Department of Earth, Atmospheric, and Planetary Sciences

The Department of Earth, Atmospheric, and Planetary Sciences (EAPS) has broad intellectual horizons encompassing the solid Earth, its fluid envelopes, and its diverse neighbors throughout the solar system and beyond. The department seeks to understand fundamental processes that define the origin, evolution, and current state of these systems and to use this understanding to predict future states. The department comprises 39 faculty (including one with a primary appointment in Civil and Environmental Engineering and one with a primary appointment in Engineering Systems Division), and more than 170 research staff, postdoctoral appointments, and visiting scholars.

EAPS is notable for its emphasis on interdisciplinary problems and is involved in numerous laboratories, centers, and programs that address broad questions in the Earth sciences. The Earth Resources Laboratory and Kuwait-MIT Center for Natural Resources and the Environment 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, satellite remote sensing, and policy. The MIT/Woods Hole Oceanographic Institution (WHOI) Joint Program continues in its mission of graduate education and research in ocean sciences and engineering.

Educational Activities

Graduate Program

EAPS has vigorous graduate educational programs in geology, geochemistry, geobiology, geophysics, atmospheres, oceans, climate, and planetary science. In fall 2009, EAPS had 158 graduate students registered in the department, including 67 students in the MIT/WHOI Joint Program. Women constituted 49 percent of the graduate student population, and four percent were members of an underrepresented minority group.

The excellence of the EAPS graduate program is built not only on the strength of teaching and supervision by the faculty but also on the involvement of EAPS graduate students in departmental activities. Students develop formal and informal ways to improve educational experience as well as student life. The department graduate students meet regularly, with one of the students presenting his/her research. Undergraduate majors are encouraged to attend these talks. The departmental Graduate Student Mentoring Program continues as a well-received approach to provide peer support for new students.

EAPS awards a prize for excellence in teaching to highlight the superior work of teaching assistants. During the 2010 academic year, Kyle Bradley, Michael Krawczynski, Hendrik Lenferink, and Jean-Arthur Olive were recognized. Daniel Enderton received the 2010 Rossby Award, presented for the best PhD thesis in the Program of Atmospheres, Oceans, and Climate.

Undergraduate Program

In the past year, the department updated its curriculum to enable students to take advantage of the interdisciplinary nature of our research fields and build on the strengths of new faculty. The new curriculum also provides the opportunity for the study of geobiology, an area of increasing student interest. In fall 2009, EAPS had 29 undergraduate majors, 75 percent of whom were women and 24 percent of whom were members of an underrepresented minority group. Eight students were awarded the SB degree in Earth, Atmospheric, and Planetary Sciences in AY2010.

At the 2010 Student Awards and Recognition Dinner, the Goetze Prize was awarded to Elizabeth Maroon in recognition of her outstanding senior thesis, Stephanie Brown received the W.O. Crosby Award for Sustained Excellence, and Alexandra Jordan was the recipient of a newly created Award for Excellence as an Undergraduate Teaching Assistant.

The department maintains a strong presence in the undergraduate program at MIT beyond the population of majors so that the general student body has access to the science underlying energy, environmental, and climate change issues. The department is committed to the Terrascope program and its problem-based approach to education during the first year at MIT, and to offering Freshman Advising Seminars. Similarly, EAPS is an active participant in the new interdisciplinary Energy Minor, with two new courses that are components in the Energy Science Foundation section of the requirements and with two classes that are electives for the minor. EAPS has formed a collaboration with the Department of Aeronautics and Astronautics to provide science rationale and input to three engineering design courses.

Community Events

The department aims to create collaborative opportunities within EAPS, at MIT, and outside the Institute. The department hosted several weekly lecture series and a memorial lecture, open to the MIT community and the public. Professor Peter G. Baines, University of Melbourne, Australia, was this year's invited Houghton Lecturer and gave two lectures focused on patterns of decadal climate variability. The 10th annual Henry Kendall Memorial Lecture was held on May 7 and professor David Battisti of the University of Washington gave a talk on geoengineering. Additionally, there was significant departmental involvement in the MIT Energy Initiative Fall Research Conference on September 17–18, the Women in Aerospace Symposium on October 19–20, the Climategate Forum on December 10, and the Rethinking Water Symposium on May 20–21.

