School of Earth Sciences

Dean: Franklin M. Orr, Jr. (on leave, Autumn)
Acting Dean: Stephan A. Graham (Autumn)

The School of Earth Sciences includes the departments of Geological and Environmental Sciences, Geophysics, and Petroleum Engineering. The interschool Earth Systems Program offers study of the geological and biological processes that operate on global scales and how they interact with international environmental issues and policies. An honors program in Environmental Science, Technology, and Policy is also available through the Institute for International Studies.

The aims of the school are (1) to prepare students for careers in the fields of environmental studies, engineering, geology, geochemistry, geomechanics, geophysics, geostatistics, hydrogeology, petroleum engineering, and petroleum geology; (2) to conduct research in the Earth sciences; and (3) to provide opportunities for Stanford undergraduates to learn about our planet's history, to understand the natural energy and resource base that underlies our economy, and to appreciate the geological and geophysical hazards that affect human societies, as well as those factors that contribute to the quality of our environment.

To accomplish these objectives, the school offers a variety of programs adaptable to the needs of the individual student: a four-year undergraduate program leading to the degree of Bachelor of Science (B.S.); a five-year program leading to the coterminal Bachelor of Science and Master of Science (M.S.), combining degrees in Earth sciences, social sciences, physical sciences, or engineering; and a graduate program offering the degrees of Master of Science, Engineer, and Doctor of Philosophy as described below. Details of individual departmental degree programs are found in the section for each department. In addition, it is possible for an undergraduate to develop an individually designed major in the Earth Sciences.

UNDERGRADUATE PROGRAMS

Any undergraduate student admitted to the University may declare a major in one of the Earth science departments or the interschool Earth Systems Program by contacting the appropriate department or program office. Students interested in creating an individually designed major should visit the dean's office.

Specific requirements for the B.S. degree are listed in each department or program section. Departmental academic advisers work with students to define a career or academic goal and assure that the student's curricular choices are appropriate to the pursuit of that goal. Advisers can help devise a sensible (and enjoyable) course of study that meets degree requirements and provides the student with opportunities to experience advanced courses, seminars, and research projects. To maximize such opportunities, students are encouraged to complete basic science and mathematics courses in high school or during their freshman year.

Each department (as well as Earth Systems) offers an honors program that involves research during the senior year. Each department also offers an academic minor for those undergraduates majoring in compatible fields.

COTERMINAL BACHELOR'S AND MASTER'S DEGREES

The Stanford coterminal degree plan enables an undergraduate to embark on an integrated program of study leading to the master's degree before requirements for the bachelor's degree have been completed. This may result in more expeditious progress towards the advanced degree than would otherwise be possible, making the program especially important to Earth scientists because the master's degree provides an excellent basis for entry into the profession. The coterminal plan permits students to be admitted to a graduate program as early as their eighth quarter at Stanford, or after earning 105 units, and no later than the eleventh quarter.

Under the plan, the student may meet the degree requirements in the more advantageous of the following two ways: by first completing the 180 units required for the B.S. degree and then completing the three quarters required for the M.S. degree; or by completing a total of 15 quarters during which the requirements for the two degrees are completed concurrently. In either case, the student has the option of receiving the B.S. degree upon meeting all the B.S. requirements or of receiving both degrees at the end of the coterminal program. Students earn degrees in the same department (including Earth Systems), in two different departments, or even in different schools; for example, a B.S. in Physics and an M.S. in Geological and Environmental Sciences. Students are encouraged to discuss the coterminal program with their advisers during their junior year. Additional information is available in the individual department offices.

GRADUATE PROGRAMS

Admission to the Graduate Program—A student who wishes to enroll for graduate work in the school must be qualified for graduate standing in the University and in addition must be accepted by one of the school's three departments. One requirement for admission is submission of scores on the verbal and quantitative sections of the Graduate Record Exam. Admission to one department of the school does not guarantee admission to other departments.

Faculty Adviser—Upon entering a graduate program, the student should report to the head of the department who will arrange with a member of the faculty to act as the student's adviser. The student, in consultation with the adviser, then arranges a course of study for the first quarter and ultimately develops a complete plan of study for the degree sought.

Financial Aid—Detailed information on scholarships, fellowships, and research grants is available from the school's individual departments. Applications should be filed by the various dates listed in the application packet for awards that become effective in Autumn Quarter of the following academic year.

