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 physical, chemical, and biological 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 (in addition, it has joint appointments with two faculty with a primary appointment in, Civil and Environmental Engineering, one in Civil and Environmental Engineering, Aeronautics and Astronautics, and one 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, including those that are among the most pressing societal issues of our time: change in climate and environment, natural resources and hazards, and the origin and evolution of life on Earth and, perhaps, elsewhere. For example, the Earth Resources Laboratory (under directorship of Prof. Van der Hilst until 31 May 2012; now Prof. Hager) integrates faculty, staff, and students across disciplinary, department, and school boundaries to investigate geophysical and geological problems in energy and resource development. The Center for Global Change Science (under directorship of Prof. Prinn) builds on the programs in meteorology, oceanography, hydrology, chemistry, satellite remote sensing, and policy. EAPS is an active participant in the MIT/Woods Hole Oceanographic Institution (WHOI) Joint Program and supports 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 2011, EAPS had 177 graduate students registered in the department, including 78 students in the MIT/WHOI Joint Program. Women constituted 46.3 percent of the graduate student population, and 5.7 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 graduate students continue to take responsibility for an expanded orientation program for the incoming graduate students. They plan a number of social events to introduce the newcomers to the EAPS, MIT, and the Cambridge area. 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 an annual prize for excellence in teaching to highlight the superior work of our teaching assistants. During the 2012 academic year, Mr. Seth Burgess, Mr. Ruel Jerry, Mr. Jean-Arthur Olive, and Mr. Ben Mandler were recognized for their contributions.

Our students were also recognized by their respective professional societies. Mr. Roger Fu won an LPI Career Development Award for his presentation "Magnetic Fields on 4 Vesta as Recorded in Two Eucrites" presented at the Lunar and Planetary Science Conference. Mr. Dan Chavas won the 2012 Max Eaton Prize for the best student paper at the American Meteorological Society's 30th Conference on Hurricanes and Tropical. Ms. Sonia Tikoo received honorable mention in the graduate student oral category at the 43rd Lunar and Planetary Science Conference for her talk "Decline of the Ancient Lunar Core Dynamo". Mr. Alan Richardson received an Outstanding Student Paper Award for his presentation "Scalable, massively parallel approaches to upstream drainage area computation" at the 2011 AGU Fall Meeting. Mr. Noah Mclean was selected by the Volcanology, Geochemistry, and Petrology Section of the American Geophysical Union, to receive an Outstanding Student Paper Award for his presentation "Quantification of Mass Independent Fractionation in Pb by TIMS and Implications for U-Pb Geochronology" at the 2011 Fall Meeting. Ms. Kimberly Huppert received the 2011 Outstanding Student Paper Award for her presentation at the 2011 American Geophysical Union Fall Meeting for her poster on "Morphodynamics of Disequilibrium Wave Ripples."

Undergraduate Program

In fall 2011, EAPS had 29 undergraduate majors, 86.2 percent of which were women and 24.1 percent members of an underrepresented minority group. Ten students were awarded the SB degree in Earth, Atmospheric, and Planetary Sciences in AY2012.

At the 2012 Student Awards and Recognition Dinner, the Goetze Prize was awarded to Ms. Deepa Rao in recognition of her outstanding senior thesis, Ms. Amber Stangroom received the W.O. Crosby Award for Sustained Excellence, and Ms. Stephanie Sallum was the recipient of the Award for Excellence as an Undergraduate Teaching Assistant. EAPS established a new award, the EAPS Achievement Award, to recognize a rising senior from across the EAPS disciplines. It is presented to a student who has distinguished her or himself through a combination of high GPA, focused course work, and leadership within EAPS. In this inaugural year Ms. Shaena Berlin was the recipient.

The department maintains a strong presence in the undergraduate program at MIT beyond the population of majors so that the general MIT student body has access to the essential geoscientific aspects of climate and environmental change, natural hazards, and natural energy resources, which will motivate and help them in the development of future technology solutions and for setting pertinent policy.

In May 2012, at a special evening faculty meeting, the ad hoc taskforce on the EAPS undergraduate education program presented its final report and recommended changes in the Undergraduate Program for implementation by the Undergraduate Committee. Specific recommendations included the development of a 3-course sequence required of all majors for a degree in *Earth, Atmospheric, and Planetary Science*. Three existing core courses will be modified (12.001, 002, 003) to provide an introduction that integrates key introductory material across the discipline areas represented in the department. The taskforce also recommended strengthening of joint course offerings with Math, Mechanical Engineering and Physics and developing new offerings that would allow the EAPS curriculum to be more accessible to students in other majors.

