Superfund sites, including the largest U.S. oil spill, industrial dumping and continual sewage overflows.

"It's probably one of the most polluted estuarine tributaries in the U.S., with a dense urban population near its banks," Dueker said. "Whatever's happening in that water is important to human health."

"It's also a question important to my own community," Dueker said. He lives in Brooklyn, just two blocks from the Gowanus Canal, another polluted urban tributary where he takes water samples to study how microbial populations change as water conditions shift.

He has investigated what happens after it rains, for example, when sewage overflows add disease-causing microbes, pollutants and excess nutrients that spur algal blooms. He has examined what happens when the abundances of phytoplankton, and the zooplankton that graze on them, are decomposed by bacteria. In the decomposition process, bacteria can seriously deplete the oxygen in the water, right up to the surface of Newtown Creek, "so you see fish with their backs out of the water, struggling to breathe at the thin surface layer still containing oxygen," he said.

The microbial communities "change hourly—'dynamic' doesn't begin to describe it," Dueker said. Though they may not be charismatic, "microbes should be the benchmarks of a healthy ecosystem, not just fish," he said, and should guide decisions on how to clean up tributaries like Newtown Creek and the Hudson River estuary as a whole.

> Newtown Creek, separating Queens from Brooklyn, is probably one of the most polluted estuarine tributaries in the U.S., with a dense urban population near its banks.

Graduate student Eli Dueker takes water samples from the Gowanus Canal in Brooklyn, N.Y., to study microbial communities and their impacts on the ecosystem and human health. *Credit: Ilana Berger*

Digging Deep Into the History and Ecology of the Hudson River

Sanpisa Sritrairat grew up on the coast of Thailand, which was rich with lush, fascinating and ecologically essential mangrove swamps and estuaries. But she lacked scientific instruments to study them as she yearned to do.

With a scholarship from the Royal Thai Government, she came to Rensselaer Polytechnic Institute (RPI) in Troy, N.Y., on the banks of a world-famous estuary. "The Hudson River became my classroom and laboratory," she said, and she studied it from as many scientific angles as she could, earning two B.S. degrees with three majors in hydrology, environmental science and biology, and a minor in economics.

Sritrairat worked on Hudson River research with Richard Bopp, an environmental geochemist at RPI who earned his Ph.D. at Columbia. Then she moved downriver to graduate school at Columbia in 2004, where she dug deeper—literally—into the Hudson estuary, by analyzing cores of sediments extracted from wetlands along the length and breadth of the river. The cores also span time—more recent sediments accumulate atop those from times gone by.

Sritrairat leapt into the decade-long mission of her adviser, Adjunct Professor Dorothy Peteet, to reconstruct the Hudson estuary's ecological history and determine how and why it has changed, especially with increasing use.

The scientists used a wide range of analytical tools, including mass spectrometry, gas and liquid chromatography, and X-ray fluorescence spectroscopy, to extract clues from the cores. Fossilized pollen, spores, seeds, needles and stems indicated how plant life shifted over time, which, in turn, told the story of changes in climate and sea levels, invasions of non-native species, and the clear-cutting of trees by Europeans.

Charcoal fragments yielded evidence of fires and periods of drought. Sand and pebbles revealed changes in erosion and river flow patterns. At the core tops, pollutants conveyed a history of industry.

"You use one tool to determine one part of the story and the next tool for another," Sritrairat said. "We want to make all the stories come together to broaden understanding of how nutrients, sediments, toxins, climate change and biology—from microbes to humans—affect the ecosystem. Such baseline knowledge is essential for making decisions on how to maintain and restore wetlands."

Sritrairat's career goals also include "teaching to produce more quality scientists to work in the environmental field," she said. She taught undergraduate and graduate classes at RPI and Columbia and in 2007 won the Department of Earth and Environmental Science's "Best Teaching Assistant Award."

"She's great with students," Peteet said. "She always volunteers for the Lamont-Doherty Open House and she's always up for going with us on River/Summer," an eight-week educational program for high school teachers and students who travel by boat up and down the Hudson River.

Somewhere in there, Sritrairat also found time to take care of another ecosystem: Lamont's community garden.

Graduate student Sanpisa Sritrairat studies how and why wetlands change, especially with increasing use. Here she uses an auger to take a mud sample from a wetland in Maryland [left] and teaches a group of high school students about sediment analysis at Piermont Marsh on the Hudson River [right].

Lamont-Doherty's Secondary School Field Research Program gives high school students opportunities to participate in research. Haydee Gomez [above] sets minnow traps in Piermont Marsh as part of an ongoing study of wetlands ecology.
Credit: Susan Vincent

Lamont-Doherty Expands Commitment to Education

While relentlessly pursuing their primary mission of research into our planet, Lamont-Doherty scientists have quietly pursued another goal: to convey their discoveries and knowledge to the public and to teachers and students of all ages. Now, with a challenge grant from the Henry L. and Grace Doherty Foundation, Lamont-Doherty is formalizing and significantly expanding its programs in earth and environmental science education and outreach.

"By examining climate change, earthquakes and volcanic activity, and environmental hazards, the Lamont-Doherty Earth Observatory provides society with a scientific basis to make difficult choices in the stewardship of this dynamic planet," said Lamont-Doherty Director G. Michael Purdy. "However, as our world becomes increasingly developed and human activity increasingly impacts the way our planet evolves, a new responsibility is being placed upon the shoulders of the research community: to educate our population about what is happening and why."

"We must better educate teachers, so that they can communicate the excitement and importance of earth science to young minds," he said. "We must catch the imagination of bright undergraduates and bring excitement to the general public."

Lamont has long been involved in education at higher levels, working with Columbia's Department of Earth and Environmental Sciences to teach and train undergraduate and graduate students. Each fall, Lamont invites the public to an open house, and Lamont researchers regularly give presentations to academic and lay audiences.

For many years, Lamont-Doherty researcher Dallas Abbott has coordinated a summer internship program, funded by the National Science Foundation (NSF); it pairs undergraduates from around the country with scientist mentors at Lamont, immerses students in research, and gives them hands-on experience in the lab or in the field. A companion program, solely for Columbia and Barnard undergraduates, has taken off, doubling opportunities for students to learn and for Lamont scientists to teach.

Lamont-Doherty researcher Bob Newton launched a similar summer internship program called the Lamont-Doherty Secondary School Field Research Program. It brings in high school teachers and their students to work side-by-side with Lamont scientists on ongoing research projects. Students and teachers have gone hip-deep into Hudson River mud to collect samples in Piermont Marsh for marine biologist Ray Sambrotto and strapped on portable sensors to test equipment and measure air quality for geochemist Steve Chillrud. The students come back to Lamont labs to learn how to analyze their data. Both students and teachers receive stipends for their work.

"Financial support makes the program a viable summer activity for students from a diverse range of economic backgrounds," Newton said. "Several of our students have used their experience in the program to get ongoing part-time jobs as laboratory technicians. So far, all of our participants are in college or college-bound."

"The goal is to give teachers and students a hands-on understanding of the scientific process," Newton said. "Participating in fieldwork and seeing their students work alongside professional scientists changes teachers' sense of what is possible for the students. For teachers and students alike, the program validates science as a career choice."

To enhance science education in seven New York City middle and high schools, NSF awarded a $3.1-million grant to expand and integrate Lamont-Doherty's secondary school program and the Columbia Center for Environmental Research and Conservation's Teacher Training Institute. The NSF grant and additional Columbia support provides graduate students and teachers stipends for students to spend one day a week working at the schools.

"The teachers spend the summers apprenticed to graduate students, and, during the school years, the graduate students are apprenticed to the teachers," Newton said. "They trade their experience and knowledge back and forth."

And real-life, real-time research gets directly injected into high school curricula. For example, Columbia graduate student Phil Orton and Harlem teacher Maricio Gonzalez and their students built "a monitoring station based on a catamaran in the East River, practically in the school's backyard, with an Internet uplink into the classroom," Newton said.