EARTH SYSTEMS PROGRAM

Director: Pamela Matson

Advisory Committee: David Ackerly (Biological Sciences), Kevin Arrigo (Geophysics), Carol Boggs (Biological Sciences), Brendan Bohannan (Biological Sciences), Mark Denny (Biological Sciences, Hopkins Marine Station), Robert Dunbar (Geological and Environmental Sciences), Gary Ernst (Geological and Environmental Sciences), Walter Falcon (Institute for International Studies), Scott Fendorf (Geological and Environmental Sciences), Deborah Gordon (Biological Sciences), Lawrence Goulder (Economics, Institute for International Studies), Elizabeth Hadly (Biological Sciences), Donald Kennedy (Biological Sciences, Institute for International Studies), Julie Kennedy (Earth Systems), Jeffrey Koseff (Civil and Environmental Engineering), Anthony Kovscek (Petroleum Engineering), Gilbert Masters (Civil and Environmental Engineering), Pamela Matson (Geological and Environmental Sciences, Institute for International Studies), Michael McWilliams (Geological and Environmental Sciences), Stephen Monismith (Civil and Environmental Engineering), Harold Mooney (Biological Sciences), Rosamond Naylor (Institute for International Studies), Franklin Orr, Jr. (Dean, School of Earth Sciences), Adina Paytan (Geological and Environmental Sciences), Joan Roughgarden (Biological Sciences), Stephen Schneider (Biological Sciences, Institute for International Studies), Jonathan Stebbins (Geological and Environmental Sciences), James Sweeney (Management Science and Engineering), Barton Thompson (Law), Peter Vitousek (Biological Sciences), Virginia Walbot (Biological Sciences), Mark Zoback (Geophysics)

Senior Lecturer and Academic Coordinator: Julie Kennedy

The Earth Systems Program is an interdisciplinary environmental studies major. Students learn about and independently investigate complex environmental problems caused by human activities in interaction with natural changes in the Earth System. Earth Systems majors become skilled in those areas of science, economics, and policy needed to tackle the globe's most pressing environmental problems, becoming part of a generation of scientists, professionals, and citizens who approach and solve problems in a new way: a systematic, interdisciplinary way.

For our students to be effective contributors to the solutions of such problems, their training and understanding must be both broad and deep. To this end, Earth Systems students take courses in the fundamentals of biology, calculus, chemistry, geology, and physics, as well as in computer science, economics and policy, and statistics. After completing breadth training in these areas, students concentrate on advanced course work in one of six focus areas: biology, energy, environmental economics and policy, geology, land management, or oceanography. Along with formal course requirements, all Earth Systems students complete a 9 unit (270 hour) internship. The internship provides a "hands-on," rigorous academic experience working on a supervised field, laboratory, government or private sector project of their choice.

The following is an outline of the sequential knowledge and skills needed in this major.

1) The fundamental components of the Earth Systems: these help students understand current environmental problems against the backdrop of natural change.

   Training in the fundamentals comes through introductory course work in geology, biology, and economics. Depending on the Earth Systems track chosen, training may also include introductions to the study of the energy systems, microbiology, oceans, or soils. As students begin to question the role that humans play in affecting these systems, they find that many programs and departments at Stanford offer courses that approach this question from different directions. The department encourages students to come to the Earth Systems office for course selection advice or to pick up a current list of environmental courses at Stanford.

2) The fundamental interactions among the physical, biological, and human components of the Earth System: these must be understood in order to understand and solve environmental problems.

   Several Earth Systems courses introduce students to the dynamic and multiple interactions that characterize global change problems. They include the introductory course, Introduction to Earth Systems, and three core courses, the Geosphere, the Biosphere, and the Anthrosphere.

   Competence in understanding system-level interactions is critical to development as an Earth Systems thinker, so additional classes that meet this objective are excellent choices as electives. More information on such classes is available in the program office.

3) To recognize, quantify, and report change in the environment, key analytical and computational tools and measurement systems are used for insight into global and regional environmental change, and are used to identify change and develop solutions.