In alumni outreach, EAPS faculty actively participated in the department's development efforts, participating in 17 events geared toward alumni and friends. These included the annual reception for EAPS alumni at the fall meeting of the American Geophysical Union in San Francisco; a dinner for EAPS alumni in Houston generously hosted by Jie Zhang, PhD '97; a "Jimboree" in celebration of the achievements of professor James L. Elliot; and talks at MIT Clubs of Boston, Santa Barbara, and New York.

Faculty

The department continues its efforts to hire and promote young faculty members. Effective July 1, 2010, Sara Seager, Ellen Swallow Richards professor of planetary science, will be promoted to full professor.

Professor Frederick A. Frey recently retired after 44 years of service to MIT and a symposium in his honor was held on June 11–12. The event featured scientific talks by prominent colleagues of Dr. Frey, personal reminiscences by family, friends, and colleagues, and a reception and dinner.

Honors and Awards

Assistant professor Linda Elkins-Tanton has been chosen to receive the Lowell Thomas Award from the Explorers Club.

Professor John Marshall received the Audrey Buyrn and Alan Phillips' Ally of Nature Award for his contributions to environmental research.

Assistant professor Paul O'Gorman was awarded the Victor P. Starr career development chair.

Assistant professor Taylor Perron was named a member of the Canadian Institute for Advanced Research.

Professor Maria Zuber shared a NASA Group Achievement Award recognizing the achievements of the Lunar Reconnaissance Orbiter Laser Ranging Team.

Research Highlights

Professor Richard Binzel's analysis, published in *Nature*, of the spectral colors of asteroids making close encounters with the Earth (within about 1/3 the lunar distance) reveal evidence that the Earth can induce "seismic shaking" on these objects. The seismic activity is revealed by a change of color that results from fresh new surface grains (regolith) being exposed as a result of the shaking. While classical physics tells us that tidal forces from the Earth will rip apart any small body passing within about two Earth radii (known as the Roche limit), Binzel's work points to an important new understanding that encounters far outside the Roche limit have physical consequences as well.

Professor Edward Boyle obtained the first profile of anthropogenic lead (Pb) in the Indian Ocean, finding high levels in surface waters due to late phase-out of leaded gasoline by nations in the region. He also obtained the first oceanic (W.N.Atl.) Pb isotope data that includes precise data on the scarce isotope Pb-204 (1.4 percent of total Pb), providing three dimensions of isotope fingerprinting for identifying sources of Pb. He also mapped the distribution of natural iron (Fe) in the upper 1,000 m of the tropical North Atlantic and found that all levels show that Fe:Carbon remineralization is a factor of 3–4 higher than other regions of the ocean, which he attributes to the supply of iron from North African desert dust.

For the past year, professor Clark Burchfiel has been working on a book on the tectonics of southeastern Tibet and adjacent regions." It will be the summary of 25 years of work between MIT and Chinese colleagues from the Chengdu Institute of Geology and Mineral Resources. The book will be unique in geological literature because it will have with it two digital maps covering the geology of a huge area of Southeast China that can be manipulated by the reader. The maps will be on CDs containing files in Adobe Illustrator or other programs that can be upgraded, and will have particular features and layers highlighted so that the reader may display just certain layers to do their own syntheses. Such maps have not been published in the geological literature before, and he hopes it will start a new trend for all geological maps.

Professor Elkins-Tanton's group is making encouraging progress on the role of melting in the evolution of the Earth and planets. She and her group developed models to simulate how accreting protoplanet interiors could have melted during the first few million years of planet formation, producing magnetic dynamos; some of these bodies may remain in the asteroid belt today. They have also developed models to show that the formation of the earliest atmospheres on young planets were likely not continuous, but occurred in a violent burst at the end of solidification. She and her group have also collected and analyzed Siberian flood basalts and determined that their eruption released chlorofluorocarbons into the atmosphere at a rate at least 10^3 times higher than mankind's peak. The work sheds light on a process that could have contributed to extinctions in the Earth's geologic record.