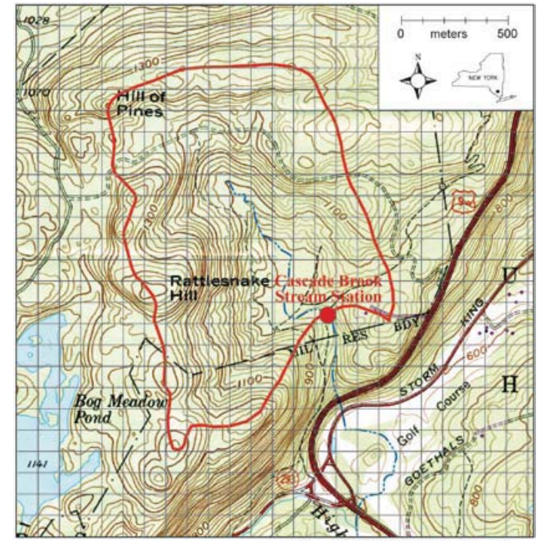
With another NSF grant, Lamont oceanographer Kim Kastens worked with Liberty Science Center and local middle and high school teachers to develop lesson plans that she calls "Lamont-Doherty Geoscience Data Puzzles." The lessons give teachers and students opportunities to learn how to use real scientific data to solve problems and illuminate fundamental earth science processes. Lamont scientists and teachers worked together to conceive and iterate the lessons, test them in classrooms, and disseminate them via the Web and teacher workshops.

The data puzzles included datagraphs, maps, tables or images in amounts small enough to be non-intimidating for teachers and students. They include questions to guide students through the process of interpreting the data to solve each puzzle in less than an hour. So far, Kastens and colleagues have created seven data puzzles on topics such as earthquakes, seafloor spreading and the water cycle.

The data puzzles "purposefully present a low barrier-to-entry for teachers and a high ratio of insight-to-effort for students," Kastens said. "Every puzzle offers one or more 'Aha' insights, a moment when the connection between data and process or data and problem comes clear in a rewarding burst of insight and illumination."

Expanding these sorts of programs and creating new synergies among them is a goal of the Doherty grant. To provide leadership and coordination, Lamont seeks to endow a new position: director of the Earth and Environmental Science Education Program.

"Our efforts to live responsibly and securely within our natural environment are blocked—not by an inadequate knowledge of the science or by a shortage of engineering solutions or economic capacity, but by a lack of public knowledge, leadership awareness and political will," Purdy said. "Education and outreach are the only ways to overcome this barrier."



[top] Lamont scientists worked with teachers to create lesson plans called "Data Puzzles." Students use real data and maps (like this one of a watershed in Black Rock State Forest) to solve problems and learn about basic earth science processes such as earthquakes, seafloor spreading or, in this case, the water cycle.
Credit: Kim Kastens

[bottom] Liz Logan [left] and Sarah Starke were two of 25 undergraduates who participated in Lamont-Doherty's summer internship program in 2008.
Credit: William Menke

Suzana Camargo
Doherty Associate Scientist
Credit: Mark Inglis

When and Where Will Cyclones Hit?

Scientists seek more reliable and precise forecasts of tropical storms

Katrina, Rita, Wilma, Gustav—the parade of infamous Atlantic Ocean hurricanes keeps on coming. In the Pacific and Indian Oceans, these huge swirling storm systems are called typhoons or cyclones and, despite their lack of name recognition, they are no less deadly and destructive. In May 2008, a cyclone named Nargis killed nearly 150,000 people in Myanmar.

Scientists have long sought to make hurricane predictions that would help coastal populations, businesses and government agencies make preparations that could save lives and reduce economic losses. Starting in the mid-1980s, researchers began finding that hurricanes are statistically correlated with ocean temperatures and other environmental conditions. Based on these factors, they began issuing seasonal forecasts of hurricane activity. But these forecasts haven't yet developed to the point where they are reliable or specific enough to provide help on one of the most critical pieces of information—where hurricanes are likely to make landfall—said Suzana Camargo, Doherty Associate Scientist.

In an effort to improve seasonal forecasts of tropical cyclones, Camargo and colleagues first analyzed all 1,393 tropical storms and cyclones that formed in the Pacific Ocean between 1950 and 2002. They found that the cyclones tended to have one of seven distinct trajectory patterns, which they named Clusters "A" through "G," and cyclones in each cluster began to form in a distinctive region (see figure on opposite page).

Typhoons in Cluster A, for example, formed just south of 20 degrees north and 140 degrees east, east of the Philippines and Taiwan. They followed a curving path northwest, but then "recurved," veering to the northeast. Cluster G typhoons originated farther south, near the equator, and farther east, near 180 degrees east, and took straight pathways over the Philippines, Taiwan, China, Korea or Japan. Clusters D and E both tended to form in roughly the same location east of the Philippines, but D typhoons shot straight across the Philippines to southern China and northern Vietnam, while E typhoons recurved and tracked northeast over Taiwan, the eastern Chinese coast, Korea and Japan.

Camargo and colleagues—Andrew Robertson of the International Research Institute for Climate and Society (IRI) on the Lamont campus; Scott Gaffney and Padhraic Smyth of the University of California, Irvine; and Michael Ghil of UCLA—published their results in two papers in the *Journal of Climate* in 2007. In these papers, they analyzed other characteristics and behaviors of each cluster that they had identified, including:

- How often they occurred: Clusters A, B and C accounted for 60 percent of all the cyclones, while F and G were relatively rare at 8 percent.
- Which months each formed: A's in July, August and September; F's peaked from October to December.
- Which were short-lived: B's averaged only 5.25 days.
- Which tended to last longer and intensify: G's lasted 13.1 days.
- Which tended to make landfall: 85 percent of B's did, but C's recurved out to sea and only 7 percent hit land.

The research team then investigated how the various clusters were affected by the El Niño/Southern Oscillation and other known air-sea oscillations in the Pacific. They found, for example, that Cluster E and G cyclones occur more often during El Niño years, when eastern Pacific temperatures are warmer than usual, while Cluster A typhoons are more frequent in La Niña years, when eastern Pacific temperatures are colder than usual.

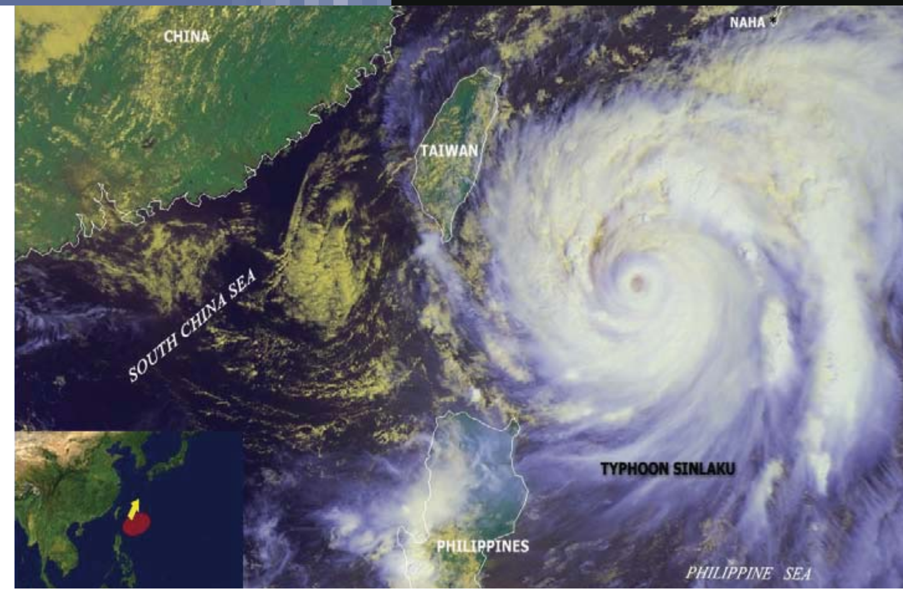
The goal of the research is to isolate types of typhoon behavior that can help improve seasonal cyclone forecasts and landfall risk maps. Once tropical cyclones are identified as belonging to one of these clusters, the historical information can guide scientists to predict, for example, that "this is an El Niño year, so there should be a higher probability of cyclones forming in these regions and taking these trajectories and making landfall in these regions," Camargo said.

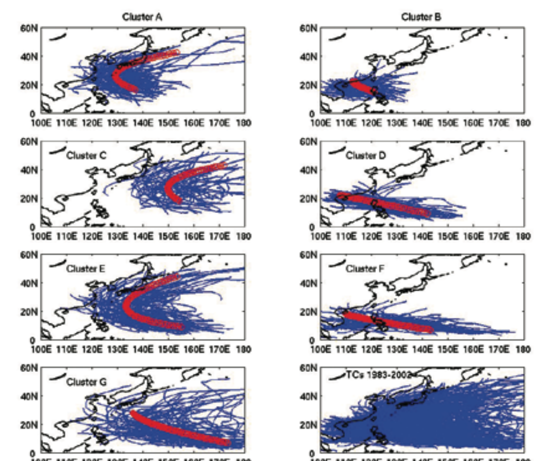
Camargo and colleagues didn't stop there. Beyond statistical models, they have begun to explore the underlying mechanisms and physics that lead to the formation of cyclones. Working with Kerry Emmanuel of the Massachusetts Institute of Technology, Adam Sobel of Columbia and Anthony Barnston at IRI, Camargo examined the relationship between cyclones and several environmental factors—phenomena such as low-level vorticity, relative humidity, vertical wind shear and potential intensity. The researchers found, for example, that certain factors (like relative humidity and vertical shear) reduce the formation of hurricanes in the Atlantic, while in the western North Pacific, relative humidity and vorticity play important roles in shifting cyclone formation. With such insights into the mechanisms underlying cyclone formation, the researchers have begun to explore climate models that incorporate such physical factors to simulate climate dynamics.

