

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 Biology), 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, and satellite remote sensing in the Schools of Science and Engineering. The MIT/Woods Hole Oceanographic Institution (WHOI) Joint Program continues in its mission of graduate education and research in ocean sciences and oceanographic engineering; the 40th anniversary of the MIT/WHOI Joint Program was celebrated on September 25, 2008.

Educational Activities

Graduate Program

EAPS has vigorous graduate educational programs in geology, geochemistry, geobiology, geophysics, atmospheres, oceans, climate, and planetary science. During the past academic year, 195 graduate students were registered in the department, including 75 students in the MIT/WHOI Joint Program. Women constitute 41 percent of the graduate student population.

The excellence of the EAPS graduate program is built not only on the strength of teaching and supervision by the faculty but also on involvement of EAPS graduate students in departmental activities. Students develop formal and informal ways to improve educational experience as well as student life. The graduate students in three of the four discipline groups meet weekly, with one of the students presenting his/her research. In an outreach to the undergraduate majors, the graduate students encourage them to attend and hear the talks. The departmental Graduate Student Mentoring Program continues as a well-received approach to providing peer support for new students. This year, the graduate students laid the groundwork for an improved and more flexible program in AY2010. The junior graduate student is now encouraged to extend his/her support network beyond the original mentor to additional senior graduate students and/or postdocs. In addition, the mentor program coordinator will send out a monthly newsletter that includes suggested topics for discussion at mentor-mentee meetings. Funding for the revised program is being supplied by EAPS and a student life grant from the Office of the Dean for Graduate Education.

EAPS awards a prize for excellence in teaching to recognize the superior work of teaching assistants in many of our classes. Prizes were awarded to Terrence Blackburn, Laura Meredith, Alexander Petroff, and Alessondra Springmann for service during the 2009 academic year. Elke Hodson is the 2009 recipient of the Rossby Award for her doctoral thesis “The Municipal Solid Waste Landfill as a Source of Montreal Protocol-Restricted Halocarbons in the United States and United Kingdom.” Professor Carl-Gustaf Rossby was the founder of the study of meteorology and physical oceanography at MIT and this award, in his honor, is presented for the best PhD thesis in the Program of Atmospheres, Oceans and Climate (PAOC). Cristina Thomas, a presidential fellow studying the origin of asteroids and meteorites, was featured in the fall issue of *Spectrum*. PAOC master’s student Garrett Marino won the grand prize in the US Department of Energy’s inaugural Science and Energy Research Challenge for his poster titled “False Spring Occurrence over the Southeastern United States, 1901–2007.”

Undergraduate Program

EAPS believes one of the greatest challenges for the department and MIT is to find a pathway to expose every undergraduate at MIT to the earth sciences. With the rise of energy, environmental, and climate change issues as central foci of policy debate, it is critical that our MIT graduates have a knowledge base for discussion and decision making in their role as citizens. The department acts on this belief by maintaining a strong presence in the undergraduate program at MIT beyond our population of majors. The department is committed to Terrascope and its problem-based approach to education during the first year at MIT. We continue to provide many Undergraduate Research Opportunities Program (UROP) projects supervised by EAPS faculty, participate in freshman advising seminars, and sponsor a weekly undergraduate seminar. An overwhelming majority of students in these programs have not been EAPS majors. Similarly, EAPS has been an active participant in planning the new interdisciplinary energy minor. The department will have two new courses included in the science foundations category and three courses among the energy electives.

EAPS looks forward to utilizing the strengths and enthusiasm of our new faculty as we review the curricula for our four tracks within the major and revise and expand our degree requirements. In AY2009, we added a communication intensive in the major (CI-M) subject, 12.335 Experimental Atmospheric Chemistry, to the atmospheres and oceans track. This will provide students interested in atmospheric chemistry with a dedicated CI-M instead of having to take an atmospheric dynamics-focused class.