Professor Elliot and his students and colleagues recorded the first stellar occultation by a Kuiper belt object (KBO), with two successful stations in Hawaii for the October 8, 2010 occultation by KBO 55636. They found that 55636 has a radius of 143 ± 5 km, much smaller than previously thought. Hence this body reflects nearly 90 percent of the incident sunlight, which is consistent with a water-ice surface that had been inferred from spectroscopic observations. KBO 55636 is thought to be a member of a collisional family of KBOs formed over a billion years ago.

Professor Kerry Emanuel has been working on various aspects of cumulus convection of relevance to understanding the climate system. He proposed that the phenomenon of self-aggregation of cumulus clouds into large-scale clusters might be understood as an example of self-organized criticality of the ocean-atmosphere system that, if true, would lead to a strong regulation of tropical climate. He continues work on tropical cyclones and has recently coupled his hurricane model to a model of storm surges. Professor Emanuel served on the special review of the University of East Anglia climate research unit, headed by Lord Oxburgh, in the wake of the climategate scandal.

Professor Frey and associated students and staff are doing geochronological and geochemical studies of lavas recovered from the 5000-km-long, north-south, linear trend of submarine volcanoes forming the Ninetyeast Ridge in the Indian Ocean. Determination of eruption ages show a systematic south-to-north increase in age indicating that this volcanic chain formed as the Indian Plate migrated northward, eventually colliding with Southeast Asia, over a nearly fixed hotspot magma source. Compositions of these lavas are diverse and unlike lavas erupted at spreading ridges; consequently they can constrain and understand the processes, such as deep recycling of oceanic plates that lead to hotspot volcanoes.

Professor Timothy Grove and students have performed experiments on certain lunar glasses to gain a better understanding of melting processes in the deep lunar interior. Astronauts discovered this unique lunar volcanic deposit during the Apollo 15 mission. The deposit consisted of a layer of nearly pure emerald green glass beads that were erupted on the lunar surface in a fire fountain event. The eruption temperatures were very high (> 1500 ^{o}C) making these magmas some of the highest temperature eruptions in the inner solar system. Melting and crystallization studies on these lunar magmas have allowed the composition of the Moon's deep interior to be inferred. Early in lunar history a magma ocean was present on the Moon; this work constrains the volume of melting and the processes by which it formed.

Professor Thomas Herring is using global positioning system (GPS) and very long baseline interferometry data to develop geophysically based models of changes in the rotation of the Earth and Earth deformations on global, regional, and local scales. He is also using interferometric synthetic aperture radar to study fine-scale surface deformations. The geodesy and geodynamics group in the department is using high-precision GPS measurements in many different study areas. These areas include the tectonic deformations over much of the southern Eurasian plate boundary, southern New Zealand, and the western United States. Processes on time scales of years leading up to earthquakes, days to years in the domain of post-seismic deformation, and seconds for surface wave propagation during earthquakes, are all studied. The group is also involved in monitoring and modeling human-induced deformations in oil fields.

In the last year, assistant professor Oliver Jagoutz and his research group continued study of formation and evolution of the continental lithosphere. They determined the composition of new crust formed in modern island arc settings, and investigated physical and chemical processes that lead to formation. They also determined the precise time of the initiation of the collision of India and Asia that produced the Himalayan mountains.

Assistant professor Alison Malcolm continues to make progress on the development of imaging algorithms for complicated geological problems. She and her group are developing algorithms capable of imaging the change in a reservoir with applications to CO_2 sequestration and to heavy oil. They have been developing methods of seismic interferometry with sparse source coverage with applications in particular to hydraulically fractured geothermal and oil reservoirs. They are also using multiply scattered waves to improve images and are also developing methods of change detection and scattering strength in geological media. This work has applications in the oil industry and in CO_2 sequestration.

Professor Marshall's research interests are in the role of the ocean in climate and climate variability. A recent focus has been on the dynamics and biogeochemistry of the southern ocean. As part of MIT's Climate Modeling Initiative, he has also been studying geometrical constraints on ocean heat transport and the possibility that the climate may possess multiple equilibria.

Professor O'Gorman's group focuses on understanding atmospheric circulations and the hydrological cycle and how they vary under climate change. His recent research has focused on the question of how best to account for moist processes in simple dynamical theories of the atmospheric general circulation. This is important because most existing theories for the general circulation do not take into account latent heating associated with phase changes of water, and latent heating is expected to increase in magnitude in a warmer atmosphere. They also recently submitted a paper on changes in the distribution function of tropical precipitation that occur in response to a warmer atmosphere. The models resolve the dynamics of moist convection and are expected to be more reliable than simulations with the coarse-resolution global climate models that are currently available.

