Department of Earth, Atmospheric, and Planetary Sciences

The Department of Earth, Atmospheric, and Planetary Sciences (EAPS) has broad intellectual horizons that encompass the solid Earth, its fluid envelopes, and its diverse neighbors throughout the solar system and beyond. The department seeks to understand the fundamental processes that define the origin, evolution, and current state of these systems and to use this understanding to predict future states. The department currently comprises 39 faculty, including two with primary appointments in Civil and Environmental Engineering, and over 110 research staff, postdoctoral appointments, and visiting scholars.

EAPS is notable for its emphasis on interdisciplinary problems. The Earth Resources Laboratory and the newly formed Kuwait Center at MIT bring together faculty, staff, and students in intensive and multidisciplinary efforts to investigate geophysical and geological problems in energy and resource development. The Center for Global Change Science builds on the programs in meteorology, oceanography, hydrology, chemistry, and satellite remote sensing in the Schools of Science and Engineering. The center joins with the Center for Energy and Environmental Policy Research to form the Joint Program on the Science and Policy of Global Change. This program conducts policy analysis and public communication on issues of global environmental change. With faculty from the departments of Civil and Environmental Engineering, Chemistry, and EAPS, the Environmental Science Initiative fosters collaboration in both research and education on the physical, biological, and chemical interactions that define the Earth.

Educational Activities

Graduate Program

EAPS has vigorous graduate educational programs in geology and geochemistry, geophysics, atmospheres, oceans, climate, and planetary science. During academic year 2005, 157 graduate students were registered in the department, including 67 students in the MIT/Woods Hole Oceanographic Institution (WHOI) Joint Program in Oceanography. Women constitute 40 percent of the graduate student population, and 31 percent of the graduate population is composed of international students.

The excellence of the EAPS Graduate Program is built not only on the strength of the teaching and supervision by the faculty but also on the involvement of the EAPS graduate students in the activities of the department. The students develop both formal and informal ways to improve their educational experience, as well as student life. The departmental Graduate Student Mentoring Program continues as a well-received approach to provide peer support for new students. Student involvement also contributed to an expansion and strengthening of the orientation program for new graduate students. EAPS awards a prize for excellence in teaching to recognize the superior work done by teaching assistants in many of our classes. Last year prizes were awarded to Benjamin Crosby, Peter James Dennedy-Frank, Rebecca Flowers, Jon Moskaitis, and William Ouimet for their service during the academic year. David Fike received the first MIT Global Habitability Longevity Award, awarded for an outstanding

contribution toward understanding long-term environmental trends affecting the Earth and its habitat for supporting life.

Undergraduate Program

Increasing the number of undergraduate majors in the department continues to be a priority. In AY2004, we saw a 9 percent increase in the number of undergraduate majors. In AY2005 we increased our undergraduate major population again—to the highest level in over 20 years. We are committed to maintaining and building upon this new level of undergraduate involvement. The department's commitment to fostering undergraduate research is illustrated by our annual award of the Goetze Prize for Undergraduate Research, presented for research conducted within the Undergraduate Research Opportunities Program (UROP) or for a senior thesis. At the 2005 Commencement, the Goetze Prize was awarded to graduating seniors Lindsay Hayes and Susannah Dorfman.

EAPS presents the undergraduate student body with opportunities to become acquainted with the world from an Earth sciences' perspective. The department acts on its belief that EAPS should have a strong presence in the undergraduate program at MIT beyond our population of majors. In prior years, this has expressed itself in the many UROP projects supervised by EAPS faculty, by participation in freshman advising seminars, and through department sponsorship of a weekly undergraduate seminar. The overwhelming majority of students in these programs have not been EAPS majors.

Faculty

- Professor Raffaele Ferrari was awarded the Killian and Lee Scholar Award.
- Professor John Marshall was awarded the Adrian Gill Prize of the Royal Meteorological Society of the United Kingdom for contributions to oceanography.
- Professor F. Dale Morgan was named codirector of the Kuwait Center at MIT.
- Professor Paola Malanotte-Rizzoli served as associate chair of the faculty.
- Professor Julian Sachs will be promoted to associate professor without tenure on July 1, 2005.
- Professor Sang-Heon Dan Shim was awarded the Jeptha H. and Emily V. Wade Award.
- Professor Maria Zuber received the NASA Distinguished Public Service Medal and was elected to membership in the American Philosophical Society.

Current Research

Professor Samuel Bowring's research group is working on two major themes: the origin and evolution of the continental lithosphere and using high-precision geochronology to sequence the history of life. Professor Bowring's leadership in geochronology contributed to the approval of the National Science Foundation's Earthtime Initiative, which will create a virtual network of geochronology labs that will sequence Earth history at better than 0.1 percent.