"We are examining existing climate models to understand how good they are in their ability to simulate tropical cyclone activity," Camargo said. "Given our growing understanding of the mechanisms by which large-scale environmental conditions influence cyclone activity, we are analyzing where the models aren't doing a good job yet in forming [simulated] cyclones, so that we can make necessary improvements. We want to move beyond forecasts based on statistics to forecasts based on physics.

"A model based on statistics can only forecast events that have happened in the past," Camargo said. "They cannot reproduce situations that have never happened before."

Global warming will likely shift climate conditions into unprecedented territory, so improved climate models that can reliably simulate cyclone formation based on underlying physics offer the prospect of making better predictions of whether cyclones will become more frequent or severe in a warming world—and when and where they are more likely to hit.





[top] Typhoon Sinlaku was a category-3 storm when it made landfall in Taiwan in September 2008, before it curved back northeastward and out to sea.
Credit: NOAA

[bottom] Climatologist Suzana Camargo and colleagues analyzed 1,393 cyclones that formed in the Pacific Ocean between 1950 and 2002 and found seven distinct clusters (A through G)—each with distinctive characteristics and trajectories.
Credit: Camargo et al., Journal of Climate, 2007

The Tree-Ring Lab's Monumental Monsoonal Mission

Dendrochronologists sweep across Asia to learn why monsoon rains vary

Their scientific campaign has elements of Johnny Appleseed and Genghis Khan. Since 2004, a modest horde of researchers in Lamont-Doherty's Tree-Ring Laboratory (TRL) has fanned out across the breadth of the Asian continent, not to plant new trees, but to find ancient ones. In these long-lived trees lies evidence to reconstruct how the Asian monsoons have come, or not come, each year through the centuries.

The goal of the five-year project, funded by the National Science Foundation, is to conquer complex questions: What environmental conditions drive the Asian monsoons and how might they change in a warming world? The answers are critical for billions of people from Pakistan to Taiwan and from North Asia to Indonesia. They depend on monsoon rains to water their crops, endure droughts when monsoons sputter, and suffer devastating floods when the rains come on too strong.

The energy that drives the monsoons is heat from the sun. The vast, high Tibetan Plateau sits like a mammoth brick in the middle of the continent, baking in the summer sun. Air above the plateau becomes warmer and rises; to replace it, air filled with moisture evaporated from surrounding oceans rushes in, bringing the monsoonal rains.

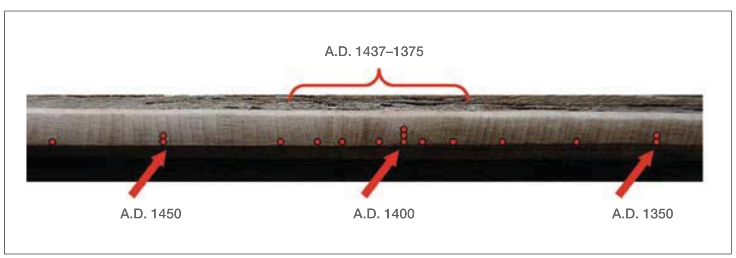
In addition to changes in solar radiation and land temperatures, changes in ocean temperatures can influence the monsoons. Naturally occurring oscillations shift pools of warmer waters back and forth in the Pacific and Indian Oceans; warmer waters evaporate more readily, adding more moisture to the air.

Which factors—or combinations of factors—hold the most sway on the monsoons? That's the ultimate question Lamont-Doherty tree-ring scientists, or dendrochronologists, sought to answer as they journeyed to remote Asian forests. They nondestructively took thin core samples from tree trunks to obtain intact records of the trees' concentric annual growth rings. The ring widths vary, depending on growing conditions such as air temperature and water availability, which in turn depend on the monsoons.

The researchers dispatched in four cadres, each dedicated to locating and sampling trees in a particular region. They also enlisted colleagues to contribute samples. Along the way, they trained Asian scientists and students in dendrochronology and helped establish more than a half-dozen tree-ring labs in several countries throughout Asia.

Ed Cook led expeditions with TRL research associate Paul Krusic to the region around the northern Tibetan Plateau, where TRL scientist Gordon Jacoby, working with Chinese scientists and students, had previously cored a living tree that was more than 1,435 years old. Cook and Krusic also collected specimens from several tree species in Bhutan, while Columbia graduate student Jinbao Li sampled trees in three different Chinese provinces. Adjunct TRL researcher Jonathan Palmer, collaborating with a Pakistani scientist, added samples from northern Pakistan, some of which are 600 years old. Colleagues contributed other samples from China and from the Indian Himalayas.

Lamont-Doherty's Tree-Ring Lab is reconstructing the history of the Asian monsoons, whose rains govern the lives of billions of people. The researchers nondestructively take thin core samples from tree trunks to obtain records of the trees' concentric annual growth rings. The ring widths vary [example at right], depending on growing conditions such as air temperature and water availability, which in turn depend on the monsoons.



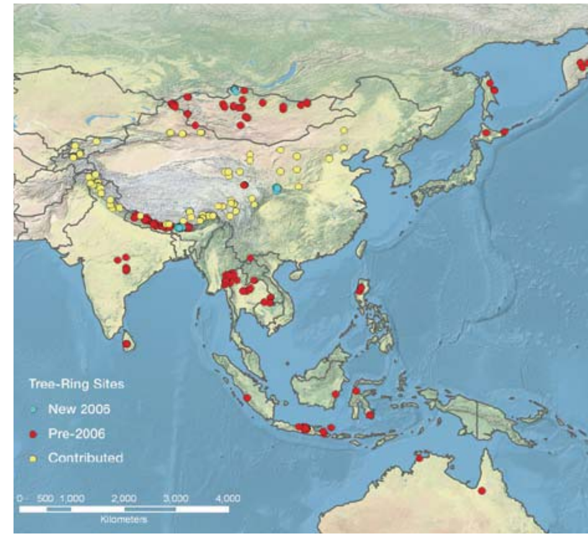
TRL scientists Brendan Buckley and William Wright, along with TRL researchers Kevin Anchukaitis, Ben Cook and Kali Abel, focused on Southeast Asia, collecting samples from Thailand and the remote Bidou Nuiba National Forest in Vietnam, where several conifer species are believed to be more than 1,000 years old. Collaborating with researchers at the University of the Philippines and National Taiwan University, they located new tree sites on the island of Luzon and cored yellow false cypress in Taiwan, whose oldest tree rings extend back 1,278 years. With a colleague at Nanjing University in China, they sampled timbers from several 100- to 400-year-old buildings.

Rosanne D'Arrigo's territory took her farther south. In 2007, she, Krusic and John Sakulich sampled living trees and fossil wood, mainly teak excavated from streambeds on the Indonesian islands of Java, Sulawesi, Sumbawa and Sumatra. Palmer collected samples in Australia and scouted out potential future sites in Papua New Guinea.

Gordon Jacoby and TRL researcher Nicole Davi concentrated on Mongolia and Eurasia. In 2007, he and former research assistant Erica Mashig and Mongolian colleagues revisited one of the TRL's best and oldest tree-ring sampling sites in Mongolia, which previously had produced one of the clearest records of past temperature changes in Asia. "Unfortunately the site had been devastated by fire since our last visit in 1999," the scientists wrote. After their initial shock, they managed to take samples from small pockets of living and dead trees that had escaped the fire. The new samples extended the record to A.D. 164, long beyond Genghis Khan's 12th- to 13th-century conquests.

The tree-ring samples stretch across the continent and reach back in time. Together, all the rings from all the trees from all the locations will be woven together to paint a comprehensive picture of how temperatures and precipitation—governed by the monsoons—have fluctuated year to year over the past centuries across Asia.

Buckley, for example, found evidence from a nearly 500-year tree-ring record that two 30-year megadroughts struck between 1690 and 1720 and between 1735 and 1765 in Thailand. The megadroughts, caused by extended periods of weak monsoons, may have been felt from India all the way to northern Vietnam, he reported in 2007 in the journal *Climate Dynamics*. In studies published in the *International Journal of Climatology,* D'Arrigo and colleagues have begun to successfully correlate Indonesian tree-ring drought records with records of natural oscillations in ocean conditions, notably the El Niño/Southern Oscillation and the Indian Ocean Dipole Mode.



