EARTH AND PLANETARY SCIENCES

Director of undergraduate studies: Mary-Louise Timmermans (mary-louise.timmermans@yale.edu), 111 KGL, 432-3167; earth.yale.edu

The Earth and Planetary Sciences (EPS) program, formerly Geology and Geophysics, prepares students for the application of scientific principles and methods to the understanding of Earth and other planets, the environment, and life on a regional and a planetary scale. Subjects range from the history of Earth and life to present-day environmental processes and climate change, the deep interiors of Earth and other planets, tectonic plates, oceans, atmospheres, climates, land surface, natural resources, and biota. The emphasis of the curriculum is on employing basic principles from the core sciences (physics, chemistry, and biology) to further an understanding of Earth's past and present, and addressing issues relating to its future. Students gain a broad background in the natural sciences, and also select a specific track to focus their work on planetary or environmental phenomena of particular interest. The four B.S. tracks emphasize hands-on research experience in fieldwork, in laboratories, or in theoretical analyses and computer modeling. While some graduates continue on to research, consulting, or industrial careers in Earth, environmental, and planetary sciences, the major's broad scientific training prepares students for a wide variety of other paths, including medicine, law, public policy, and teaching. There is also a B.A. track, which is most suitable for students who wish to study Earth and Planetary Sciences as a second major, complementing other majors in, for example, Mathematics, Economics, Physics, Biology, or Engineering, and who do so in preparation for a career in law, business, government, or environmental fields.

PREREQUISITES

With permission of the director of undergraduate studies (DUS), acceleration credits awarded at matriculation for high scores on national or international examinations (such as Advanced Placement subject tests) may be used to satisfy prerequisites, even if the student does not choose to accelerate. Higher-level courses may, with the permission of the DUS, be substituted for prerequisites and for specific required courses. For prerequisites specific for each track, see Requirements of the Major.

REQUIREMENTS OF THE MAJOR

B.S. degree program Majors in the B.S. program in Earth and Planetary Sciences choose from four tracks: Atmosphere, Ocean, and Climate; Environmental and Energy Geoscience; Paleontology and Geobiology; and Solid Earth Science. The tracks are suggested pathways to professional careers and major areas of research in earth and planetary sciences. Students may change tracks during their course of study with guidance from the DUS.

1. The Atmosphere, Ocean, and Climate track provides a comprehensive understanding of the theory, observation, and prediction of the atmosphere-ocean-climate system. Topics range from past climate changes, including the ice ages, to present-day storms and weather, to forecasting climate change and global warming. The prerequisites are CHEM 165 or CHEM 167; PHYS 180, 181 and PHYS 205L, 206L; ENAS 130 or equivalent; and mathematics through differential equations (MATH 120 or ENAS 151, and ENAS 194).

For students in the Class of 2021 With approval from the DUS, the following changes to the requirements of the major may be fulfilled by students who declared their major under previous requirements.

For students in the Class of 2022 and subsequent classes The major requirements consist of at least eleven term courses, for eleven course credits, beyond the prerequisites, including either the senior essay or the senior thesis. To begin study of Earth processes, majors take an introductory course in EPS, with any accompanying laboratory, selected from EPS 100, 101, 110, and EPS 111L, or EPS 125 and EPS 126L. Five core courses, totaling five course credits, introduce students to Earth's climate system (EPS 140), meteorology (EPS 322), physical oceanography (EPS 335), fluid mechanics (MENG 361), and statistics or linear algebra (S&DS 230 or 238 or MATH 222). Other higher-level courses in EPS can be substituted with the permission of the DUS. Four electives are chosen from topics in the environment and in processes that govern the atmosphere, ocean, and land surface, physics, and statistics. A list of suggested electives is available from the office of the DUS or on the department website. At least one elective must be from EPS.