   The test of an Earth Systems degree is the student's ability to recognize, describe, quantify, and help solve complex problems that face our society. Through required cognates and specific track classes, students build skills in these areas. For example, training in satellite remote sensing and geographic information systems is either required or highly recommended for all tracks. Quantification of environmental problems requires solid training in calculus, linear algebra, physics, chemistry, programming, and statistics. These courses are required of all majors. Specialized training, such as in laboratory or field methods, may be necessary and is highly recommended.

   Having the ability to effectively communicate ideas and results is critical. Indeed, workable solutions to our environmental problems begin with common understanding of the issues. Writing intensive courses (WIM) help students to communicate complex concepts to expert and non-expert audiences alike. Stanford requires that each student complete one WIM course in his or her major. The Earth Systems major requires two writing intensive courses, Biosphere and Senior Seminar, with an option for a third course for coterminal master's students through the Master's Seminar. Oral communication skills are also a focus of the Senior Seminar and the Master's Seminar.

4) To develop solutions to environmental problems that take into consideration natural processes as well as human needs, human needs must be met in a sustainable way.

   Many courses at Stanford focus on solutions. A comprehensive list of environmental courses, and advice on those that focus on problem solving, is available in the program office. Students can also review the quarterly *Time Schedule* for solution-based courses. Among others, the following departments may provide subject areas that are a useful guide: Anthropoloical Sciences, Biological Sciences, Civil and Environmental Engineering, Earth Systems, Economics, Geological and Environmental Sciences, Geophysics, Human Biology, International Policy Studies, International Relations, Latin America Studies, Law, Petroleum Engineering, Political Science, Public Policy, and Urban Planning. The Earth Systems Program emphasizes the importance of workable solutions in several ways, including a required 9-unit internship, knowledge synthesis in the Senior Seminar, and an optional upper division course on environmental problem solving.

Students interested in Earth Systems should come to the program office for current information on our curriculum, alumni career paths, environmental jobs and internships, and undergraduate honors options. The Earth Systems Program provides a strong advising network that includes faculty, staff, and students.

UNDERGRADUATE PROGRAMS

BACHELOR OF SCIENCE

The B.S. in Earth Systems (ESys) requires the completion of at least 109 units that can be divided into three levels of courses. The student must complete a series of courses comprising a broad base of specialized study and must complete five required and three elective courses in that track. Finally, the student must carry out a senior-level research or internship project and participate in the senior seminar (WIM). Note: students interested in earning a California Teaching Credential for general high school science should contact the program office for specific guidelines.

REQUIRED CORE

Course No. and Subject	*Units*
ESys 10. Introduction to Earth Systems	3
ESys 110. Geosphere	3
ESys 111. Biosphere	3
ESys 112. Anthrosphere	5
ESys 210. Senior Seminar	4
ESys 260. Internship	
or ESys 250. Directed Research	9

REQUIRED COGNATE COURSES

Biology (any one course below):	
Biol. Sci. 51. Evolution, Genetics, and Ecology	5
or Biol. Sci. 52. Biochemistry, Molecular, and Cell Biology	5
Chemistry:	
Chem. 31. Chemical Principles	3
Chem. 33. Organic Chemistry*	4
Computer Programming:	
Comp. Sci. 106. Programming Methodology	5
or Comp. Sci. 138. Matlab and Maple for Science and Engineering Applications	5
Economics:	
Econ. 1. Elementary Economics	5
Econ. 50. Economic Analysis I	5
Geological and Environmental Sciences:	
Geol. & Envir. Sci. 1. Fundamentals of Geology	4
Mathematics:	
Math. 19. Calculus and Analytic Geometry	3
Math. 20. Calculus and Analytic Geometry	3
Math. 21. Calculus and Analytic Geometry	4
or	
Math. 41. Calculus and Analytic Geometry	5

Math. 42. Calculus and Analytic Geometry	5
and	
Math. 51. Linear Equations and Differential Calculus	5

Probability and Statistics (any one course below):

Biol. Sci. 141. Biostatistics	4
Geol. & Envir. Sci. 160. Introduction to Statistical Methods for Earth and Environmental Sciences	4
Stat. 190. Statistics for Social Scientists	5

Physics:

Physics 41. Mechanics	4
Physics 47 Light and Heat*	4
(Additional physics cognate for Energy Track only) Physics 43. Electricity	3

* Students may take either Physics 47 or Chem. 33; Biosphere students must take Chem. 33.