Professor Edward Boyle and his group have continued their work on trace element chemical oceanography and marine paleoclimatology. This year's major activity was a research cruise in the western North Atlantic to trace the advective transport of lead

by the upper and lower North Atlantic Deep Water. In addition, they obtained the first data on the zinc (Zn) isotopic composition of deep seawater, as well as measurements of plankton from throughout the North Pacific and North Atlantic. Professor Boyle has also spent time organizing a new international program to determine the global distribution of trace elements and their isotopes (GEOTRACES).

Professor Clark Burchfiel's main research effort continues from 24 years of work in China and focuses on the tectonic evolution of the eastern part of the Tibetan Plateau and regions to the southeast into Indochina. A second area of research has been in the Balkan region of southern Europe, where the Cenozoic history of extensional tectonism has yielded a complex evolution.

Professor James Elliot, his students, and colleagues have completed their four-year survey of the ecliptic with wide-field cameras at the Kitt Peak and Cerro Tololo observatories. They discovered 500 new Kuiper belt objects (pristine samples of the early solar nebula) orbiting the sun beyond Neptune. Most of these newly discovered objects now have well-determined orbits, which facilitates investigations of the dynamical history of the solar system.

Professor Kerry Emanuel spent much of the past year engaged in new pursuits related to assessing hurricane risk and how that might be affected by global warming. Working with a postdoc and a series of visiting undergraduate interns from France, he developed a new technique for comprehensively assessing hurricane risk in any given climate. Models run under a global warming scenario with a modest increase in tropical ocean temperatures of 0.5° C yielded an 80 percent increase in the destructive potential of tropical cyclones, consistent with observations over the past 50 years.

Professor Brian Evans and coworkers are working to understand the evolution of transport properties including permeability and electrical resistivity and of mechanical properties including brittle fracture strength and plastic flow strength. One important result that has emerged is that pore structures may be altered quite rapidly in a geologic sense.

Professor Raffaele Ferrari is the principal investigator of the Climate Process Team on Eddy-Mixed Layer Interactions, the purpose of which is to improve climate models. In addition, he is studying the role of eddies in the formation of water masses as part of the CLIMODE project, aimed at collecting information on the variability of the upper ocean.

Professor Tim Grove and his colleagues have been measuring the solubility of helium in minerals and melts and have produced the first experimental determination of the solubility of this important noble gas. They have found that helium (He) is more soluble in the most common mineral in the Earth's mantle—olivine—than the elements uranium (U) and thorium (Th). This is important because it allows a new interpretation of the significance of high $^{3}He/^{4}He$ that is found in some mantle reservoirs.

Professor James Hansen is exploring the impact of model inadequacy and nonlinearity on state estimation, ensemble construction, and probabilistic forecasting. He is developing a laboratory analog of atmospheric/oceanic flow for both research and education purposes.

Professor Thomas Herring and his group are using high-precision global positioning system (GPS) measurements to study tectonic deformation over much of the southern Eurasian plate boundary, southern New Zealand, and the western United States. The group is also involved in monitoring and modeling human-induced deformations in oil fields.

Professor Richard Lindzen and his research group are working on a number of different problems in the broad areas of climate and atmospheric dynamics. In one study, they are working on improving techniques for using geostationary satellite data to measure rainfall and to determine cumulus mass flux, which is potentially an important negative feedback for climate. In addition, they are analyzing meteorological data to determine the degree to which and the mechanism whereby subtropical jet instabilities drive the Madden-Julian Oscillation, a 40–50 day planetary scale oscillation in the neighborhood of the equator.

Professor John Marshall is studying the role of the ocean in climate and climate variability. His recent focus has been on the dynamics and (in collaboration with Mick Follows and his group) the biogeochemistry of the Southern Ocean. As part of MIT's Climate Modeling Initiative, he has been studying geometrical constraints on ocean heat transport and the partition of heat transport between the atmosphere and ocean in the context of highly idealized coupled atmosphere-ocean-ice models.

Professor F. Dale Morgan assumed the codirectorship of the Kuwait Center at MIT, a joint effort by the Institute and the country of Kuwait to perform research on scientific and technological aspects of hydrocarbon identification and extraction, including environmental impacts.

Professor Ronald G. Prinn and colleagues in the Advanced Global Atmospheric Gases Experiment (AGAGE) have reported and used 26 years of AGAGE measurements of 1,1,1-trichloroethane to deduce annual global hydroxyl radical (OH) values for 1979–2003. They infer a small maximum around 1989 and a larger minimum around 1998, with OH levels in 2003 being comparable to those in 1979. The minimum coincides with and is likely caused by major global wildfires and an intense El Niño at that time.