Lamont-Doherty scientists have amassed samples of tree rings from sites across the length and breadth of Asia.

What factors will govern the strength and timing of the monsoons—and the associated patterns of droughts and floods—in the future?

What factors could cause such droughts and govern the strength and timing of the monsoons in the future? Computer models provide clues by incorporating the known physics of the complex interplay among air, sea and land into simulations of ocean and climate dynamics. But how do we know how reliable the models are?

The best way to find flaws in the models and to improve them is to test them against the actual track record of the monsoons' behavior over the long run in the planet's history. That track record is assiduously being assembled by the Lamont-Doherty Tree-Ring Lab.

The Lamont-Doherty OBS Lab maintains 30 broadband ocean-bottom seismometers [shown here outside the Lab facility] designed for deployments of up to a year and available to the scientific community through the U.S. National Ocean Bottom Seismograph Instrument Pool (OBSIP). *Credit: Patrick Jonke*

Listening to Deep Vibrations at the Ocean Bottom Seismology Lab

Scientists help map the world's structure with sound

The interior of our planet is not as still and silent as many might think. It may not have the bustle of Tokyo or Times Square or the roar of a sports stadium, but our planet is awash with the din of rumbling, groaning and humming. And if you listen very closely, you might just learn something.

That is exactly what Andrew Barclay, Spahr Webb and the staff at the Lamont-Doherty Ocean Bottom Seismology (OBS) Lab do best—tune in to Earth's vibrations using seismometers planted on the bottom of the world's oceans. In the process, they are helping seismologists and geophysicists around the world map the structure of our planet, reveal the processes that shape its interior and surface, and assess the risks that natural disasters pose to millions of people around the globe.

They may at first seem like unnecessary lengths to go to in order to capture these faint signals, but the depths are often the best place for these sensitive instruments to do their work. Most earthquakes occur beneath the oceans, many of them too small or too far from land to measure and locate accurately. Moreover, Earth's crust is thinnest beneath the oceans, a mere four miles thick compared to 20 miles beneath the continents, making it the best spot to peer beneath the rocky crust, down to the mantle and even as deep as the planet's core—much the way ultrasound is used to look inside the human body.

"If you're studying the Earth and you're just sitting on shore, you're almost certainly going to miss things," said James Gaherty, a seismologist and Doherty Research Scientist who uses ocean-bottom seismometers (OBSs) to examine how the boundaries between Earth's plates form. "Two-thirds of the Earth is covered by water, so most of the action is occurring offshore."

Crew members on the SUNY Stonybrook research vessel *Seawolf* retrieve an ocean-bottom seismometer during a test deployment off the coast of New Jersey.
Credit: Ken Kostel

To help researchers get in on the action, the National Science Foundation funded an initiative in 2000 to establish the Ocean Bottom Seismograph Instrument Pool (OBSIP), a consortium of labs and staff at Lamont-Doherty, Woods Hole Oceanographic Institution and Scripps Institution of Oceanography that is devoted to developing, maintaining and operating a fleet of OBSs and providing technical support at sea. The OBSIP provides equipment, expertise and logistical support that enables researchers to carry out seagoing experiments that may involve sending several research vessels and dozens of instruments to remote corners of the ocean over the course of many months.

There are generally two types of OBSs: short-period instruments tuned to high-frequency energy and broadband instruments that record low-frequency vibrations. Short-period instruments are primarily used in experiments involving sound sources such as air guns to actively probe beneath the planet's surface. Broadband instruments are designed for long deployments to passively record the faint, low-frequency seismic energy from sources such as earthquakes or volcanoes.

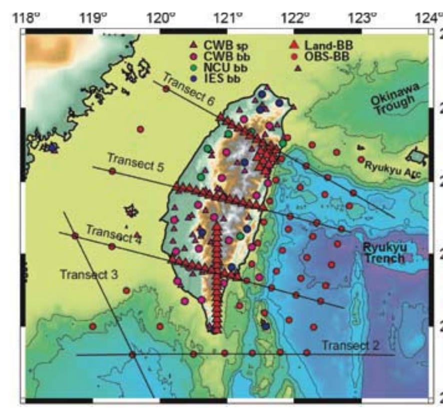
Rock and sediments are opaque to light, but these vibrations from earthquakes and air guns pass easily through sediments and rock into the planet's interior. The materials they pass through alter the vibrations in ways that researchers can interpret to create detailed images of the crust and mantle. These can reveal the physical structure of the planet and how it is changing.

Lamont-Doherty's OBS Lab formed in 2000 when Spahr Webb arrived from Scripps Institution of Oceanography with his design for a long-period OBS. Since then, the facility has grown to seven scientists and technicians, including Andrew Barclay, who came from the University of Washington in 2006 to head the lab, as well as engineer David Gassier and technician Stephen Pugsley.

To date, Lamont-Doherty instruments have helped reveal previously unknown details about the planet such as the architecture of an island volcano in the Antarctic and how tectonic plates in the western Pacific are colliding. Although the process of ocean-bottom seismology is fairly straightforward—encase a seismometer in a pressure-proof housing, sink it to the bottom of the ocean, record seismic waves—the reality of actually doing science on the seafloor is daunting. The sensitive instrument has to be protected from pressures exceeding 9,000 pounds per square inch. It also has to withstand rough handling on the deck of a heaving ship as well as extreme changes in temperature and the corrosive environment of salt water for up to a year. And the entire instrument has to operate autonomously on the seafloor and return to the surface on command.

"When you consider what we put them through, it's a wonder they come back at all," said Maya Tolstoy, a marine geophysicist and Doherty Senior Scientist who regularly deploys OBS arrays in her work to study seafloor spreading at mid-ocean ridges. That the instruments return to the surface with their data about 90 percent of the time is a testament to the work done by Lamont-Doherty's OBS Lab and the other members of the OBSIP.

And their designs continue to evolve and improve to incorporate new ideas and the latest technologies, setting the stage for a new generation of instruments. Webb and Barclay recently received funding from the National Science Foundation to construct an OBS that includes a shielded "vault" to protect it from vibrations caused by deep-sea currents. In 2006, Barclay, Webb and Gaherty received a $20,000 grant from the Paros-PGI Observatory Technical & Innovation Center to design a compact, low-maintenance OBS to be used along with the state-of-the-art multichannel seismic imaging system aboard Lamont-Doherty's new research vessel, the *Marcus G. Langseth*. The instrument could be easily stored on and quickly deployed from the *Langseth* and vastly improve scientists' ability to listen in on Earth's secrets.



Instruments from the Lamont-Doherty OBS Lab are currently deployed off the coast of Taiwan as part of TAIGER (TAiwan Integrated GEodynamics Research), a multinational ocean- and land-based project to study Earth's structure beneath the seismically active island.
Credit: TAIGER

06

2006 Awards

September 29, 2006

2005 Editors' Citation for Excellence in Refereeing
Stan Jacobs and Alexey Kaplan

November 17, 2006

2006 Economic Development Award
Rockland County Economic Development Corporation

2006 Events

September 22, 2006

Jardetzky Lecture
The Origin of the Earth's "Hum": Bridging the Gap Between Seismology and Oceanography
Barbara Romanowicz, University of California, Berkeley

The Jardetzky lecture in geophysics honors the late Wenceslas S. Jardetzky, a renowned European researcher who immigrated to the U.S. after World War II. From 1949 until his death in 1962, he was a research associate at Lamont-Doherty, where he collaborated with Frank Press and Maurice Ewing on a widely used scientific book "Elastic Waves in Layered Media." The Jardetzky lecture was established in 1992 by Jardetzky's son Oleg.

September 26, 2006

Groundbreaking Ceremony for Comer Building

Stephanie Comer and Bill Schleicher of the Comer Science and Education Foundation join Lamont and Columbia faculty and administrators at the groundbreaking ceremony.
Credit: Ken Kostel

Open House 2006

October 7, 2006

Oceans of Discovery

07

2007 Awards

Wallace S. Broecker awarded the 2006 Crafoord Prize in Geosciences by the Royal Swedish Academy of Sciences for his innovative and pioneering research on the operation of the global carbon cycle within the ocean-atmosphere-biosphere system and its interaction with climate.

January 26, 2007

Peter Schlosser elected as an AGU Fellow by the American Geophysical Union, joining the top 0.1 percent of the membership.