More extensive work in mathematics and physics may be expected for those planning graduate study. Graduate study in ecology and evolutionary biology and in economics requires familiarity with differential equations, linear algebra, and stochastic processes. Graduate study in geology and geophysics may require more physics and chemistry. Check with your adviser about recommendations beyond the requirements specified above.

TRACKS

GEOSPHERE

Geochemistry (choose one):

Geol. & Envir. Sci. 90. Introduction to Geochemistry	3
Geol. & Envir. Sci. 163. Introduction to Isotope Geology	3
Geol. & Envir. Sci. 170. Environmental Geochemistry	4
Geol. & Envir. Sci. 171. Geochemical Thermodynamics	3

Oceans/Atmosphere (choose one):

Geol. & Envir. Sci. 8. The Oceans: Introduction to the Marine Environment	3
Civ. & Envir. Engr. 63. Weather and Storms	3

Remote Sensing/GIS (choose one):

Geol. & Envir. Sci. 195. Integrating Remote Sensing and Geographic Information Systems	3
Geol. & Envir. Sci. 196. Introduction to GIS	2

Rocks/Minerals

Geol. & Envir. Sci. 80. Earth Materials	5

Surface Processes (choose one):

Geol. & Envir. Sci. 140. Geomorphology	3
Geol. & Envir. Sci. 151. Sedimentary Geology and Petrography	4-5

BIOSPHERE

Biol. Sci. 51. Evolution, Genetics, and Ecology	5
Biol. Sci. 52. Biochemistry, Molecular Biology, and Cell Biology	5
Biol. Sci. 53. Development and Physiology of the Organism	5

Biogeochemistry (choose one):

Biol. Sci. 124. Ecosystem Physiology	4
Biol. Sci. 216. Biogeochemistry/Ecosystem Ecology (same as Geol. & Envir. Sci. 220)	4
(Check with program office for new courses)	

Conservation Biology (choose one):

Biol. Sci. 144. Conservation Biology	4
or Biol. Sci. 173H. Marine Conservation Biology	3

Ecology (choose two):

Biol. Sci. 138. Plant Ecology	4
Biol. Sci. 145. Behavioral Ecology	4
Biol. Sci. 142. Principles of Ecology (same as Geophys. 176)	4
(Check with program office for new courses)	

ANTHROSPHERE

Economics and Environmental Policy (choose three):

Econ. 51. Economic Analysis II	5
Econ. 102. Introduction to Econometrics	5
Econ. 106. The World Food Economy	5
Econ. 118. Economics of Development	5
Econ. 150. Economics and Public Policy	5
Econ. 160. Game Theory and Economic Application	5

Legal and Political Institutions and the Environment (choose one):

Econ. 154. Economics of Legal Rules and Policy	5
Pub. Pol. 101. Politics and Public Policy	5

LAND MANAGEMENT

See program office for requirements.

ENERGY SCIENCE AND TECHNOLOGY

Civ. & Envir. Engr. 173B. The Coming Energy Revolution	3
Civ. & Envir. Engr. 176A. Energy Efficient Buildings	4
Civ. & Envir. Engr. 176B. Electric Power: Generation and Conservation	4
Esys 103. Energy Resources	3
or Esys 101. Energy and the Environment	3
Engr. 30. Engineering Thermodynamics	3

OCEANS

Physics of the Sea

Civ. & Envir. Engr. 164. Introduction to Physical Oceanography	4

Biological Oceanography (choose one):

Biol. Sci. 163H. Principles of Oceanic Biology	4
Geophys. 130. Biological Oceanography	4

Marine Chemistry

Geol. & Envir. Sci. 159. Marine Chemistry	3

Remote Sensing of the Ocean (choose one):

Geol. & Envir. Sci. 196. Introduction to GIS: Arc/Info and ARC-View	2
Geophys. 135. Remote Sensing of the Ocean	4

Coastal Ocean Dynamics: A Systems Approach

(Check with program office for new course information)

UPPER-DIVISION ELECTIVES

Three intermediate to advanced courses, 100-level or above, consistent with the primary track are required of all majors and are to be selected with the advice and consent of the adviser. Eligible upper-division electives are listed below. Additional courses may be selected; see the program office for the most current list.