Professor Perron's group is studying the self-organization of river networks and the response of landscapes to varying climate. To understand how the familiar branching pattern of river networks emerges, they are building numerical landscape evolution models and comparing the predictions with airborne LIDAR surveys of sites in the California Coast Ranges and the Appalachian Plateau. The first stage of this project led to a recent *Nature* paper explaining the origin of uniformly spaced ridges and valleys.

Professor Ronald Prinn and colleagues have published a new probabilistic forecast for 21st-century climate indicating much greater odds for significant warming, absent policy, than previously estimated. Six recent papers report new emission estimates for the important greenhouse and ozone depleting gases SO_2F_2, CF_4, C_2F_6, C_3F_8, CHF_3, CCl_4, CH_3Cl, SF_6 and CH_4. Other papers report on the evolution of wildfire plumes, the cycles of pollution in Nepal, the emissions of ozone-depleting gases from waste sites, and the significant climate impacts of very large-scale deployment of wind turbines.

Professor Paola Rizzoli and her postdoctoral associates have continued in their work in the tropical Pacific/Indian oceans with focus on the South China Sea and the Indonesian through-flow. Areas of emphasis include transport dynamics, storm surges, and coupled models of climate variability in the Pacific and Indian oceans. Professor Rizzoli stepped down on September 1, 2009 from her position as director of the MIT/WHOI Joint Program in Oceanography. In recognition of her 12 years of service, the WHOI Board of Trustees has established the Paola Rizzoli Fellowship for a first year Joint Program student starting with the 2010–2011 academic year.

Professor Daniel Rothman has developed a method to transform chemical signals in the rock record to physical fluxes in the past carbon cycle. By applying this new technique to the geochemical record of the end-Permian extinction, he has shown that the late Permian carbon cycle underwent an instability similar to that of a singular blow-up. Aside from its dynamical interest, this result provides a way to test hypotheses for end-Permian environmental change and, ultimately, the causes of the extinction.

Assistant professor Noelle Selin's current research focuses on providing policy-relevant insights into air pollution issues such as mercury pollution, health impacts of aerosols and other pollutants, and pollutant-climate change interactions. A recent paper on mercury combined atmospheric modeling with ecosystem and ocean modeling in order to identify the sources of mercury exposure for US seafood consumers, and implications for policy over time. In the area of pollutant-climate change interactions, she and her group recently published a paper estimating the global health and economic implications of future ozone pollution.

Associate professor Sang-Heon Dan Shim's work on the perovskite to post-perovskite transition has generated much excitement and work in the field of geophysics over the past five years. This transition appeared to explain many seismic observations at the core-mantle boundary region, sources of which have been enigmatic. However, they found that iron and aluminum increases the thickness of the perovskite to post-perovskite transition to 400–600 km, which is much larger than the seismologically inferred thickness (< 30 km) of the D″ discontinuity that overlies the core. Their results challenge the isochemical phase transition model for D″, and suggest other effects, such as compositional change, as an explanation.

Professor Carl Wunsch and his students, postdocs, and collaborators continue their efforts to understand the climate system, past and present, with a specific focus on the role of the ocean. The so-called Estimating the Circulation and Climate of the Ocean consortium has developed models, data sets, and optimization machinery permitting the discussion of the three-dimensional global ocean circulation and its transports of heat, nutrients, etc., both in the modern and paleo worlds. Much effort is directed at understanding the extent to which real trends exist in the modern circulation and what if anything they imply about future climate states.

Using data from their laser altimeter on the Lunar Reconnaissance Orbiter spacecraft, Professor Zuber and colleagues published a topographic model for the Moon that is the highest spatial resolution global altimetry model for any planet. As part of this experiment, they also demonstrated the first use of Earth-based laser ranging in precision orbit determination of a spacecraft in orbit around another planetary body. Professor Zuber's Gravity Recovery and Interior Laboratory (GRAIL) mission, the first robotic space mission led by MIT, passed its critical design and system integration reviews, and is on track for a September 2011 launch.

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