EAPS began AY2009 with 27 undergraduate majors. The students organize and run both the Geology Club and the Weather/Climate Club. Each has an active schedule of meetings. The Geology Club runs local field trips over weekends. In addition, a delegation attended a field trip to Newfoundland sponsored by the Canadian Geological Survey and Newfoundland University. The Weather/Climate Club participates in the WxChallenge, the North American collegiate weather forecasting competition, on a team with undergraduates, graduate students, and research scientists. Our team consistently outperforms teams from peer institutions.

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 UROP or for a senior thesis. At the 2009 Student Awards and Recognition Dinner, the Goetze Prize was awarded to Sarah Gelman for her senior research thesis "Mantle Thermal Evolution of Tidally-locked Super-Earths." Roxana Safipour received the W.O. Crosby Award for Sustained Excellence in recognition of her achievements, academically and intellectually, and participation in department activities.

Community Events

The department aims to create collaborative opportunities within EAPS, at MIT, and outside the Institute. As part of this effort to share research and explore ideas, we hosted several weekly lecture series and two memorial lectures open to the MIT community and the public, including the department lecture series, the MIT Atmospheric Science Seminar Series, the Oceanography and Climate Sack Lunch Seminar Series, the MIT Chemical Oceanography and Biogeochemistry Seminar Series, and the Earth Resources Laboratory's Friday Informal Seminar Hour s=Series. Professor Kenneth M. Golden of the University of Utah was this year's invited Houghton lecturer, and he gave three lectures focused on sea ice and its role in the climate system, its structures and processes, and remote sensing and monitoring. The annual Victor P. Starr Memorial Lecture was held on October 8 and Dr. Geoffrey K. Vallis of Princeton University gave a talk entitled "Science in the Age of Models: Is Theory Still Relevant in Climate Research?" The 9th annual Henry Kendall Memorial Lecture was held on May 1 and professor Lonnie G. Thompson of Ohio State University gave a talk entitled "Global Climate Change: A Paleoclimate Perspective from the World's Highest Mountains." For faculty, weekly informal lunches were held during the fall and spring terms, giving them the opportunity to hear talks from colleagues about their research.

Faculty, staff, and students are active promoters of Course 12 and participated in the Academic Expo in August, Family Weekend events in October, the Exploring the Majors Fair in November, the Freshman Open House and MIT/WHOI Joint Program Open House in March, and Campus Preview Weekend events in April. Additionally, there was significant departmental involvement in the Kuwait-MIT Center for Natural Resources and the Environment's forum on carbon sequestration on October 20–21, MIT's Darwin Bicentennial Symposium on January 24–25, MIT's Women in Aerospace Symposium on April 2–3, and MIT's Apollo 40th Giant Leaps Symposium on June 10–12. EAPS faculty and students presented sessions on weather/climate, geochronology, energy/climate change, and space exploration at the 2009 Cambridge Science Festival from April 24 through May 2 and the associated Sally Ride Science Festival on May 2.

Faculty

The department continues its efforts to hire and promote young faculty members and welcomed Paul O'Gorman and J. Taylor Perron. O'Gorman was appointed assistant professor of atmospheric science on September 1 and his primary research interest is in developing mathematical models to problems of importance in climate. Perron began his appointment as assistant professor of geology on January 1 and he studies the relationships between landscapes and the processes that create them, including both terrestrial landscapes and those on solid planets and satellites such as Mars and Titan.

Effective July 1, 2009, Raffaele Ferrari, Cecil and Ida Green professor of oceanography, will be promoted to full professor and Benjamin P. Weiss, Victor P. Starr professor of planetary sciences, will be promoted from assistant professor to tenured associate professor.

Sadly, we note the loss of professor emeritus William H. Pinson, Jr., who passed away on October 30 at age 89. Dr. Pinson received his PhD in 1952 from MIT, where he taught earth science and astronomy until his retirement in 1984. As a professor emeritus, Dr. Pinson continued to teach at area colleges and universities, including Bentley College, Tufts University, and Bridgewater State College until the mid-1990s.