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 two interdisciplinary minor programs; the broadly based Energy Minor and the Astronomy Minor, with Physics. EAPS has two courses that are components in the Energy Science Foundation section of the requirements and two classes that are electives for the minor.

Community Events

On 3 February 2012, the newly appointed Department Head presented the “State of EAPS” to an audience of about 250 citizens of the department. This was the first even of this kind, and it is the intention to address the entire EAPS community at least once a year.

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. The 12th annual Henry Kendall Memorial Lecture was held on May 1 and the guest lecturer was Professor Jonathan Foley of the Institute on the Environment at the University of Minnesota, who gave a talk entitled “How Can We Feed a Growing World and Sustain the Planet.” This year there were two Houghton Lecturers who each gave two presentations: Susan Solomon, CIRES/University of Colorado at Boulder (now an MIT–EAPS Professor) spoke about the forces driving climate change, and Leo P. Kadanoff, Perimeter Inst./ University of Chicago gave two free-ranging lectures about non-linear systems, with an eye to issues of understanding Earth’s climate. The 2011Victor Starr Lecturer was Judith Curry from Georgia Tech. On September 29, 2011 she presented a lecture entitled “Climate Science and the Uncertainty Monster.”

EAPS faculty continued to play an active role in the department’s development and alumni relations efforts, meeting with prospective major gift donors and participating in events geared toward alumni and friends in cooperation with the School of Science, Resource Development, and the MIT Alumni Association. These included a celebration of the GRAIL launch in Cape Canaveral for prospective major gift donors on September 7-8, the annual reception for EAPS alumni and friends at the fall meeting of the American Geophysical Union in San Francisco, a dinner for key donors to the Toksoz Fellowship in Houston, Texas on April 11 and a breakfast for Houston area alumni hosted by Chuck Peng the following morning. In addition, Professor Rick Binzel was the featured presenter at a reception for WBRS members at New York’s Museum of Natural History on April 16, and Fred Middleton hosted a reception for major gift prospective donors in Menlo Park, California on December 6, which featured a talk by Professor Sara Seager.

Faculty

The department continues its efforts to hire and help young faculty members develop careers. Susan Solomon, a Nobel laureate whose scientific interests are related to climate change, was hired as a full professor. Dr. Daniel Cziczo, an atmospheric chemist, joined as Associate Professor in the summer of 2011; David McGee, a paleoclimate expert, joined as Assistant Professor in January 2012, and Dr. Colette Heald, an atmospheric chemist with primary affiliation with CEE, got a joint appointment as associate professor. Two new assistant professors will join the department in July of 2013. Dr. Hilke Schlichting, a planetary scientist and Dr. German Prieto, a geophysist, both agreed to join our faulty ranks. We are excited to have the opportunity to bring such a talented duo into our department. Tanja Bosak and Paul O'Gorman were promoted to the rank of associate professors.

Honors and Awards

Professor Kerry Emanuel was awarded Deerfield Academy's Heritage Award and will give a presentation to that prep school in October. He was also given an editor's award for reviews he conducted for the American Meteorological Society's *Journal of Climate*.

Professor Timothy Grove was made a fellow of the Geochemical Society this year.

Assistant Professor Alison Malcolm was one of 3 recipients of the J. Clarence Karcher Medal from the Society of Exploration Geophysicists (SEG). Her student, Gabi Melo, won a $ 10,000 scholarship from Anadarko/SEG. Her student, Alan Richardson, was selected to participate in the SEG/Chevron Student Leadership Symposium, which covers his trip to the SEG annual meeting.

Assistant Professor Taylor Perron was awarded the Luna B. Leopold Young Scientist Award by the American Geophysical Union, and delivered the Robert P. Sharp Lecture at the Fall 2011 AGU meeting in San Francisco. Professor Perron's graduate students Kimberly Huppert and Alan Richardson were awarded Outstanding Student Paper Awards for their presentations at the Fall 2012 AGU meeting.