GEOSPHERE TRACK

Esys 103. Energy Resources	3
Geol. & Envir. Sci. 110. Structural Geology	5-6
Geol. & Envir. Sci. 111. Structural Geology and Rock Mechanics	4
Geol. & Envir. Sci. 112. Structural and Engineering Geology II	3
Geol. & Envir. Sci. 164. Stable Isotopes	3
Geol. & Envir. Sci. 185. Volcanology	4
Geol. & Envir. Sci. 162. Cosmochemistry	3
Geol. & Envir. Sci. 220. Biogeochemistry	3
Geol. & Envir. Sci. 221. The Origins of the Solar System	3
Geol. & Envir. Sci. 223. Seminar in Environmental Problem Solving	3
Geol. & Envir. Sci. 254. Paleoceanography	3
Geol. & Envir. Sci. 255. Introduction to Micropaleontology	5
Geol. & Envir. Sci. 257. Climate Variability	3
Pet. Engr. 260. Groundwater Pollution and Oil Spills: Environmental Problems in the Petroleum Industry	3

BIOSPHERE TRACK

Biol. Sci. 120. General Botany	5
Biol. Sci. 125. Ecosystems of California	3-4
Biol. Sci. 139. Biology of Birds	3
Biol. Sci. 184. Principles of Biosystematics	4
Biol. Sci. 161H. Invertebrate Zoology	5
Biol. Sci. 163H. Principles of Oceanic Biology	4
Biol. Sci. 164H. Marine Botany	4
Biol. Sci. 215. Biochemical Evolution	3
Biol. Sci. 216. Ecosystem Ecology and Global Biogeochemistry	3
Biol. Sci. 217. Climate Theory, Modeling, Applications, and Implications	3
Biol. Sci. 283. Theoretical Populations Genetics	3
Geol. & Envir. Sci. 255. Introduction to Micropaleontology	5

ANTHROSPHERE TRACK

Anthro. Sci. 161. Conservation and Community Development in the Amazon	3-5
Anthro. Sci. 172. Indigenous Forest Management	5
Civ. & Envir. Engr. 171. Environmental Planning Methods	4
Civ. & Envir. Engr. 266. Environmental Policy Design and Implementation	4
Econ. 158. Antitrust and Regulation	5
Econ. 165. International Economics	4
Econ. 243. Economics of the Environment	5
Geol. & Envir. Sci. 133. Introduction to Assessment of Environmental Risk	3
Internat. Pol. Stud. 205. The Political Economy of Environmental and Resource Policy	5
Internat. Pol. Stud. 209. Economic Development Policy Analysis	5
Internat. Pol. Stud. 215. International Environmental and Resource Economics	5

Manage. Sci. & Engr. 194. The Role of Analysis in Environmental Policy Decisions	3-5
Pol. Sci. 216M. Environmental Politics in the Asia/Pacific Region	5
Pub. Pol. 103. Introduction to Political Philosophy	3
Urban Studies 133. The Politics of Development	4
Urban Studies 182. Urban Environmental Policy	4
Urban Studies 183. Land Use Control	4

ENERGY SCIENCE AND TECHNOLOGY TRACK

Econ. 158. Antitrust and Regulation	5
Elect. Engr. 293A. Fundamentals of Energy Processes	3
Elect. Engr. 293B. Fundamentals of Energy Processes	3
Hum. Bio. 148. Environmental Policy	3
Mech. Engr. 130. Internal Combustion Engines	3
Mech. Engr. 131A. Heat Transfer	3
Pet. Engr. 120. Fundamentals of Petroleum Engineering	3
Pet. Engr. 178. Solar Energy Thermal Processes	3
Pet. Engr. 260. Groundwater Pollution and Oil Spills	3
Pet. Engr. 269. Geothermal Reservoir Engineering	3
Pol. Sci. 114. The Political Economy of Development	3

OCEANS TRACK

Biol. Sci. 161H. Invertebrate Zoology	5
Biol. Sci. 163H. Principles of Oceanic Biology	4
Biol. Sci. 164H. Marine Botany	4
ESys 166. Fishing for Solutions: Issues in Marine Conservation	3-5
Geol. & Envir. Sci. 119. Introduction to Paleoceanography	3
Geol. & Envir. Sci. 163. Introduction to Isotope Geology	3
Geol. & Envir. Sci. 205. Advanced Oceanography	3
Geol. & Envir. Sci. 225. Isotopes in Geological and Environmental Research	3
Geol. & Envir. Sci. 254. Paleoceanography	3