A symposium to honor our late friend and colleague, professor emeritus Edward N. Lorenz, was held on September 13 at the American Academy of Arts and Sciences. The event was attended by colleagues, former students, family, and friends and featured scientific talks by three prominent colleagues of Dr. Lorenz, personal reminiscences by friends and colleagues, and an afternoon concert.

Honors and Awards

Professor Clark Burchfiel was awarded the Penrose Medal, the highest honor of the Geological Society of America. He was also invited to give the Baldwin Lecture at the University of Miami and was the keynote speaker on the 2008 Sichuan earthquake at the American Geophysical Union's fall meeting.

Professor Linda Elkins-Tanton was a recipient of MIT's Outstanding Faculty UROP Mentor Award.

Professor Timothy Grove has completed the first of a two-year term as president of the American Geophysical Union. He completed a year-long task force that recommended sweeping changes to the structure of this 56,000-plus member organization. At the annual spring meeting held in May in Toronto, they successfully passed three measures that actualize the recommended changes: (1) a change in the governance structure of the union, (2) a plan that will lead to the identification and hiring of a new executive director, and (3) a new strategic planning initiative.

Professor Bradford Hager was elected to the American Association for the Advancement of Science.

Professor Oliver Jagoutz was selected as the holder of the Kerr-McGee development professorship for the period September 1, 2008, through June 30, 2011.

Professor John Marshall was elected a fellow of the Royal Society (UK Academy of Sciences).

Emeritus Professor John Southard was honored by the Society for Sedimentary Geology with his selection to receive the Distinguished Service Award for his contributions to science and the society during his career.

Professor Ben Weiss will be awarded the 2009 Macelwane Medal by the American Geophysical Union to recognize his significant contributions to the geophysical sciences by an outstanding young scientist.

Professor Maria Zuber was named to the *US News & World Report*/Harvard University's Kennedy School of Government list of America's best leaders. She participated in the "Innovation Agenda" roundtable with Nancy Pelosi, Speaker of the House of Representatives, and Rep. Rush Holt at Princeton University on December 15 and testified before the House Committee on Science and Technology on the 50th anniversary of NASA as well as before the Steering and Policy Committee of the US House of Representatives on the role of science research and education as economic stimuli. She also received a Group Achievement Award from NASA for the lunar reconnaissance orbiter laser ranging team.

Research Highlights

Professor Richard Binzel spent a sabbatical year at the Paris Observatory analyzing the spectral properties of near-Earth asteroids and advising the European Space Agency on asteroid sample return missions. Two research publications in *Nature* show that the largest and most hazardous near-Earth asteroids have compositional links to the innermost edge of the asteroid belt and that the solar wind is the dominant process for altering the surface colors of asteroids, reddening their spectra on a timescale as fast as 10^6 years.

Professor Clark Burchfiel has been completing his work in the Balkans (Bulgaria, Macedonia, and Greece) and has been very busy trying to finish his magnum opus on the geology of southeastern Tibet and adjacent regions. This will be a major work summarizing 25 years of work in this part of China. His group had two very timely papers published. The first paper was a multidisciplinary report on the May 2008 earthquake in Sichuan, China, that was the headliner for the *GSA Today* monthly bulletin and was the first on the subject to reach publication. The second paper, in a similar vein, was published in *Science* this year with Leigh Royden as the lead author.

Professor Edward Boyle led a one-month research expedition through the tropical North Atlantic Ocean to establish the source of enriched iron in the oxygen minimum zone; his group finds that marine phytoplankton take up iron from wind-blown Sahara dust and then release it into the underlying waters when they sink and decompose. He also participated in the GEOTRACES intercalibration cruises to prepare the chemical oceanographic community for the first US GEOTRACES section in 2010, on which Professor Boyle will be the chief scientist.