2. The Environmental and Energy Geoscience track provides a scientific understanding of the natural and anthropogenic processes that shape the Earth-atmosphere-biosphere system, including energy and material flows among its components. It emphasizes comparative studies of past and current Earth processes to inform models of humankind's role within the environment's future. The prerequisites are broad and flexible and include CHEM 165 or CHEM 167 and mathematics through multivariate calculus (MATH 120 or ENAS 151). Depending on their area of focus, students may choose a prerequisite in physics (PHYS 170, 171; or PHYS 180, 181; or PHYS 200, 201), or they may choose cellular biology (BIOL 101 and 102, or MCB 120) and evolutionary biology (BIOL 103 and 104, or E&EB 122, or EPS 125 and 126L). The major requirements consist of at least eleven term courses, for eleven course credits, beyond the prerequisites, including either the senior essay or the senior thesis. To begin study of the Earth system, majors take two introductory courses in EPS, with any accompanying laboratories, selected from EPS 100, 101, 110 and 111L, 140, or 125 and 126L. Four core courses are chosen from topics in general resource use and sustainability (EPS 205), Earth’s surface processes (EPS 232), the microbiology of surface and near-surface environments (EPS 255), fossil fuels and energy transitions (EPS 274), renewable energies (EPS 275), geochemical principles (EPS 301), structural geology (EPS 312), meteorology (EPS 322), and satellite-based image analysis (EPS 362). Other higher-level courses in EPS can be substituted with the permission of the DUS. Four electives chosen from Earth & Planetary Sciences, Environmental Studies, Ecology and Evolutionary Biology, Engineering, or related fields provide
a broad approach to scientific study of the environment. A list of suggested electives is available from the office of the DUS or on the department website. Electives may be chosen from the core courses, and at least two must be from EPS.

3. The Paleontology and Geobiology track focuses on the fossil record of life and evolution, geochemical imprints of life, and interactions between life and Earth. Topics range from morphology, function, relationships, and biogeography of the fossils themselves, through the contexts of fossil finds in terms of stratigraphy, sediment geochemistry, paleoecology, paleoclimate, and geomorphology, to analysis of the larger causes of paleontological, geobiological, and evolutionary patterns. Integrative approaches are emphasized that link fossil evidence with the physical and chemical evolution of Earth. The prerequisites are college-level biology (BIOL 101–104, or MCD 120 and E&EB 122), CHEM 165 or CHEM 167, and mathematics through multivariate calculus (MATH 120 or ENAS 151). The major requirements consist of at least thirteen term courses, for twelve course credits, beyond the prerequisites, including either the senior essay or the senior thesis. Students take one of EPS 100, 101, 110 and 111L, to gain geological and environmental context, and they are introduced to the fossil record and evolution in EPS 125 and EPS 126L. Four core geological and environmental courses include majors a comprehensive background in sedimentary rocks and rock correlation (EPS 232 or equivalent), the study of evolution (E&EB 225 or equivalent), microbiology in past and present environments (EPS 235 or equivalent), Earth’s carbon cycle and climate (EPS 310, 402, or equivalent), and statistical data analysis as applied to the life sciences (SRDS 101 or equivalent). Other higher-level courses in EPS can be substituted with the permission of the DUS. Four electives selected from Earth and Planetary Sciences, Ecology and Evolutionary Biology, Molecular, Cellular, and Developmental Biology, and related fields offer students flexibility in pursuing their specific interests. A list of suggested electives is available from the office of the DUS or on the department website. At least one elective must be from EPS.

4. The Solid Earth Science track emphasizes an integrated geological, geochemical, and geophysical approach to the study of processes operating within Earth and their manifestation on the surface. It includes the structure, dynamics, and kinetics of Earth’s interior and their impacts on our environment both in the long term (e.g., the evolution of the land surface) and in the short term (e.g., the causes of natural disasters such as earthquakes, tsunamis, and volcanic eruptions). Students acquire a fundamental understanding of the solid Earth system, both as it exists today and as it has evolved over geologic time scales. The prerequisites are CHEM 165 or CHEM 167, physics (PHYS 170, 171; or PHYS 180, 181; or PHYS 200, 201), and mathematics through multivariate calculus (MATH 120 or ENAS 151). The major requirements consist of at least eleven courses, for eleven course credits, beyond the prerequisites, including either the senior essay or the senior thesis. To begin study of the Earth system, majors take two introductory courses in EPS, with any accompanying laboratories, selected from EPS 100, 101, 110, and 111L, 125 and 126L, or 140. The core of the track consists of four courses chosen from topics in mountain building and global tectonics (EPS 232), rocks and minerals (EPS 220), sedimentary rocks and processes (EPS 235 or equivalent), geochemical principles (EPS 301), and structural geology (EPS 312). Other higher-level courses in EPS can be substituted with the permission of the DUS. Students also select four electives in geology, geochemistry, geophysics, or related topics. A list of suggested electives is available from the office of the DUS or on the department website. Electives may be chosen from core courses, and at least two must be from EPS.