February 9, 2007

Louisa Bradtmiller receives an Outstanding Student Paper Award for her presentation at the 2006 AGU Fall Meeting in San Francisco titled: "Equatorial Atlantic opal and 231Pa/230Th records over the last 30 yrs."

September 7, 2007

Richard Seager receives the Director's Award for Outstanding Research Accomplishment.

September 26, 2007

Lamont-Doherty Earth Observatory wins the "Recycle Dude" trophy and First Place Per Capita Recycling Rate standing among 250 university campuses nationwide during the 10-week Recyclemania competition.

October 12, 2007

Karen Bocsusis and Paula Kolacia (Travel) and Dick Greco (B&G) recognized with the first annual Lamont Service Award for their efforts on behalf of the campus.

Karen Bocsusis, Dick Greco and Paula Kolacia
Credit: Ronnie Anderson

2007 Events

May 2, 2007

Memorial Symposium in Honor of Gary C. Comer
Featuring presentations by:
G. Michael Purdy, Director, Lamont-Doherty Earth Observatory
Steven A. Cohen, Executive Director and Chief Operating Officer, The Earth Institute at Columbia University
Wallace S. Broecker, Newberry Professor of Earth and Environmental Sciences, Columbia University
Geroge Denton, Libra Professor of Earth Sciences, University of Maine
Richard Alley, Evan Pugh Professor of Geosciences, Pennsylvania State University
David S. Battisti, Professor of Atmospheric Sciences and Tamaki Endowed Chair, University of Washington

May 11, 2007

Jardetzky Lecture
Changing Carbon Cycle and Accelerating Climate Change
Inez Fung, Professor and National Academy Member, UC Berkeley

Director G. Michael Purdy pictured with the Marie Tharp Symposium lecturers.
Credit: Bruce Gilbert

October 15, 2007

Marie Tharp Symposium
Featuring a keynote speaker and lectures.

Keynote speaker:
Rita Colwell, Chair, Canon U.S. Life Sciences; Distinguished University Professor, University of Maryland at College Park and John Hopkins University Bloomberg School of Public Health

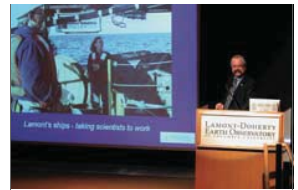
Lecturers:
William B.F. Ryan, Lamont-Doherty Earth Observatory
Suzanne O'Connell, Wesleyan University
Suzanne M. Carbotte, Lamont-Doherty Earth Observatory
Deborah K. Smith, Woods Hole Oceanographic Institution
Robin E. Bell, Lamont-Doherty Earth Observatory
Marilyn Laurie, Trustee, Columbia University; Former Executive Vice President, AT&T

November 12, 2007

Dedication Ceremony of R/V *Marcus G. Langseth* in Galveston, Texas

November 30, 2007

Ribbon-Cutting Celebration of the Gary C. Comer Geochemistry Building



John Diebold speaks at the March 18, 2007 public lecture.
Credit: Ronnie Anderson

Spring 2007 Public Lectures

March 18, 2007

A New Era in Ocean Exploration: Introducing Research Vessel *Marcus G. Langseth*
A panel presentation by:
Suzanne Carbotte, Ph.D., Doherty Research Scientist
John Diebold, Ph.D., Senior Research Scientist
G. Michael Purdy, Ph.D., Director

March 25, 2007

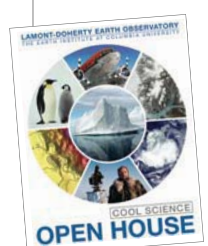
Cosmic Impact! Evidence from Madagascar
Dallas Abbott, Ph.D., Adjunct Research Scientist
Lamont-Doherty Earth Observatory

April 15, 2007

From Satellites to Camels: In East Africa Studying the Biggest Magmatic Rift Event Ever Seen
Roger Buck, Ph.D., Doherty Senior Research Scientist
Lamont-Doherty Earth Observatory

April 22, 2007

Climate Change in Greenland: Perspectives from the Present and Past
Meredith Kelly, Postdoctoral Research Fellow
Meredith Nettles, Postdoctoral Research Scientist



Open House 2007

October 6, 2007

Cool Science

08

2008 Awards

January 18, 2008

Terry Plank elected as an AGU Fellow by the American Geophysical Union, joining the top 0.1 percent of the membership.

May 2, 2008

Paul Olsen elected to the National Academy of Sciences.

Paul Richards elected to the American Academy of Arts and Sciences.

May 23, 2008

Wallace S. Broecker receives an honorary Doctor of Science degree from Southern Methodist University.

June 20, 2008

Inaugural Advisory Board Innovation Fund awards seed funding to Principal Investigators Veronica Lance, Andy Juhl and Bob Anderson for "Carbon Productivity Responses to Increased Dissolved Inorganic Concentrations in the Surface Ocean."

Open House 2007 attendees examine rocks collected from around the world.
Credit: Bruce Gilbert

2008 Events

June 13, 2008

Book Signing: Wallace S. Broecker and Robert Kunzig celebrate the publication of their new book, "Fixing Climate: What Past Climate Changes Reveal About the Current Threat—and How to Counter It."

[top] Wallace S. Broecker
Credit: Stacey Vassallo
[bottom] Greg Mountain
Credit: Ronnie Anderson

Spring 2008 Public Lectures

March 30, 2008

Is the Ocean Shrinking? The Earth's Biggest Water Cycle
Terry Plank, Ph.D., Professor, Lamont-Doherty Earth Observatory

April 13, 2008

The Ocean Floor: What We Know and How We Know It
Greg Mountain, Ph.D., Adjunct Senior Research Scientist, Lamont-Doherty Earth Observatory

May 4, 2008

A Slippery Slope? The Watery World Beneath the Changing Ice Sheets
Robin Bell, Ph.D., Doherty Senior Research Scientist, Lamont-Doherty Earth Observatory

May 18, 2008

Climate Is Changing Our Forests and Plants: New Evidence From Alaska and Our Own Backyard
Kevin L. Griffin, Ph.D., Associate Professor, Lamont-Doherty Earth Observatory

[left to right] Doug Brusa, Stacey Vassallo, Sarah Huard, Ronnie Anderson

Your contributions help ensure the continued leadership of the Lamont-Doherty Earth Observatory in the earth sciences.

Development Office

During the last two fiscal years, the Observatory recorded more than $23 million in new gifts and payments on pledges from individuals, private foundations and corporations.

Most notable among these were the final pledge payments of $15 million from Gary Comer and the Comer Science and Education Foundation for completion of the Gary C. Comer Geochemistry Building, which opened in November 2007. Other extraordinary contributions for the building during this period included $1.7 million from Columbia University trustee Gerry Lenfest and $500,000 from an anonymous donor.

The Comer Foundation also maintained its generous support of education and scientific research at the Observatory with additional grants of more than $1.5 million. We are also grateful to the G. Unger Vetlesen Foundation, which continued its unrestricted operational support of Lamont-Doherty's mission through this period in the amount of $1.4 million, providing critical support that allowed the director to fund priority projects across a range of disciplines.

A new endowment gift of $1.5 million from Jerry Paros established the Jerome M. Paros Senior Research Scientist of Observational Geophysics that will support research projects with an initial emphasis on sensor technologies directed at solving first-order fundamental research problems.

A challenge grant of $750,000 from the Henry L. and Grace Doherty Charitable Foundation established a matching endowment fund to create a new position: director of the Earth and Environmental Science Education Program. Over the last two fiscal years, Lamont Advisory Board Vice Chair Frank Gumper and his wife Joanne contributed more than $100,000 towards this match, and Frank has helped Lamont researchers connect with locals schools and other institutions in the metropolitan region.

Other important contributions over this period have come from supporters like the Brinson Foundation, whose $150,000 gift helped fund postdoctoral fellows in the Seismology, Geology and Tectonophysics Division and the establishment of an Earth Microbiology Laboratory; an anonymous donor, whose $250,000 gift will support the Geochemistry Division; Jesse and Betsy Fink, whose gifts support an Immediate Rapid Climate Change Initiative; the Green Family Foundation, which has helped the National Center for Disaster Preparedness; Robert Kaplan, who supported carbon sequestration research; the Hudson River Foundation, which gave three grants for research to examine conditions in the Hudson River; and ConEdison, which helped evaluate a prototype power substation weather monitoring system.

Lamont-Doherty's Advisory Board also continued to grow during this period. Under the leadership of Quentin J. Kennedy, the Board supported production of "Science to Sustain the Planet," a promotional video narrated by Tom Brokaw that highlights Lamont-Doherty's leadership in the earth sciences over more than six decades. The Board also established a competitive seed fund for innovative projects. We are grateful to these individuals whose time and talents are devoted selflessly to furthering the mission of the Observatory.