SUMMARY OF COURSE REQUIREMENTS AND UNITS

Earth Systems Introduction and Core	16
Required allied courses	47-50
Tracks:	
Anthrosphere	20
Biosphere	20
Geosphere	20
Energy Science and Technology	23
Land Management	23
Upper-division electives	9-15
Senior project or internship	9
Senior seminar	4
Total units (depending on track, electives)	109-125

COTERMINAL B.S. AND M.S. DEGREES

The Stanford coterminal degree enables an undergraduate to embark on an integrated program of study leading to the master's degree before requirements for the bachelor's degree have been completed. An undergraduate majoring in Earth Systems may apply to work simultaneously toward B.S. and M.S. degrees. The M.S. degree in Earth Systems provides the student with enhanced tools to evaluate the primary literature of the discipline most closely associated with the student's track and allows an increased specialization through additional course work that may include 9 units of thesis research. Integration of earth systems concepts is furthered by participation in the master's seminar.

To apply, complete and return to the Earth Systems office an application that includes a statement of purpose; a Stanford transcript; two letters of recommendation, one of which must be from a faculty member of the program; and a list of courses that fulfill degree requirements signed by the master's adviser. Students may be admitted as early as their eighth quarter at Stanford, or after earning 105 units, but no later than their eleventh quarter. Students may either (1) complete 180 units required for the B.S. degree and then complete the three quarters required for the M.S. degree, or (2) complete a total of 15 quarters during which the requirements of the degrees are fulfilled concurrently. The student has the option of receiving the B.S. degree after completing that degree's requirements or receiving two degrees concurrently at the end of the master's program. Note: students interested in enrolling in the STEP Program during their fifth year and gaining a California Teaching Credential for high school general science should come by the program office.

Three levels of requirements must be fulfilled to receive a M.S. degree:

1. All requirements for the B.S. degree.
2. Further course work (and/or thesis research), all of which should be at the 100-level or above, including 18 units at the 200-level or above, leading to further focus within the student's track.
3. Participation in the master's seminar.

The program consists of a minimum of 36 units of course work and/or thesis research, at least 18 of which must be at the 200-level or above.

The student must devise a program of study that shows a level of specialization appropriate to the master's level, as determined in consultation with the adviser. At least 18 units must be at the 200-level or above. The program should demonstrate further specialization and focus within the student's undergraduate track.

With the adviser's approval, 9 units may be in the form of research. This may culminate in the preparation of a master's thesis; however, a thesis is not required for the degree. Master's students must take part in the Winter Quarter master's seminar (ESys 290) and have additional responsibilities appropriate to the master's level (thesis presentation, modeling problems, and so on), 2 units.

A more detailed description of the coterminal master's degree program may be obtained from the program office.

COURSES

(WIM) indicates that the course meets the Writing in the Major requirements.

UNDERGRADUATE

10. Introduction to Earth Systems—For non-majors and prospective Earth Systems majors. Multi-disciplinary approach to how the Earth works as a system, utilizing the tools of geology, biology, and economics to understand global change on all time scales. Topics: origin of the solar system and earth, paleoclimate and climate modeling, ocean-atmosphere circulation, extinction and speciation, energy and mineral resources, economic attitudes and the environment. Case studies: acid rain, hunger and food, policy and the environment. GER:2a (DR:5)

3-5 units, Win (Ernst)

101. Energy and the Environment—(Same as Petroleum Engineering 101.) Where the energy that powers society comes from, acknowledging that most current energy is generated from fossil resources. Case studies consider the consequences of current energy use patterns. Focus is on energy definitions, use patterns, resource estimation, pollution. Recommended: Mathematics 21 or 42, Engineering 30.

3 units, Spr (Kovscek)

103. Energy Resources—(Same as Civil and Environmental Engineering. 173A.) Overview of oil, natural gas, coal, nuclear, hydro, solar, geothermal, biomass, wind, and ocean energy resources in terms of supply, distribution, recovery and conversion, environmental impacts, economics, policy, and technology. The opportunities for energy efficiency, electric power basics, the changing role of electric utilities, transportation basics, and energy use in developing countries. Field trip. Recommended: Civil and Environmental Engineering 70.