B.A. degree program The B.A. degree in Earth and Planetary Sciences requires fewer upper-level courses than the B.S. degree. It may be more appropriate for students who plan to fulfill the requirements of two majors, who study Earth and Planetary Sciences in preparation for a career in law, business, government, or environmental fields, or who decide to pursue a science major only after the first year. The prerequisites include mathematics (MATH 115), biology (BIOL 101 and 102, or MCD 120, or EPS 255), and a lecture course in chemistry. The major requirements consist of at least nine term courses beyond the prerequisites. These include two courses in EPS numbered 100–140, with any accompanying laboratories; courses in natural resources (EPS 205) and geochemical processes (EPS 220 or EPS 232 or EPS 280 or EPS 301); and five additional courses at the 200 level or higher in Earth and Planetary Sciences or related fields, approved by the DUS and including either the senior essay or the senior thesis. Course selections can be guided by any of the B.S. tracks described above.

Credit/D/Fail Courses taken Credit/D/Fail may not be applied to the prerequisites or to the requirements of the major.

SENIOR REQUIREMENT
Seniors in both degree programs must prepare either a senior essay based on one term of library, laboratory, or field research (EPS 492) or, with the consent of the faculty, a two-term senior thesis (EPS 490, EPS 491), which involves innovative field, laboratory, or theoretical research. Students electing to do a senior thesis must first select a topic and obtain the consent of a faculty member to act as an adviser. They must then petition the faculty through the DUS for approval of the thesis proposal. The petition should be submitted by the start of the senior year. If the two-term senior thesis is elected, EPS 491 may count as an elective toward the major. A copy of each senior thesis or senior essay is made available on the department website.

ADVISING
Qualified juniors and seniors are encouraged to enroll in graduate courses, with permission of the instructor, the DUS, and the director of graduate studies. Descriptions of graduate courses are available at the office of the DUS.

Practical experience In addition to prerequisites and required courses in Earth and Planetary Sciences, candidates for the B.A. and B.S. degrees are strongly encouraged to gain practical experience. This can be done in two ways: (1) by attending a summer field course at another academic institution, or (2) by participating in summer research opportunities offered by the Department of Earth and Planetary Sciences, by other academic institutions, or by certain government agencies and private industries. Consult the DUS or see the department website for further information.
Combined B.S./M.S. degree program Exceptionally able and well-prepared students may complete a course of study leading to the simultaneous award of the B.S. and M.S. degrees after eight terms of enrollment. See Academic Regulations, section K, Special Arrangements, “Simultaneous Award of the Bachelor’s and Master’s Degrees.” Interested students should consult the DUS prior to the sixth term of enrollment for specific requirements in Earth and Planetary Sciences.

Physics and Geosciences major The Department of Earth and Planetary Sciences also offers a combined major with the Department of Physics. For more information, see Physics and Geosciences.

REQUIREMENTS OF THE MAJOR

Prerequisites B.A. – MATH 115; BIOL 101 and 102, or MCDB 120, or EPS 255; a lecture course in chem; B.S. — All tracks — CHEM 165 or CHEM 167; MATH 120 or ENAS 151; Atmosphere, Ocean, and Climate track — ENAS 150 or equivalent; ENAS 194; PHYS 180, 181, 205L, 206L; Environmental and Energy Geoscience track — physics (PHYS 170, 171, or PHYS 180, 181, or PHYS 200, 201) or biology (BIOL 101 and 102, or MCDB 120; and BIOL 103 and 104, or E&EB 122, or EPS 125 and EPS 126L); Paleontology and Geobiology track — BIOL 101–104, or MCDB 120 and E&EB 122; Solid Earth Science track — PHYS 170, 171, or PHYS 180, 181, or PHYS 200, 201

Number of courses B.A. — at least 9 courses beyond prereqs for letter grades (incl senior req); B.S. — Atmosphere, Ocean, and Climate, Environmental and Energy Geoscience, and Solid Earth Science tracks — at least 11 courses beyond prereqs for letter grades (incl senior req); Paleontology and Geobiology track — at least 13 courses, for 12 credits, beyond prereqs for letter grades (incl senior req)

Specific core courses B.A. — EPS 205; 1 from EPS 220, 222, 280, or 301; B.S. — Atmosphere, Ocean, and Climate track — EPS 140, 322, 335, MENG 261, S&D 230 or 238 or MATH 222; Environmental and Energy Geoscience track — 4 from EPS 205, 225, 226, 245, 255, 275, 301, 312, 322, 362; Paleontology and Geobiology track — EPS 125, EPS 126L, 4 from EPS 232, 225, 255, 310, S&D 101 or equivalents; Solid Earth Science track — 4 from EPS 212, 220, EPS 232 or equivalent, EPS 301, 310, 312