Finally, we thank more than 400 individual, foundation and corporate donors who have supported Lamont-Doherty over this two-year period through the annual fund, Open House sponsorship and other gifts. Your contributions help ensure the continued leadership of the Lamont-Doherty Earth Observatory in the earth sciences.

Friends of Lamont-Doherty

Friends of Lamont-Doherty (FOLD) recognizes donors who contribute annual gifts of $500 or more to the Observatory for unrestricted gifts to be used at the director's discretion to support special projects or research in need of funding. These leadership gifts enable the continued advancement of research by Lamont-Doherty scientists and students. In return, FOLD members receive special invitations to Observatory events.

Torrey Cliff Society

For many donors, carefully planned gifts can offer significant estate and income tax benefits, while at the same time allowing individuals or families to make a larger impact than would otherwise be possible. The Torrey Cliff Society is comprised of supporters who have included the Lamont-Doherty Earth Observatory in their estate plans or who have made life income arrangements with Columbia University for the benefit of LDEO.

Reflecting the original name of the estate on which the Observatory is located, the Torrey Cliff Society pays homage not only to the extraordinary generosity of Thomas and Florence Lamont who donated their weekend estate—named after famed 19th century botanist John Torrey—to Columbia University in 1948, but also to those who choose to support the Observatory's decades of scientific achievement through gifts of enduring legacy.

TORREY CLIFF SOCIETY MEMBERS AS OF JUNE 30, 2008

Nestor Granelli
Lillian Langseth
John Maguire
Rudi Markl
Andrew and Barbara McIntyre
Marie Tharp (deceased)

Thank you to our donors of $250 and more.

JULY 1, 2006 THROUGH JUNE 30, 2008

Dennis M. Adler and Robin Aronow
Columbia University Alumni Club
AMG Charitable Gift Foundation
American Chemical Society
O. Roger Anderson
Thomas F. Anderson
Anonymous (5)
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The Earth Institute
Electronic Sales of New England
The Estate of Fred Elmer
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Zern Family Foundation

The Advisory Board is made up of community leaders, loyal friends and Lamont-Doherty alumni, all of whom believe deeply in our mission—to generate fundamental knowledge about the origin, evolution and future of the natural world.

[left to right] Advisory Board members Frank Gumper, Dennis Adler, Jeffrey Gould, Leon Thomsen, G. Michael Purdy, Quentin J. Kennedy, Walter Brown and Florentin Maurrasse
Credit: Bruce Gilbert

LDEO ADVISORY BOARD 2006–2008

Quentin J. Kennedy, Chair
Frank J. Gumper, Vice Chair
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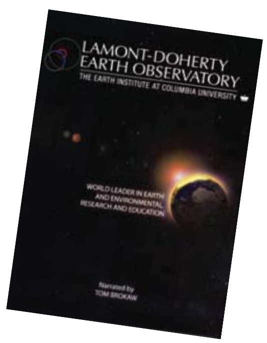
William F. Baker
Walter R. Brown
Steven C. Cande, Ex Officio
Barbara Engel
Jeffrey Stuart Gould
Carolyn P. Hansard
Lawrence R. Lynn
Florentin Maurrasse
W. Barnabas McHenry
Neil Opdyke
Samuel G. Philander
Frank Press
G. Michael Purdy, Director
Ian Strecker
Leon A. Thomsen
Seymour Topping

Members of the Advisory Board build awareness of and support for the Observatory through various projects, such as the production of "Science to Sustain the Planet." Released in early 2008, this DVD, narrated by Tom Brokaw, highlights the achievements of Lamont-Doherty over the last 60 years. Advisory Board members also contribute to an Innovation Fund, awarded on a competitive basis each year to Observatory researchers in need of seed funding for initiatives with potential long-term impact at the Observatory.



Alumni Association

The Observatory draws its strength from the dedicated people who have worked and studied here over the past 60 years, and the Alumni Association strives to connect these "Lamonters" to one another—and to Lamont-Doherty—long after they leave.

Since 1999, an Alumni Association Board has planned the activities of the Association. Membership in the Board reflects the research divisions and departments at the Observatory and includes former scientists, support staff, visiting professors and past graduate students. The Board meets three times a year: at the alumni-sponsored Spring Public Lecture, at Open House in the fall, and at the December AGU conference in San Francisco.

In December 2006 Steve Cande, who received his Ph.D. in marine geophysics from Columbia University in 1977, succeeded Jeff Fox when he stepped down after four years as Alumni Association president. Cande enthusiastically seeks to increase alumni activity and will work closely with Observatory staff to build alumni support.

During the last two years, local alumni board members have expressed interest in the upkeep of Lamont's historic grounds and the preservation of important scientific records. Mary Ann Brueckner spearheaded a Lamont Gardening Group that cares for the rose garden; Rudi Markl committed a planned gift to support landscape preservation; Denny Hayes and Arnold Finck launched a fundraising campaign to support the formal exhibition of significant aspects of Lamont history in the Worzel Room of Lamont Hall.

We are grateful to the many Lamonters who support the Observatory with financial contributions and to those who volunteer time for special projects. We invite all alumni to participate in Association activities. Look for alumni news and upcoming events at www.ldeo.columbia.edu and subscribe to Lamont-Doherty's *Alumni and Friends Newsletter* by sending your contact information to alumni@ldeo.columbia.edu.

LAMONT-DOHERTY ALUMNI ASSOCIATION BOARD OF DIRECTORS 2006–2008

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Steven C. Cande

Directors
Mary Ann Brueckner
Jessica Cherry
Millard Coffin
H. James Dorman
Stephen Eittreim
Emma Christa Farmer
W. Arnold Finck
P. Jeffrey Fox
Rudi Markl
Arthur McGarr
Gregory Mountain
Joyce O'Dowd Wallace
Michael Rawson
William Ryan

[left to right] Alumni Association Board Members
Front Row: Mary Ann Brueckner, Joyce O'Dowd Wallace
Back Row: William Ryan, Arnold Finck, Rudi Markl and G. Michael Purdy
Credit: Bruce Gilbert

Although formally an extension of Columbia University's central operations, the Observatory's administration offers direct, on-site services to the research community on the Lamont campus.

[left to right] Thomas Eberhard, Viriginia Maher, Howard Matza, Maribel Respo, Richard Greco, Victoria Nazario, Edith Miller and Karen Hoffer (Not pictured: Patrick O'Reilly)
Credit: Bruce Gilbert

Central Administration

The primary responsibility of the Lamont-Doherty Earth Observatory's administration is to ensure compliance with the terms and conditions of our funding while facilitating the day-to-day work of the research scientists. To achieve this goal Lamont has created a multitiered administrative management structure that provides the checks and balances necessary to ensure appropriate stewardship of sponsored projects, endowments, gifts and other institutional funding. Although formally an extension of Columbia University's central operations, the Observatory's administration offers direct, on-site services to the research community on the Lamont campus.

Lamont-Doherty's central administrative departments are responsible for a core set of activities including grants and contracts management, finance and accounting, purchasing, human resources, facilities management and engineering, shipping and traffic, and campus safety and security. Administrators also manage a range of ancillary services including a copy center, food services and campus housing operations. In addition to these central departments and activities, each of the five research divisions and Earth Institute programs located on the Lamont campus has an administrator and an administrative assistant who provide day-to-day support to scientists.

Because of the complexity of our programs and the strength of our staff, the Lamont-Doherty Administration is routinely used by Columbia as a test site for new programs and initiatives. We are proud to provide quality services to the Lamont scientific community and to be regarded as administrative leaders within the University.