4 units, Aut (Woodward)

110. Geosphere—(Same as Geological and Environmental Sciences 120.) Geological processes, from local to global, affect people and civilization. The reverse is also true; civilization is beginning to influence the geosphere. The processes experienced at the earth's surface (catastrophic earthquakes, volcanic eruptions, and longer term atmospheric and climate changes) are linked to what goes on in the earth's deep interior. How geochemical, geophysical, and biological processes interact over time scales from 4.5 billion years to the nearly instantaneous. Topics: the origin and evolution of the atmosphere and oceans, heat flow and global tectonics and how they have changed over time, geochemical cycles, climate change, catastrophic impacts, and the roles played by organisms. Prerequisite: Geological and Environmental Sciences 1 or 2.

3 units, Aut (Paytan, Stebbins, McWilliams)

111. Biosphere—(Same as Biological Sciences 117.) The biological causes and consequences of anthropogenic and natural changes in the atmosphere, oceans, and terrestrial and freshwater ecosystems. Topics: glacial cycles and marine circulation, greenhouse gases and climate change, tropical deforestation and species extinctions, and human population growth and resource use. Prerequisites: Biological Sciences or Human Biology core, or graduate standing in any department.
3 units, Win (Matson, Vitousek, Mooney)

112. Anthrosphere: Human Interactions with the Earth and Environment—(Same as Economics 155.) The economic sources of environmental problems and the alternative policies for dealing with them (technology standards, emissions taxes, and marketable pollution permits). An evaluation of the policies addressing regional air pollution, global climate change, water allocation in the western U.S., and the use of renewable resources. The connections between population growth, economic output, environmental quality, and human welfare. Prerequisite: Economics 50.
5 units, Spr (Goulder)

124. The Global Environmental System—(Graduate students register for 224.) Among the effects of the expansion of population and economic activity in the 20th century were anthropogenic changes in the global environment. One of the admirable advances in human knowledge was the increase in understanding of the global environmental system. An overview of the functioning of the global environmental systems and society's impacts on the system, combining knowledge from different disciplines and using "systems thinking" as a framework for thinking about the global system.
2 units, Aut (Alcmao)

130. Biological Oceanography—(Same as Geophysics 130.) Interdisciplinary look at how oceanic environments control the form and function of marine life. Topics: distributions of planktonic production and abundance, nutrient cycling, the role of ocean biology in the climate system, an expected effect of climate changes on ocean biology. Local field trips on weekends. Prerequisites: Biological Sciences core, Geological and Environmental Sciences 8, or equivalent.
4 units, Spr (Arrigo)

135. Remote Sensing of the Ocean—(Same as Geophysics 135.) How to observe and interpret physical and biological changes in the oceans using remote technologies such as satellites and instrumented moorings. Topics: principles of satellite remote sensing, classes of satellite sensors and mooring platforms, converting radiometric data into biological quantities, sensor calibration and validation, interpreting large-scale oceanographic features. Prerequisites: Earth Systems 130 or Hopkins Marine 163H/263H.
4 units (Arrigo) alternate years, given 2001-02

147. Controlling Climate Change in the 21st Century—(Enroll in Human Biology 147.)
3 units, Aut (Schneider, Rosencranz)

150/240. Seminar in Sustainable Agriculture—The interactions of agriculture and environment and the range of meanings and approaches to sustainable agriculture. Topics: ecological, economic, institutional, and political aspects of sustainability as they pertain to a range of cropping systems. For 2 units: participation in team research evaluating current and potential sustainable agriculture approaches in specific global cropping systems. Group presentation on research findings.
1-2 units, Spr (Matson, Naylor, Kennedy)
alternate years, not given 2001-02

159. Marine Chemistry—(Same as Geological and Environmental Sciences 159.) For upper-division undergraduates and graduate students in the earth, biology, and environmental sciences. The oceans are in interactive contact with the atmosphere, biosphere, and lithosphere, and virtually all elements pass through the ocean at some point in their cycles. The first-order processes take place within the sea, which affects its chemistry. What controls the distribution of chemical species in water and sediments? How long do different elements spend, on average, in the ocean? How do marine chemical processes interact with the biological, geological, and physical processes in the oceans? Prerequisite: Geological and Environmental Sciences 8, or the consent of the instructor.
3 units, Spr (Paytan)