Professor Linda Elkins-Tanton's group is making encouraging progress in understanding the chemistry and physics of planetary accretion and solidification, with different projects focusing on planetesimals, the Moon, Mercury, Super Earth exoplanets, and the fine scale of degassing the earliest atmospheres on Earth. Her large collaborative project on the Siberian flood basalts and the end-Permian extinction led to the discovery of high concentrations of toxic fluorine and chlorine in lavas, indicating the potential for significant climate change and extinction forcing.

Professor James Elliot, research scientist Dr. Michael Person, and their colleagues analyzed a 2001 stellar occultation data set for Neptune's largest moon, Triton, and found that the expansion of Triton's atmosphere that they noted in 1995 and 1997 had continued through August 2001.

Professor Kerry Emanuel has been working during the past year on the diurnal cycle of tropical convection over land with his postdoctoral fellow Larissa Back, on improving the representation of convection in climate models with postdoc Bo Yang, and with several graduate students on various aspects of tropical cyclones. He has developed a method for estimating hurricane return periods at shoreline locations by using information from tropical cyclones at sea. He continues to work on the connections between tropical cyclones and climate as well.

Professor Raffaele Ferrari's research this year focused on the role of ocean turbulence in shaping the observed climate. With colleagues at Scripps Institution of Oceanography and Woods Hole, he began a three-year observational campaign aimed at estimating the role of turbulence in setting the rate of ocean heat and carbon uptake in the Southern Ocean, a crucial region for predicting climate change. With colleagues at NASA, he is developing the Surface Water Ocean Topography altimetric mission to sample from space oceanic motions down to scales of 10 kilometers, an order of magnitude better than present altimetric missions. With graduate student Maxim Nikurashin, he was able to show that turbulent mixing drives the abyssal circulation in the Southern Ocean.

Professor Frederick Frey and his research group are performing geochronological and geochemical studies of the igneous rocks from the Ninetyeast Ridge in the Indian Ocean and have demonstrated an age progression from ~38 Ma in the south to 77 Ma in the north. Their results indicate that this structure formed as the Indian plate moved rapidly northward over a nearly fixed hotspot source of magma. Eventually, the Indian Plate collided with Southeast Asia to form the Himalayan Range.

Professor Tim Grove and students are carrying out melting and crystallization studies on high-titanium lunar magmas and have found that variations in oxidation state have dramatic effects on the melting behavior. This result has important implications for the size of the original magma ocean and for the physical processes that occurred during the later stages of solidification and remelting.

Professor Thomas Herring and colleagues are using Global Positioning System (GPS) and very long baseline interferometry data to develop models of changes in the rotation of the Earth and Earth deformations on global, regional, and local scales. They are also using interferometric synthetic aperture radar to study fine-scale surface deformations. Study areas include tectonic deformations over much of the southern Eurasian plate boundary, southern New Zealand, and western United States. The group is also involved in monitoring and modeling human-induced deformations in oil fields. To support these activities and to improve even further the accuracy of GPS measurements, MIT is a data analysis center for the International GPS Service and acts as the GPS Analysis Center coordinator of the National Science Foundation Plate Boundary Observatory (PBO), which is part of the EarthScope program.

Professor Oliver Jagoutz's research group focused on the effects of melt percolation on the dynamics of melt extraction channels in the upper mantle. Using detailed field studies coupled with fabric and petrological analyses in exposed upper mantle peridotite, they documented the effect of melt percolation on mantle dynamics. The broader impact of these effects for the regional and global mantle dynamics are currently investigated by numerical simulations in collaboration with scientists from ETH Zurich.

Professor Alison Malcolm continues to work on various aspects of seismic wave propagation and nonlinear imaging; this past year her research has advanced in two parallel directions. First, she is working with colleagues at the Mayo Clinic, the University of Minnesota, and Boise State University to extend the nonlinear medical imaging technique known as ultrasound vibro-acoustography to imaging Earth materials. This research aims to improve our ability to understand the distribution of fluids in rocks by exploiting their nonlinearity. The second line of research involves improving our ability to see difficult-to-image structures through the use of nonlinear techniques. This work has applications in oil prospecting, geothermal energy, and CO₂ sequestration.