Professor Roger Summons' former graduate student, Jacob Waldbauer was awarded the a Cozzarelli Prize by the Editorial Board of PNAS for his 2011 paper entitled: "Microaerobic steroid biosynthesis and the molecular fossil record of Archean life." His Postdoctoral Fellow, Paula Welander, who has just accepted a faculty position at Stanford University will be presented with a Geochemical Society 'Best Paper Award' for her work, published in PNAS in 2010,

Professor Carl Wunsch was elected an Honorary Fellow of the Royal Meteorological Society (UK).

Professor Maria Zuber was awarded MIT's James R. Killiian, Jr. Faculty Achievement Award.

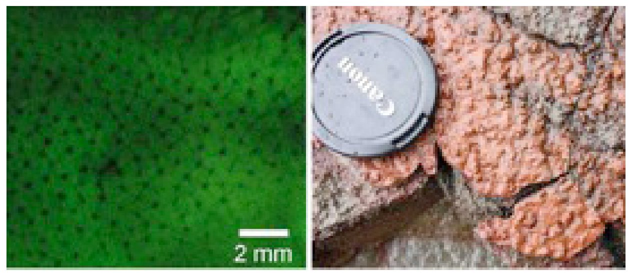
Research Highlights

Richard Binzel

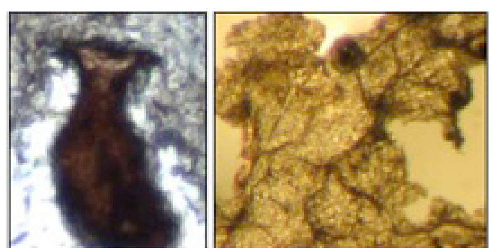
Prof. Richard Binzel is a science team member for the NASA OSIRIS-REx asteroid sample return mission scheduled for launch in 2016. In addition to mission responsibilities for spectral characterization of the target asteroid, he also led a student proposal team that was selected to build and fly a regolith imaging x-ray spectrometer (REXIS) aboard the OSIRIS-REx spacecraft. This NASA education funded instrument is built by students across Schools of Science and Engineering, involving both EAPS and Aero-Astro as well as collaboration with Harvard. Collaborating MIT faculty are Professors Miller (Aero Astro) and Seager (EAPS). Prof. Binzel succeeded the late Prof. Elliot in teaching the Institute Laboratory 12.410/8.287 Observational Techniques of Optical Astronomy conducted at the MIT Wallace Astrophysical Observatory in Westford, MA.

Tanja Bosak

Prof. Bosak explores the co-evolution of life and the environment through the lens of microbial sediments, carbon, sulfur and oxygen cycling. Her team uses microbial cultures to identify and understand microbial structures in sedimentary rocks, including some of the oldest structures produced by oxygen-exhaling microbes, and to explore the microbial role in the coupled carbon and sulfur cycles. In addition to physiological, morphological and isotopic studies, they also develop a fossil record of eukaryotic life and evolutionary innovations between the two low-latitude Neoproterozoic glaciations, and they use these fossils to explore the puzzling records of carbon cycling during this time.



Sub-mm spaced clumps formed by modern cyanobacteria (left) and similarly sized and spaced fossil clumps in a 2.7-billion-year-old conical stromatolite (right). Formation and persistence of modern clumps depend on oxygen and lead to growth of larger cones. The same morphological sequence from sub-mm clumps to cm-scale conical stromatolites at 2.7 billion years ago suggests that microbes were generating oxygen 200–400 million years before the rise of oxygen in the atmosphere.



The oldest fossil putative ciliates (left) and macroscopic multicellular red algae from 715–635-million-year-old limestones. These fossils track the evolution of eukaryotes with robust shells and cell walls and the increasing complexity of food webs before the rise of animals. The isotopic composition of these organic fossils is also used to understand the unusual cycling of carbon and large carbon isotope excursions during this time.

Sam Bowring

The Bowring group focuses on high-precision geochronology applied to the stratigraphic record, timescales of pluton construction, links between large igneous provinces and extinctions, and the thermal history of continental lithosphere deduced from lower crustal xenoliths. Their new thermal ionization mass spectrometer met specifications and operates 24 x 7 producing very high quality data for isotopes of U, Pb, Nd, and Sr. They now have three instruments that are working well and are refurbishing a fourth. Their *Science* paper on "The exhumation history of continents over billion-year time scales" [Blackburn, et al., 2011] received much press attention:

http://www.ouramazingplanet.com/2224-north-america-continent-erosion.html; http://phys.org/news/2012-01-north-american-continent-eroder.html; http://web.mit.edu/newsoffice/2011/stable-continents-0106.html