STATEMENT OF ACTIVITIES (in 1,000s)

Sources of Revenue	2006–07	2007–08	
National Science Foundation	20,119	29, 682	(1)
National Oceanic and Atmospheric Administration	5,696	6,343	
National Aeronautics and Space Administration	2,870	2,704	
National Institute of Environmental Health and Safety	1,460	1,626	
Office of Naval Research	641	600	
U.S. Geologic Survey	808	658	
USDA	53	96	
Department of Energy	71	60	
Department of State	77	30	
Department of the Air Force	230	252	
New York State	0	63	
Government Funds via Subcontracts With Other Institutions	7,225	4,925	
Miscellaneous Federal Funds	120	328	
Total Government Grants	**39,370**	**47,367**	(2)
Private Grants	1,299	995	
Gifts	1,283	870	
Endowment Income	4,616	5,199	
Miscellaneous	70	7	
Indirect Sources	973	1,785	
Total Sources	**47,611**	**56,223**	
Uses of Revenue			
Research Expenses	23,329	23,349	
Instruction and Research Support	3,799	3,608	
General and Financial Administration	3,480	3,300	
Operation and Maintenance of Plant	3,845	4,216	
Equipment	1,994	2,616	
Other Instruction-Related	3,486	9,664	(1)
External Affairs and Fundraising	671	620	
Debt Service	435	923	
Indirect Uses	6,122	6,076	
Total Government Grants	**47,161**	**54,372**	
Net Operating Gain/(Loss)	**450**	**1,851**	
Capital Expenses	(1,932)	(490)	
Transfers From Endowment	95	89	
Subtotal Non-Operating Expenses	(1,387)	(1,450)	
Beginning Fund Balance	9,998	8,611	
Ending Fund Balance	8,611	10,061	

NOTES:
(1) FY08 ship operations begin. 2008 operating year awards are not received until August 2008. Other Instruction-Related is higher due to unbilled 2008 ship operating costs.
(2) FY07 increase of $1.8M due to Ocean Drilling Ltd. Borehole award.

Director's Office

Purdy, G. Michael	Director
Lehnert, Kerstin A.	Administrative Director
Cinquegrana, Miriam I.	Administrative Assistant
Wuerfel, Beverly	Coordinator

Biology and Paleo Environment

D'Arrigo, Rosanne Dorothy	Associate Director
Tiwari, Sandra	Division Administrator

SENIOR SCIENTIFIC STAFF

Cook, Edward R.	Doherty Senior Scholar
D'Arrigo, Rosanne Dorothy	Doherty Senior Research Scientist
DeMenocal, Peter B.	Professor
Griffin, Kevin L.	Associate Professor
Olsen, Paul E.	Professor

JUNIOR SCIENTIFIC STAFF

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Burdloff, Didier	Doherty Associate Research Scientist
Chekalyuk, Alexander M.	Doherty Associate Research Scientist
Juhl, Andrew R.	Doherty Associate Research Scientist
Liepert, Beate Gertrud	Doherty Research Scientist
Sambrotto, Raymond N.	Doherty Research Scientist
Semyanov, Konstantin A.	Associate Research Scientist
Subramaniam, Ajit	Doherty Associate Research Scientist
Wright, William E.	Associate Research Scientist

POSTDOCTORAL STAFF

Anchukaitis, Kevin	Postdoctoral Research Fellow
Lance, Veronica P.	Postdoctoral Research Scientist
Key, Erica	Postdoctoral Research Scientist
Previdi, Michael	Postdoctoral Research Scientist

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Sritrairat, Sanpisa	Graduate Research Assistant

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Jacoby, Gordon
Kukla, George
Marra, John Frank

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Boelman, Natalie T.	Adjunct Associate Research Scientist
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Gastrich, Mary Downes	Adjunct Research Scientist
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Hoshina, Sadayori	Adjunct Research Scientist
Kent, Dennis V.	Adjunct Senior Research Scientist
Koutavas, Athanasios	Adjunct Associate Research Scientist
Langdon, Christopher	Adjunct Research Scientist
Letourneau, Peter M.	Adjunct Associate Research Scientist
Linsley, Braddock	Adjunct Research Scientist
Lynch-Stieglitz, Jean	Adjunct Research Scientist
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McManus, Jerry F.	Adjunct Senior Research Scientist
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Schuster, William S.F	Adjunct Senior Research Scientist
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Class, Cornelia	Doherty Research Scientist
Goldstein, Steven L.	Professor
Hemming, Sidney R.	Associate Professor
Herron, Michael	Visiting Senior Research Scientist
Ho, David T.	Doherty Research Scientist
Kelemen, Peter B.	Arthur D. Storke Memorial Professor
Longhi, John	Doherty Senior Research Scientist
McGillis, Wade R.	Doherty Research Scientist
Plank, Terry A.	Professor
Schlosser, Peter	Vinton Professor Earth and Environmental Engineering
Simpson Jr., Harry James	Professor
Smethie Jr., William Massie	Doherty Senior Research Scientist
Stein, Mordechai	Visiting Research Scientist
Takahashi, Taro	Doherty Senior Scholar
Van-Geen, Alexander F.	Doherty Senior Research Scientist
Walker, David	Higgins Professor

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Kenna, Timothy C.	Doherty Associate Research Scientist
Matter, Jurg M.	Doherty Associate Research Scientist
Newton, Robert	Associate Research Scientist
Schaefer, Joerg M.	Doherty Associate Research Scientist
Straub, Susanne M.	Associate Research Scientist
Winckler, Gisela	Doherty Associate Research Scientist

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Kaplan, Michael	Postdoctoral Research Scientist
Keimowitz, Alison R.	Postdoctoral Research Scientist
O'Shea, Bethany M.	Postdoctoral Research Scientist
Pahnke, Katharina	Postdoctoral Research Scientist
Rodriguez, Sedelia A.	Postdoctoral Research Scientist
Siddall, Mark	Postdoctoral Research Scientist
Variano, Evan A.	Postdoctoral Research Scientist
Yan, Beizhan	Postdoctoral Research Fellow
Yu, Jimin	Postdoctoral Research Scientist

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McGee, David	Graduate Research Assistant
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Radloff, Kathleen A.	Graduate Research Assistant
Schmieder, Paul J.	Graduate Research Assistant
Spieler, Abigail R.	Graduate Research Assistant
Streit, Elisabeth	Graduate Research Assistant
Van Tongeren, Jill A.	Graduate Research Assistant
Wovkulich, Karen M.	Graduate Research Assistant

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Bonatti, Enrico

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Barker, Stephen R.	Adjunct Associate Research Scientist
Bopp, Richard F.	Adjunct Senior Research Scientist
Bory, Aloys Jean-Mathias	Adjunct Associate Research Scientist
Braman, Stuart	Adjunct Associate Research Scientist
Burckle, Lloyd	Adjunct Senior Research Scientist
Brueckner, Hannes K.	Adjunct Senior Research Scientist
Chaky, Damon A.	Adjunct Associate Research Scientist
Cheng, Zhongqi	Adjunct Associate Research Scientist
Cole, Jennifer M.	Adjunct Associate Research Scientist
Commins, Deirdre C.	Adjunct Associate Research Scientist
Denton, George H.	Adjunct Senior Research Scientist
Ebel, Denton S.	Adjunct Associate Research Scientist
Grousset, Francis E.	Adjunct Senior Research Scientist
Hales, Burke R.	Adjunct Associate Research Scientist
Harlow, George E.	Adjunct Senior Research Scientist
Hemming, N. Gary	Adjunct Associate Research Scientist
Henderson, Gideon Mark	Adjunct Associate Research Scientist
Hohmann, Roland	Adjunct Associate Research Scientist
Kavner, Abby	Adjunct Associate Research Scientist
Langmuir, Charles H.	Adjunct Senior Research Scientist
Machlus, Malka L.	Adjunct Associate Research Scientist
Mandeville, Charles William	Adjunct Associate Research Scientist
Marcantonio, Franco	Adjunct Research Scientist
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Matsumoto, Katsumi	Adjunct Associate Research Scientist
Rinterknecht, Vincent R.	Adjunct Associate Research Scientist
Rutberg, Randye L.	Adjunct Associate Research Scientist
Shepherd, John G.	Adjunct Senior Research Scientist
Stute, Martin	Adjunct Research Scientist
Sweeney, Colm	Adjunct Associate Research Scientist
Tomascak, Paul B.	Adjunct Associate Research Scientist
Torgersen, Thomas	Adjunct Research Scientist
Turk, Daniela	Adjunct Associate Research Scientist
Van De Flierdt, Christina-Maria	Adjunct Research Scientist
Walsh, Daniel C.	Adjunct Senior Research Scientist
Webster, James Dale	Adjunct Research Scientist
Zellmer, Georg F.	Adjunct Associate Research Scientist
Zheng, Yan	Adjunct Research Scientist

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Ross, James M.	Staff Associate
Schwartz, Roseanne G.	Staff Associate
Fleisher, Martin Q.	Senior Staff Associate
Mey IV, Jacob L.	Senior Staff Associate
Protus Sr., Thomas J.	Senior Electronic Technician

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Lee, Hoyle	Systems Analyst/ Programmer Intermediate