Professor Paul O'Gorman's research group is studying atmospheric circulations and the hydrological cycle under climate change. In recent research, they have studied the physical basis for how precipitation extremes can be expected to change with global warming. Their analysis of simulations suggests that global climate models are not reliable with respect to precipitation extremes in the tropics. Another aspect of their research is to understand how extratropical storm tracks behave over a range of climates. They have previously shown that storm track intensity can vary nonmonotonically as the climate warms, such that a climatic optimum in storminess can occur. Because the amount of water vapor in the atmosphere is very sensitive to temperature changes, they are currently developing theories of extratropical storm tracks that can properly account for changing atmospheric water vapor content.

Professor Paola Malanotte-Rizzoli and her postdoctoral associates have continued their work in the tropical Pacific and Indian Oceans with a focus on the South China Sea and the Indonesian through-flow. Three major research topics have been pursued: the South China Sea as a conduit of mass and heat transport affecting the Indonesian through-flow and the coupled modes of climate variability in the Pacific and Indian Oceans, the storm surges of the South China Sea and associated extreme sea-level anomalies in the Singapore Strait, and identification and prediction of flow features such as vortices and jets in local domains in the Singapore channels and assimilation of fieldwork data.

Professor John Marshall's research during the last year includes his participation in a field experiment to observe wintertime convection in the Gulf Stream. He continues a series of numerical experiments inquiring into the climate of Earth-like planets but with highly idealized land distributions, and he has linked the study to the climates of exoplanets.

Professor Taylor Perron is studying the evolution of landforms on Earth and other planets. His recent research has explored the emergence of self-organized patterns in landscapes, including periodic sequences of ridges and valleys. His current research aims to understand how the hierarchical branching structure of large-scale river

networks records the combined effects of climate, tectonics, and biota on erosion. Planetary research efforts are currently focused on polar climate records on Mars and river network development on Titan (Saturn's largest moon).

Professor Stéphane Rondenay has pursued, with his research group, development of new high-resolution seismic imaging techniques, applications of these techniques to exploration and lithospheric targets, and interpretation in terms of tectonic/geological models. They collaborated with researchers from Schlumberger-Doll Research on implementation of a novel deconvolution approach for array teleseismic data that may double the number of useable events and allow for automated receiver-function analysis. They are also developing an imaging method based on borehole seismic interferometry and are working with WHOI scientists on methods for the joint inversion of seismic and electromagnetic data. They completed an imaging analysis of subduction zones in the Pacific Northwest and in Greece, with the resulting images providing unparalleled insight into subducted slab dehydration. They also produced a high-resolution image of the central Slave craton of Canada, which shows the most compelling colocated seismic-magnetotelluric structure ever observed in a continental setting. This structure suggests that the central Slave represents >3.5-Gyr-old fragments that were assembled by subduction.

Professor Daniel Rothman and his group have developed theoretical methods for determining the distribution of timescales over which organic carbon resides on land and in the oceans. Using data collected from dozens of North American forests, they have shown that these age distributions have a surprising canonical form that explains the accumulation of "old" carbon in reservoirs with ostensibly fast recycling rates. This finding should considerably simplify future estimates of rates of change within Earth's carbon cycle.