Kerri Cahoy

Prof. Cahoy leads the MIT Wavefront Control Laboratory and is interested in wavefront control systems, space weather, and nanosatellites for remote sensing. Current wavefront control projects include demonstrating visible-light wavefront control using MEMS deformable mirrors and liquid crystal spatial light modulators. Wavefront control systems are needed for applications such as space-based direct imaging of exoplanets (planets around other stars), laser communication systems (to improve bit error rate and bandwidth), and imaging systems (to correct for atmospheric turbulence or aberrations caused by the imaging system optics). She also leads the MIT team entry in the University Nanosatellite Program-7 competition called the Trapped Energetic Radiation Satellite, which is a low earth orbit very low frequency electromagnetic wave transmitter and receiver to study the effect of low frequency radio waves on the hazardous trapped energetic particles in the Earth's magnetic field. Recent projects in radio science include a study using Mars Reconnaissance Orbiter and Mars Global Surveyor data to constrain the sizes of carbon dioxide cloud particles on Mars and analyzing GRAIL engineering data.

Daniel Cziczo

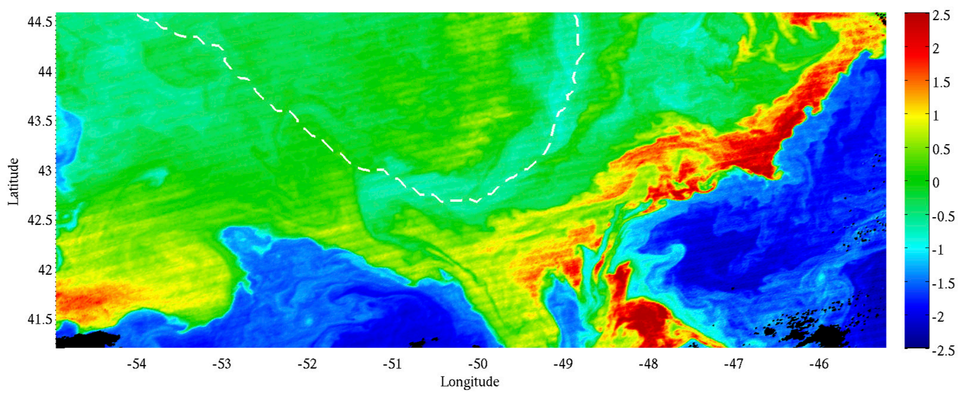
Prof. Daniel Cziczo's research focuses on the microphysics and chemistry of how particles interact with the vapor phase to nucleate new phases. The primary foci of this research have been heterogeneous chemistry and the Earth's climate system, but he has also conducted research on topics such as the ablation and composition of meteorites. His recent work on ice nucleation by mineral dust or various compositions was conducted with the Earth's atmosphere as a focus but the fundamental physics are directly applicable to the proposed research on cloud formation around other planets.

Kerry Emanuel

Prof. Emanuel continued to work on tropical climate and on tropical cyclones. Working with Dr. Richard Rotunno (NCAR) he discovered that the density stratification of hurricane outflow (rather than being set by the far environment – as had been assumed for 25 years) is set internally by turbulence, whose effect is to hold constant a non-dimensional number involving the stratification and the vertical shear of the horizontal wind. They examined the consequences of this for the steady state structure and intensity of axisymmetric storms and found that this simple idea resolves a number of outstanding conundra in tropical cyclone physics. Working with Prof. Molnar (Colorado Univ.) and graduate student Tim Cronin, they developed and tested the hypothesis that islands near the equator can have a profound effect on tropical atmospheric circulation, through a kind of nonlinear rectification of the diurnal cycle. He also worked on the effect of global warming on U.S. hurricane damage, finding that the climate change signal in damage emerges from background noise over several decades.

Raffaele Ferrari

Prof. Ferrari's research group focused on quantifying the ocean uptake of heat and carbon driven by ocean eddies, the equivalent of atmospherics' storm. They showed that previous estimates were inaccurate due to the lack of statistics in oceanic measurements. He was a lead PIs of an ambitious experiment in the Southern Ocean, where floats and dyes were released to measure accurately the eddy uptake. They showed that eddies are less efficient then previously assumed in pumping heat and carbon into the ocean. This study is being complemented with a second experiment in the North Atlantic, the Lateral Mixing Experiment, where they are following in more detail the sinking of heat and carbon into the ocean. In a separate line of research, Ferrari's group is gearing up to start an experiment to measure ocean productivity in the North Atlantic. In particular they will be testing their theory to explain why phytoplankton blooms start in late winter when the ocean starts warming.