Distribution of courses B.A. — 2 intro courses in EPS, with labs, as specified; 5 addtl courses at 200 level or higher in EPS or related fields; B.S. tracks — 2 intro courses in EPS, with labs, as specified; 4 electives as specified

Substitution permitted All programs — with DUS permission, higher-level courses for prereqs or core courses

Senior requirement All programs — senior essay (EPS 492) or, with permission of faculty, two-terrn senior thesis (EPS 490, 491)

The Earth and Planetary Sciences (EPS) program prepares students to apply scientific principles and methods in order to understand Earth, the environment, and life on a regional and planetary scale. Teaching and research cover subjects ranging from the history of Earth and life to present-day environmental processes, integrating the study of Earth’s deep interior, tectonic plates, oceans, atmosphere, climate, land surface, natural resources, and biota. The curriculum emphasizes the employment of basic principles from the core sciences (physics, chemistry, and biology) to understand Earth’s past and present and to address issues relating to its future. Majors focus on planetary or environmental phenomena of particular interest by choosing a specific track, which can be changed on an informal basis. The B.S. tracks include Atmosphere, Ocean, and Climate; Environmental and Energy Geoscience; Solid Earth Science; and Paleontology and Geobiology. The B.A. track focuses on geology and natural resources. The Earth and Planetary Sciences department also offers a combined major with the Physics department that leads to a B.S. in Physics and Geosciences.

Several introductory EPS courses have no college-level prerequisites. Each of these courses offers a rigorous introduction to an aspect of the Earth and planetary sciences:

- EPS 010, Earth, Resources, Energy, and the Environment
- EPS 100, Natural Disasters
- EPS 101, Climate Change
- EPS 110, Dynamic Earth
- EPS 125, History of Life
- EPS 140, Atmosphere, Ocean, and Climate Change
- EPS 205, Natural Resources and Their Sustainability
- EPS 210, The Geology of North America through its National Parks
- EPS 216, Global Warming: Climate Physics
- EPS 240, Forensic Geoscience

Students with college-level mathematics and physics, but no geology, can enroll in an intermediate geophysics course such as:

- EPS 322, Physics of Weather and Climate
- EPS 326, Introduction to Earth and Planetary Physics
- EPS 335, Physical Oceanography
- EPS 342, Introduction to Earth and Environmental Physics

Those with college-level chemistry may be prepared for:

- EPS 220, Petrology and Mineralogy
- EPS 255, Environmental Geomicrobiology
Those with college-level preparation in mathematics, physics, and chemistry may elect:

- EPS 301, Introduction to Geochemistry
- EPS 310, Isotope Geochemistry
- EPS 274, Fossil Fuels and World Energy
- EPS 275, Renewable Energy
- EPS 319, Introduction to the Physics and Chemistry of Earth Materials

Students major in EPS for different reasons. Some continue on to research, consulting, or industrial careers in earth and planetary sciences. The broad scientific training provided by the major also prepares students for a wide variety of other paths, including medicine, law, public policy, and teaching.

Interested first-year students should focus both on gaining direct experience in the EPS program and on fulfilling at least some of the science prerequisites for the major. Many majors complete their prerequisites concurrently with the EPS courses.

Considerable flexibility exists in the major. Students are encouraged to consult with the director of undergraduate studies (DUS) about programs of study.

FACULTY OF THE DEPARTMENT OF EARTH AND PLANETARY SCIENCES

**Professors** Jay Ague (*Chair*), David Bercovici, Ruth Blake, Mark Brandon, Derek Briggs, David Evans, Alexey Fedorov, Debra Fischer, Jacques Gauthier, Shun-ichiro Karato, Jun Korenaga, Maureen Long, Jeffrey Park, Peter Raymond, Danny Rye, James Saiers, Ronald Smith, Mary-Louise Timmermans (*DUS*), John Wettlaufer

**Associate Professor** Noah Planavsky

**Assistant Professors** Bhart-Anjun Bhullar, Pincelli Hull, Juan Lora, Alan Rooney

**Lecturers** Marilyn Fox, Michael Oristaglio, Frank Robinson, Ellen Thomas

View Courses