Professor Paola Malanotte-Rizzoli has continued to work on transport and heat exchanges between the subtropical and the tropical Atlantic Ocean and how they affect the global thermohaline circulation and development of ensemble data assimilation approaches to improve the predictability of ocean circulation models. As director of the MIT/WHOI Joint Program in Oceanography, she continues to play an important role in the graduate education in oceanography.

Professor Stéphane Rondenay's group is involved in two key areas of solid Earth seismology: the acquisition of high-quality data sets from seismic arrays and the development and application of new teleseismic approaches to image structure in the Earth's crust and mantle. His principal recent work is in seismic imaging of the upper mantle beneath a craton in northern Canada.

Professor Daniel Rothman and his group continue their work in the fields of geobiology and geomorphology. The work in geobiology primarily concerns the events in the late Proterozoic that led to the Cambrian explosion. In collaboration with EAPS geochemist Roger Summons, Rothman is developing new theoretical models for the interpretation of the changing carbon isotopic compositions of carbonate, bulk organic matter, and specific "biomarkers" or "molecular fossils." Work in geomorphology has led to a new theoretical model for the erosion of channels by subsurface "seepage" flows.

Professor Julian Sachs is discovering episodes of abrupt climate change in the recent geological past. A new effort is aimed at using the hydrogen isotopic ratio of algal lipids preserved in ocean and lake sediments to evaluate past changes in the balance between precipitation and evaporation.

Professor Sang-Heon Dan Shim has conducted synchrotron measurements to determine the atomic-scale structure of a lower mantle mineral recently codiscovered by his research group. He also recently completed a nanosecond time-resolved Raman system at a high-pressure lab at MIT. This is the first Raman system that is designed for in situ measurements at high pressure and temperature in the diamond anvil cell. The lab will be used to study mantle phase diagrams and thermodynamic properties using this system.

Professor Peter Stone and colleagues have carried out a study of the response of the meridional overturning circulation in the North Atlantic to greenhouse gas forcing. They used a coupled model of intermediate complexity whose ocean component was the MIT 3-D ocean general circulation model. The results show that there is a simple bifurcation separating the runs where the circulation collapses from those where it does not. The bifurcation is given by a critical value of the product of the total carbon dioxide (CO_2) increase and the sensitivity.

Professor Roger Summons and his group are studying intact polar lipids of marine cyanobacteria and a range of microbes from culture collections and extreme environments such as Yellowstone National Park and the Lost City hydrothermal vents of the Mid-Atlantic Ridge. They are also studying the dynamics of the carbon cycle during major redox transitions of the ocean-atmosphere system, with emphasis on analysis of sediments from Oman deposited during the radiation of the first animals.

Professor Rob van der Hilst and his coworkers analyzed broadband seismic observations to reveal variations in mantle temperature and bulk composition below 1,000 km depth under the northern Pacific and the Americas. With a technique adapted from application in the oil industry, they also began an ambitious effort to image in unprecedented detail the Earth's core mantle boundary. Professor van der Hilst also led a seismological field campaign in southwest China to image mantle structure and understand regional tectonics and seismicity.

Professor Kelin Whipple and his group showed that the details of erosion processes are critically important to the strength and nature of the dynamic coupling between climate-driven erosion and tectonics, controlling the sensitivity of mountain-belt width,

topographic relief, and rock uplift rate to climatic and tectonic variables. His work clarified how climate and tectonics combine to exert a fundamental control on particle paths through the crust.

Professor Jack Wisdom has been studying the evolution of the lunar spin axis. Prior work has assumed that the inclination of the lunar orbit is constant and that the node regresses uniformly. His new work takes into account the nonconstant inclination and nonuniform regression of the node as determined from averaged models of the motion of the lunar orbit.

Professor Carl Wunsch and his group are increasingly employing the knowledge and tools of physical oceanography to understanding the record of past climate change. This work involves a combination of modeling, time-series analysis, and theory. They are reexamining many of the basic hypotheses commonly used to explain climate variability, including the Milankovitch hypothesis and the spatial structures of changes.

Professor Maria Zuber and colleagues completed development of a laser ranging device that has been launched on the MESSENGER mission to Mercury, and they were selected to develop and build a laser altimeter for the Lunar Reconnaissance Orbiter to be launched in 2008. Her group is studying the variability of the Martian atmosphere and the annual and interannual variations of Martian volatile cycles.

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More information about the Department of Earth, Atmospheric, and Planetary Sciences can be found online at http://eapsweb.mit.edu/.