Chlorophyll concentration (a proxy for phytoplankton concentration) for an ocean patch next to Georges Bank off the eastern US coast by the MODIS instrument operating on the NASA Aqua spacecraft. (Figure generated by John Taylor.)

Glenn Flierl

Prof. Flierl and his students investigate physical and biological dynamics in the ocean and other more general problems in geophysical fluid dynamics. They have been analyzing models of the co-evolution of phytoplankton and zooplankton and are beginning to study the effects of mixing and circulation. With an intern from INSA (Lyon) he examined the physics of eddy diffusion and applied the ideas to dispersion of materials from the Deep Water Horizon. Postdoc S. Baker-Yeboah is examining the coupling of vortices in the surface and deep ocean to understand how the motion and development of eddies depends on these interactions. D. Zhu studied two-dimensional convection and the conditions under which shear flows spontaneously appear.

Grad. Student Ru Chen has shown that ``striations'' in ocean currents (long bands of coherent flow appear in the time-averaged fields) contain substantial amounts of the low-frequency energy in the ocean and are greatly altered by the large-scale flows. He collaborates with Juliana Albertoni (Univ. Sao Paolo) on modeling the flow of the Brazil Current around coastal protrusions and how it relates to eddy generation.

Timothy Grove

Prof. Tim Grove and students have developed a lherzolite-melting model that explores the effects of variations in mantle composition, pressure, temperature and H_2O content on melt composition. New experiments and a compilation of experimental liquids saturated with all of the mantle minerals are used to calibrate a model that predicts the temperature and major element composition of a broad spectrum of primary basalt types produced under anhydrous to low H_2O-content conditions at upper mantle pressures. The model can be used to calculate the temperature and pressure at which primary magmas were produced in the mantle and to model near-fractional adiabatic decompression and batch melting. Melting in the shallow upper mantle is the dominant process that leads to the production of basaltic magma in mid-ocean ridge, sub-continental and ocean island environments. This work should find wide application in the geochemical and geophysical community, as is already evident from the high download rates of their papers.

As Associate Dept. Head for Education Prof. Grove completed the evaluation of the EAPS undergraduate program. He is currently redesigning and adjusting our undergraduate program in response the findings of his Ad hoc task force. He also serves as chair of MIT's Committee on the Undergraduate Program (CUP), and as such has begun a major push to improve freshman advising in the Institute.

Bradford Hager

Prof. Hager is the new Director of EAPS' Earth Resources Laboratory, taking over the helm from Prof. Van der Hilst. In addition to maintaining ERL's traditional strength in seismology, he will increase its activity in geomechanics and induced seismicity. He is actively pursuing collaborations with companies and institutions in Abu Dhabi and elsewhere on pioneering research in geological sequestration of CO2. Hager is the lead for Solid Earth Science on NASA's DESDynI-R Science Definition Team, developing a synthetic aperture radar mission dedicated to natural hazards, ice dynamics, and ecosystem structure. He also was the Solid Earth expert on the NRC Committee that published *Earth Science and Applications from Space: A Midterm Assessment of NASA's Implementation of the Decadal Survey.*

Thomas Herring

Prof. Herring's geodesy group uses the global positioning system, interferometric synthetic aperture radar, and very long baseline interferometry data to study changes in the rotation of the Earth and Earth deformations on global, regional and local scales. He also uses geodetic methods to study the Earth's gravity field. High precision GPS measurements are used to constrain tectonic deformation over much of the southern Eurasian plate boundary and the western United States. Processes on time scales of years before earthquakes, days to years for post seismic deformation, and seconds for surface waves triggered by earthquakes, are all studied. The group also monitors human induced deformations in oil fields. 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 EarthScope. Analyses of gravity data from aircraft and Earth orbit are used for resource exploration and mass monitoring.