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Criscione, Deborah C.	Administrative Assistant
Dachille, Anthony	Senior Research Staff Assistant
Frisch, Jeremy	Laboratory Assistant
Fromentin, Daphnee	Administrative Assistant
Hickey, Emily R.	Laboratory Assistant
Ilano, Arturo	Laboratory Assistant
Martin, Maxwell D.	Laboratory Assistant
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Mendelson, Mieczyslawa	Senior Research Staff Assistant
Palmer, Emerson	Research Staff Assistant
Penman, Donald E.	Research Staff Assistant
Reid, Matthew C.	Research Staff Assistant
Rollins, Nathan A.	Research Staff Assistant
Sprecher, David A.	Laboratory Assistant
St. Clair, Uranise Moanna A.	Administrative Assistant
Suriani, Arlene	Administrative Assistant
Sutherland, Stewart C.	Research Staff Scientist

Marine Geology and Geophysics

Buck IV, Walter R.	Associate Director
Odland, Sarah K.	Division Administrator

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[bottom] Front Row: Thomas Eberhard, Patricia Ables, James Brothers and Antonio Deloatch
Back Row: Bernard Gallagher, Robert Daly and Brendan Murphy
(Not pictured: Marice Mack and Juan Torres)
Credit: Bruce Gilbert

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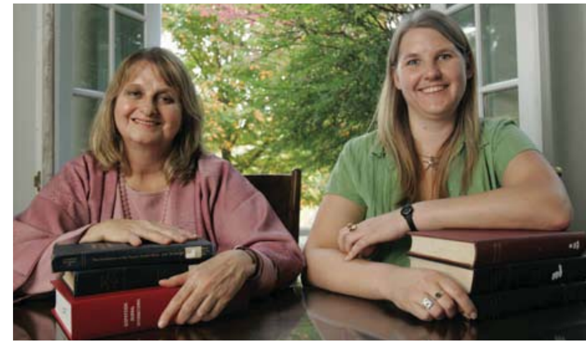

[left to right] Miriam Colwell and Amanda Bielskas
Credit: Bruce Gilbert

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Karlyn, Albert	Chief Engineer
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Front Row [left to right]: Thomas Burke, Richard Trubiroha, Leonard Sullivan, Charles Jones, Kevin Sullivan, Margaret Marrone and Bruce Baez
Back Row [left to right]: Raymond Slavin, Eric Soto, Richard Greco, Douglas Yano and Patrick O'Reilly
(Not pictured: Josep Casilli, Herbert Muench and Jacqueline Murray)
Credit: Bruce Gilbert

Two Giants of Geochemistry: From the Old Lamont Estate's Kitchen to a New State-of-the-Art Laboratory

J. Laurence Kulp

Gary Campbell Comer

J. LAURENCE KULP (1921–2006)
Pioneered chemical methods to study Earth

When the Lamont Geological Observatory was founded in 1949, research driven by World War II had set the stage to transform the field of earth sciences. In those early years, "two distinct scientific kingdoms existed at Lamont," said geochemist Wally Broecker, who came to the Observatory in 1952. "The dominant one was Maurice Ewing's geophysics and marine geology realm. But running strong and independently was the isotope geochemistry program of J. Laurence Kulp."

While Ewing blazed one trail, applying modern physics to the study of our planet, Kulp just as eagerly rushed to infuse chemistry into geology, opening up wholly new and unexplored lines of inquiry.

From the lab Kulp established in the kitchen and basement of the Lamont estate, he measured radioactive isotopes in rocks and water, giving scientists the abilities to track and date past events. At the same time, Kulp gathered young, enthusiastic researchers to perfect the novel techniques and explore wide-ranging and previously unanswerable questions about how the Earth system works. Broecker called it "a scientific Garden of Eden."

Kulp himself headed Project Sunshine in the 1950s to determine how much radioactive strontium-90 fallout from atomic bombs landed on soil and moved up the food chain to be incorporated into human bones, where it could induce cancer-causing mutations, especially in growing children.

Nearly 10,000 bone samples from cadavers of people of different ages and dietary regimes all over the world arrived at what came to be known as Kulp's Kitchen and were tested for strontium-90. The study launched a Lamont-Doherty tradition of tackling global environmental questions, and the results of Kulp's work helped to persuade politicians to negotiate the 1963 treaty banning atmospheric testing of nuclear weapons.

In 1965, Kulp moved on to run a business he created. He passed away in 2006, but the scientists he trained dispersed to universities and industries worldwide; and Lamont geochemists carried on Kulp's legacy, studying isotopes in rocks, rivers, oceans and ice to make breakthroughs in understanding how our planet works.

GARY CAMPBELL COMER (1927–2006)
Advanced scientific capacity to understand our planet

After a lifetime spent building a highly successful business, most people might rightfully turn their sights to retiring in comfort in warmer latitudes. Fortunately for earth science, Gary Comer chose a more northerly route through his golden years.

"I never expected my dad to retire," said his daughter Stephanie. "He always incorporated ideas and projects in the daily fabric of his life, and his excitement was infectious. You wanted to be in on his projects."

In 2001, the founder of the Lands' End catalogue clothing company took on a new project; he set out to navigate the Northwest Passage, a route north of Canada historically choked with ice, in his yacht *Turmoil*. When he did not need an icebreaker and traveled the passage with little difficulty, he began to wonder why.

Comer attacked the question in the same way that he built his business—through dogged research and advice from the most knowledgeable people. As he researched climate change, he kept running across the name Wally Broecker, so it was only natural that he would turn to the Lamont-Doherty geochemist for help. When the two finally met, Comer was inspired to make an impact on science and Broecker found a renewed sense of determination.

"He's really made a difference to me," Broecker told the journal *Science* in 2006. "He caught me at a time when I was thinking of retiring. He inspired me and gave me a mission."

To help facilitate the extension of Broecker's already legendary career, Comer helped give Lamont-Doherty's geochemists a new home: the Gary C. Comer Geochemistry Building, which was largely funded by an $18 million gift from Comer and dedicated in 2007. Comer's commitment to earth science also included support for young researchers and even contributions to peer-reviewed journal articles.

Comer passed away in October 2006, leaving behind an enduring legacy—one that will better enable scientists to unravel the complexities of Earth's climate.

Credits: Philip Walsh, Stephanie Comer, Richard Alley, Comer Family Archives

Lamont-Doherty Earth Observatory Celebrates 60 Years

LDEO 60

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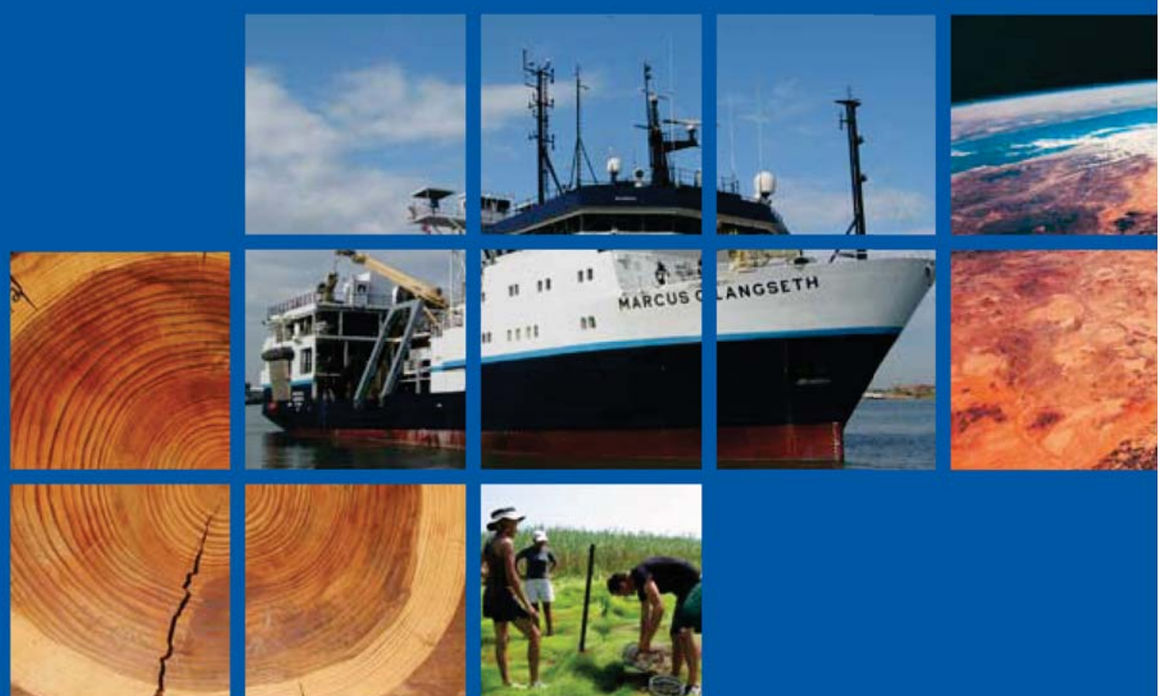
In the City of New York



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