164. Introduction to Physical Oceanography—(Same as Civil and Environmental Engineering 164.) Introduction to the dynamic basis of physical oceanography. Topics: a general description of the physical environment of the ocean; conservation equations for salt, heat, and momentum; geostrophic flows; wind-driven flows; the Gulf Stream; equatorial dynamics and ENSO; the thermohaline circulation of the deep oceans; and tides. Prerequisite: Physics 41.
4 units, Aut (Monismith)

166B. Fishing for Solutions: Issues in Marine Conservation—(Graduate students register for 266B, same as Anthropological Sciences 166B.) The stories behind communities and their fisheries relate to a resource we cannot see. The history of exploitation of cod, salmon, tuna, and grouper are instructive of the wider challenges facing marine resource management. The complex of cultural, biological, and economic facets that shape a fishery.
3-5 units, Win (Novy)

170/270. Multidisciplinary Perspectives on Environmental Justice—Introduction to environmental justice concerns and the role varied disciplines play in addressing those concerns. Topics: environmental justice in the U.S., "Brownfields," keys to successful multidisciplinary problem solving, and unique problems involved in addressing environmental justice issues.
2-3 units (Thompson) not given 2000-01

178. Solar Energy Thermal Processes—(Same as Petroleum Engineering 178.) The nature and availability of solar radiation. Radiation and convection heat transfer, radiation characteristics of opaque materials, absorptance, emittance, and reflectance. Radiation transmission through glazing. The design and performance of flat-plate solar collectors and concentrating collectors. Energy storage. Systems design for solar space and water heating. Industrial process heat.
3 units, Aut (Hewett)

189. Field Studies in Earth Systems—For advanced upper-division undergraduates and graduate students in Earth Systems, Biological Sciences, or Geological and Environmental Sciences. Field-based, focusing on the components and processes by which terrestrial ecosystems function. Topics from geology, soil science, chemistry, biology, and ecology. Lecture, field, and lab studies emphasize standard field techniques, experimental design, analysis of data, and written and oral presentation. Small team projects test the original questions in the functioning of natural ecosystems. Admission by application, see *Time Schedule*. Prerequisites: Biological Sciences 141 or Geological and Environmental Sciences 160, or equivalent.
5 units, Spr (Ackerly, Chiariello, Fendorf, Matson, E. Miller)

210. Senior Seminar in Earth Systems—Focus is on communication skills, oral and written. Each student presents results of the Earth Systems internship in an oral presentation and leads a follow-up round table discussion subsequent to talk. Group project analyzing local environmental problems requires an Earth Systems approach. Peer-reviews of internship papers as required. (WIM)
4 units, Aut, Spr (J. Kennedy)

223. Seminar in Sustainable Agriculture—(Same as Geological and Environmental Sciences 223.) For upper-division undergraduates and graduate students in the earth and biological sciences. Using case studies, evaluates and contrasts the approaches that different natural and social science disciplines bring to environmental problem solving.

2-3 units (Matson, Naylor)
alternate years, given 2001-02

250. Directed Research—Independent research into an aspect of earth systems related to the student's primary track, carried out after the junior year, during the summer, and/or during the senior year. Student develops own project with faculty supervision, or can see adviser for research ideas. 10-15 page thesis required.

9 units, quarter by arrangement (Staff)

260. Internship—Supervised field, lab, private sector, or advocacy project, normally through an internship sponsored by government agencies, research institutions or other organizations, or independently developed by the student with the prior written approval of the academic coordinator. Provides hands-on experience within the student's primary track. 10-15 page report required.

9 units, quarter by arrangement (J. Kennedy)

290. Master's Seminar—Open to Earth Systems master's students only. Focus is on critical examination and discussion of topics in Earth Systems. Requires independent research, oral presentation of results, and preparation of an original proposal for innovative Earth Systems science/ policy research.

2 units, Win (J. Kennedy)

298. Advanced Topics in Earth Systems—Open to Earth Systems master's students only. Continuation of Winter Quarter master's seminar.

2 units, Spr (J. Kennedy)

299. M.S. Thesis—Research in connection with the master's paper.

1-9 units, any quarter (Staff)