Alison Malcolm

Prof. Malcolm's research continued to focus on imaging complex sub-surface structures. She is particularly excited about (relative) microseismic event location in hydrocarbon reservoirs. They have also investigated the feasibility of applying similar ideas to lunar data with the hope of constraining the depth to the lunar core. Over the past year, they also worked on full- waveform inversion, an imaging technique that is rising in popularity with increasing computer power. With students she is working on: (i) estimating the initial model in a more efficient manner, (ii) using small events more effectively in the inversion, (iii) using the results in a statistical sense to determine where injected CO2 remains in the reservoir. With a new postdoc, they have been able to make progress on adapting techniques from medical imaging to Earth's imaging. The idea is to combine a low-resolution, high-contrast imaging with a high-resolution, low-contrast technique to develop high-contrast, high-resolution images. This work allows them to improve understanding of the nonlinear response of rocks, image fluid distributions in a novel way (that is hopefully more sensitive to fluid type) and perturb subsurface parameters.

Shuhei Ono

Shuhei Ono's stable isotope geobiology laboratory focuses on the experimental calibration for sulfur isotope effects of geobiologically significant processes. Min Sub Sim (grad student) published a Science paper set the new limit of sulfur isotope effect by microbial sulfate reduction. This provides a new isotope proxy to probe the importance and distribution of the microbial sulfate reduction in deep geologic time and deep crusts. Andrew Whitehill (grad student) studies mass-independent sulfur isotope effect during photochemistry of sulfur dioxide. This is the unique geologic record of atmospheric chemistry and our experiments have shown some fundamental aspects of the quantum dynamic process. Shuhei co-organized the International Conference of Isotopomer at Washington DC, and currently serves as an editor of Geochemical News of Geochemical Society.

Ron Prinn

During the past year, Prof. Prinn and his colleagues in the Advanced Global Atmospheric Gases Experiment have published trends and estimated budgets for 4 new heavy hydrofluorocarbons, 5 new heavy perfluorocarbons, methane, and nitrous oxide (all are powerful greenhouse gases), and introduced new combined Lagrangian and Eulerian modeling techniques for trace gas source and sink estimation. Within the Joint Program on the Science and Policy of Global Change, he has published an overview of earth system modeling incorporating human and natural process dynamics, and together with colleagues, reported the probabilities of future climate change and costs for various greenhouse gas stabilization policies, a new method for embedding urban processing into global pollution models, and the climatic impact and intermittency challenge for large scale off-shore wind power.

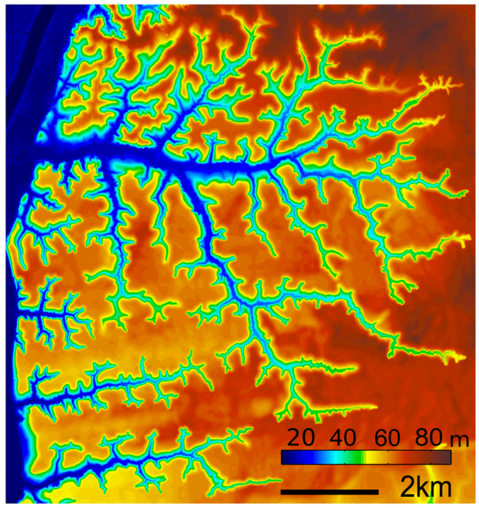
Taylor Perron

Prof. Perron and his group study how patterns in landscapes record the geologic processes that shape planetary surfaces. His group measured erosion rates across one of the world's steepest rainfall gradients on the Hawaiian island of Kaua'i, and identified a systematic relationship between rainfall and erosion that has been surprisingly difficult to detect in other studies. Their conclusion that erosion rates prior to the arrival of humans on Kaua'i were similar to modern rates will help manage land in economically critical coastal areas. In collaboration with Prof. Bowring they developed a thermochronologic technique for measuring continental erosion rates over billions of years, and found that the core of the North American continent has eroded very little over the past 1.8 billion years. Perron's group continued to study the development of striking patterns in sand ripples generated by waves. They developed a new method for approximating shear stress in turbulent, oscillatory flow over a rough boundary, which will enable a new generation of models for the development of sandy bedforms in coastal regions. Finally, using an erosion model and measurements from the Cassini spacecraft they estimated the amount of erosion that has occurred on Titan, a moon of Saturn where rivers of liquid methane slice into a surface made of ice (Black et al., 2012).