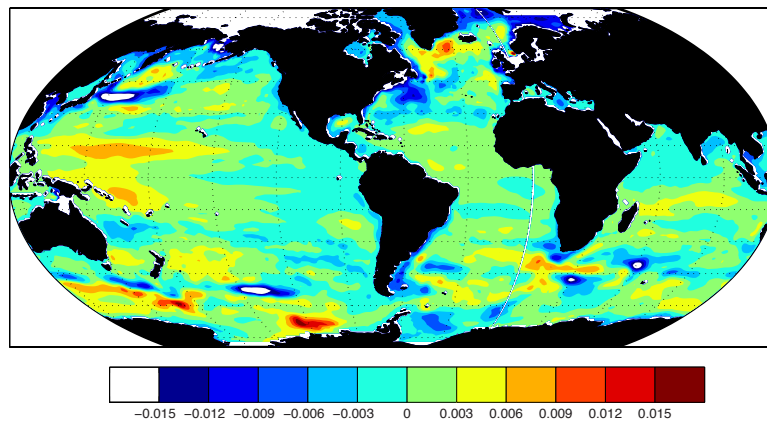
Professor Sara Seager's group has turned its focus from computer model predictions of exoplanet characteristics to interpreting a growing data set on exoplanet masses, radii, and atmospheres. The set of exoplanets whose physical characteristics can be measured are transiting planets, planets that go in front of their stars as seen from Earth. More than 50 exoplanets (of approximately 350 known exoplanets) have mass and radius measurements. Professor Seager's group has developed techniques to quantitatively constrain a planet's interior composition and atmosphere temperature and composition for the first time. Her group is also working on a concept study for a suite of nanosatellites (10x10x30 cm satellites), called ExoplanetSat that would look for transiting planets orbiting the brightest stars in the sky.

Because Fe_2O_3 transforms to the post-perovskite phase, it has provided Professor Sang-Heon Dan Shim with opportunities to study iron endmembers for the lower-mantle phases. The study also has implications for the effects of impacts for the planetary magnetic records. A paper titled "Electronic and magnetic structures of the postperovskite-type Fe_2O_3 and implications for planetary magnetic records and deep interiors" was published and highlighted in the April 7, 2009, issue of the *Proceedings of the National Academy of Sciences* ("In This Issue").

Professor Roger Summons's lab continues to compare and contrast biogeochemical processes in modern microbially dominated ecosystems and ancient sedimentary rocks. The most prominent result was publication of a paper on the discovery of chemical fossils for sponges in rocks as old as 650 million years, making them the oldest animal remains detected to date.

With students and international collaborators, Summons is working to discern the ocean redox structure in the lead-up to the great Permian-Triassic mass extinction event. They are also conducting studies of the plankton successions in the aftermath of the Cretaceous-Paleogene extinction that most people agree was the consequence of a bolide impact. The Summons research group is host to a team from the NASA Astrobiology Institute that is investigating planetary conditions required for the inception and maintenance of complex life.

Professor Carl Wunsch and his students and colleagues continue to use global oceanographic and related data sets along with general circulation ocean models to describe and understand the large-scale behavior of the ocean and its influence on climate. The figure below shows their most recent estimate of the trends in global sea level (meters/year). Although the global average is a rise of about 2 mm/year, in some regions sea level has been falling, and in others the rise is far larger than the average. These patterns are the result of a complex interplay of wind shifts, ocean dynamics, melting ice, and a warming atmosphere.



Professor Maria Zuber and colleagues published a study that used temporal variations of the Martian gravity field to characterize seasonal changes and interannual variability of the planet's atmosphere-cryosphere system. With students and colleagues, she made the first detection of waves in the Martian exosphere. Using laser-ranging observations during two flybys of the MESSENGER spacecraft past Mercury, she performed, in collaboration with students and colleagues, a study evaluating how strain was accommodated in the planet's lithosphere over planetary history.

Research and Administrative Staff

Maria Zuber continues in her second term as department head and she appointed Brad Hager as associate department head. Recent additions to headquarters staff include Craig Pearson, administrative officer, and Dawn Adelson, senior resource development officer. Mark Pendleton will retain the role of fiscal officer and head up a newly established centralized financial office.

Promotions and Awards

Lindgren librarians Christine Sherratt and Joseph Hankins were recognized for their outstanding service to the department at the annual Student Awards and Recognition Dinner held on May 15.

Dr. Michael Person received an MIT Excellence Award in the unsung hero category.

Robens Joseph, financial administrator for the Center for Global Change Science, received the School of Science Infinite Mile Award.

Maria T. Zuber

Department Head

E.A. Griswold Professor of Geophysics

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