Postdoctoral researcher Ken Ferrier collects a sample of sediment from a river on the Hawaiian island of Kaua'i. Laboratory measurements of the isotope 3He in grains of olivine (also known as the gemstone peridot) are used to measure the erosion rate of the river basin over the past several thousand years as part of a comparison of erosion on the dry and wet sides of Kaua'i, which has one of the steepest rainfall gradients in the world.

Daniel Rothman

Prof. Rothman, in collaboration with Profs. Summons and Boyle (EAPS) and Alm (CEE), has related the end-Permian extinction---the greatest extinction event in the history of life---to a major perturbation of Earth's carbon cycle caused by the emergence of a new microbial metabolic pathway. Their hypothesis is supported by a new theoretical model of observed geochemical changes and their estimate of the date for the evolution of the fast acetoclastic pathway in methanogenic microorganisms. Rothman's group also developed a theory for the ramification of stream networks. Their work predicts that streams incised by groundwater seepage branch at a characteristic angle of 0.4 pi = 72 degrees. Their theory represents streams as a collection of paths growing and bifurcating in a diffusing field. Their observations of several thousand bifurcated streams near Bristol, Florida (see figure) are in excellent accord with the new theory.



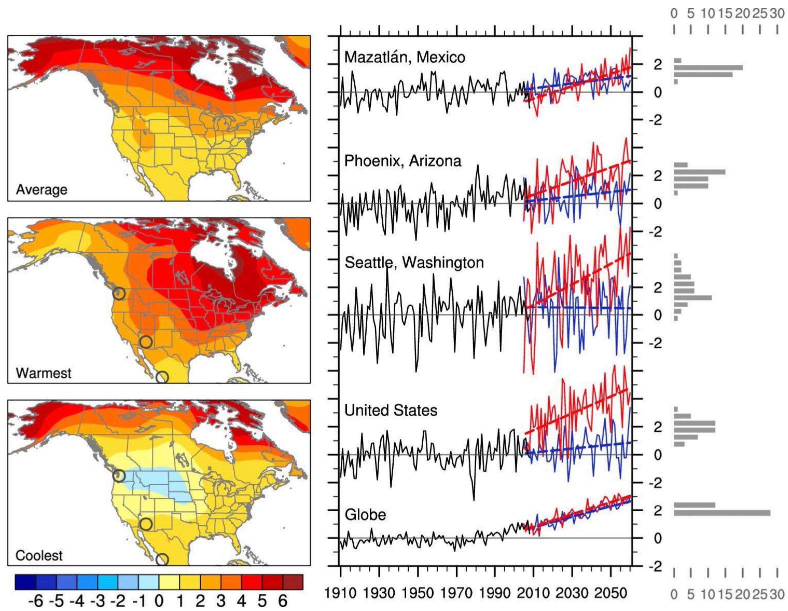
DJF (December–February) temperature trends during 2005–2060 (°C per 55 years). (Left panel) Top image shows the average of the 40 model runs (all values are statistically significantly different from zero at the 5% confidence level); middle and bottom images show the model runs with the largest and smallest trends for the contiguous US as a whole, respectively. (Middle panel) DJF temperature time series for selected cities (marked by open circles in the left panel images), the contiguous US and the globe (land areas only). Black curves show observed records from 1910–2008 (minus the long-term mean); red and blue curves show model projections for 2005–2060 from the realizations with the largest and smallest future trends, respectively, for each location or region. Dashed red and blue lines show the best-fit linear trends to the red and blue curves, respectively. For visual clarity, the model projections are matched to observations averaged over their common period of record 2005–2008. (Right panel) Distribution of projected DJF temperature trends (2005–2060) across the 40 ensemble members at the locations shown in the middle panel. The vertical axis is shared with the middle panel and indicates the linear trend in units of °C per 55 years.

Leigh Royden

Prof. Royden and Prof. Perron developed a new mathematical analysis of longitudinal elevation profiles for rivers that are cut on bedrock, as is the case for many rivers present in high mountain systems. Their results show that information about downstream river states is carried upstream via a series of migrating "slope patches" which are mathematical entities whose slope corresponds to the slope of the underlying river bed. This work shows that information carried by the slope patches is progressively lost during upstream migration, providing bounds on the possibility of reconstructing past river states and on the uplift history of the mountain belt into which the river is incised.

Susan Solomon

Prof. Solomon's research focuses on climate change, ozone depletion, and environment. Current areas of focus include: *(i) Improving the understanding of emerging local signals of anthropogenic climate change.* While it is clear that the average temperature of the Earth has warmed and that this warming is largely due to human-caused increases in greenhouse gases, warming at the local scale is more difficult to distinguish against the backdrop of large year-to-year variations. Solomon has shown that despite large warming in the Arctic, local interannual variations make it difficult to distinguish emerging signals there. Their work further demonstrated that areas of the world with the clearest emerging signals of local warming lie in the deep tropics, where very low interannual variability allows a relatively small signal to be identified. *(ii) Stratospheric changes and their links to surface climate.* Solomon and co-workers showed that changes in tropical cyclones (including hurricanes) can be linked not only to sea surface temperature but also in part to changes in temperature in the lowermost stratosphere and upper troposphere in the tropics. Stratospheric ozone changes in the tropics appear more uncertain than previously thought.



An estimate of the 16-year-average sea surface height in meters relative to a level surface.

Roger Summons

Prof. Summons' laboratory focuses on illuminating major evolutionary and environmental transitions throughout the history of life on Earth. They are currently studying Earth's surface oxygenation ~ 2.7-2.3 billion years ago, the transition to multicellular life ~580 million years ago, and mass extinction events of the last 540 million years. A major activity at the present time is improving understanding the timeframe of the end-Cretaceous mass extinction and how ocean plankton responded to the KP meteorite impact event. They also look at how ocean plankton responds to stress by combining studies in the laboratory with field geology and geochemistry. Roger Summons was selected for the science team of the Mars Science Laboratory rover 'Curiosity' and will participate in surface operations at JPL during the Fall semester.

Robert van der Hilst

Prof. Van der Hilst was Director of the Earth Resources Lab and stepped down in May 2012 to focus on his new role as head of Department of Earth, Atmospheric, and Planetary Sciences. His research continues to focus on (1) regional tectonics and seismogenesis in SE Tibet (in collaboration with colleagues at China Earthquake Administration), (2) imaging of Earth's deep interior using dense seismograph arrays and methods adapted from hydrocarbon resource exploration (in collaboration with Profs. De Hoop, Purdue University, and Shim, formerly MIT now Arizona State

University), and (3) further (theoretical) development of algorithms for high resolution seismic imaging with natural earthquakes (in collaboration with De Hoop). In 2011 Van der Hilst's team published high resolution images of the Earth's transition zone (300-1000 km depth) beneath central Pacific that suggest that volcanism in Hawaii is not fed by major plume that rises without obstruction from core-mantle boundary across transition zone to surface. This result changes the way we think about mantle dynamics and interactions between deep and shallow processes in the Earth.

Jack Wisdom

Prof. Wisdom continues to study the dynamics of the solar system. Recently, he examined the past history of the precession of the lunar core. It has been known for some time that the precession of the lunar core does not follow the precession of the lunar mantle. He found that this is also the case for much of lunar history. But when the Moon was close to the Earth the precession of the core followed the mantle. The decoupling occurred between 26 and 29 Earth radii. It has been argued that differential precession could power a lunar dynamo. So we would not expect such a dynamo when the Moon was close to the Earth. The dynamo might have been strongest during the Cassini transition, when differential precession was largest.

Carl Wunsch

Prof. Wunsch, with collaborators both inside and outside MIT, has been focusing on the general circulation of the oceans, its variability and climate consequences. The work involves combining an up-to-date oceanic general circulation model with the large variety of global ocean data sets, and meteorological estimates of the over-ocean wind stress, evaporation, precipitation and enthalpy exchange. Using the method of Lagrange multipliers, the resulting global top-to-bottom estimates over 20 years represent the ocean circulation as best fitting the data while being consistent with the fully known dynamical and thermodynamical equations. Complete description and an example of the numerous applications can be found in the references. (EAPS_PR2011_Image7 here)

Maria Zuber

Maria Zuber led or participated in studies to reveal the shape and internal structure of Mercury and the asteroid Vesta from the NASA MESSENGER and Dawn missions. She and colleagues used information from the Lunar Orbiter Laser Altimeter ionthe Lunar Reconnaissance Orbiter spacecraft to constrain the volatile content in Shackleton crater at the lunar south pole, an important potential site for future lunar exploration. Her GRAIL mission successfully completed its primary mapping mission of the Moon, yielding the highest-resolution gravity field for any planetary body, including Earth.

Robert D. van der Hilst
Department Head
Schlumberger Professor of Geosciences