SCHOOL OF EARTH SCIENCES

ENVIRONMENTAL EARTH SYSTEM SCIENCE

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Courses offered by the Department of Environmental Earth System Science are listed under the subject code EESS on the *Stanford Bulletin's* ExploreCourses web site.

Environmental Earth System Science studies the planet's oceans, lands, and atmosphere as an integrated system, with an emphasis on changes occurring during the current period of overwhelming human influence, the Anthropocene. Faculty and students within the department use the principles of biology, chemistry, and physics to study problems involving processes occurring at the Earth's surface, such as climate change and global nutrient cycles, providing a foundation for problem solving related to environmental sustainability and global environmental change.

GRADUATE PROGRAMS IN ENVIRONMENTAL EARTH SYSTEM SCIENCE

The University's basic requirements for the M.S. and Ph.D. degrees are discussed in the "Graduate Degrees" section of this bulletin.

MASTER OF SCIENCE IN ENVIRONMENTAL EARTH SYSTEM SCIENE

The purpose of the master's program is to continue a student's training in one of the earth science disciplines and to prepare students for a professional career or doctoral studies.

The department's graduate coordinator, in coordination with the departmental faculty, appoints an academic adviser during registration with appropriate consideration of the student's background, interests, and professional goals. In consultation with the adviser, the student plans a program of course work for the first year. The student should select a thesis adviser within the first year of residence and submit to the thesis adviser a proposal for thesis research as soon as possible. The academic adviser supervises completion of the department requirements for the M.S. program as outlined below until the research proposal has been accepted; responsibility then passes to the thesis adviser. The student may change either thesis or academic advisers by mutual agreement and after approval of the graduate coordinator.

The University's requirements for M.S. degrees are outlined in the "Graduate Degrees" section of this bulletin. Additional departmental requirements include the following:

1. EESS 300, Earth Sciences Seminar.
2. A minimum of 45 units of course work at the 100 level or above.
3. Half of the courses used to satisfy the 45-unit requirement must be intended primarily for graduate students, usually at the 200 level or above.
4. No more than 15 units of thesis research may be used to satisfy the 45-unit requirement.
5. Some students may be required to make up background deficiencies in addition to these basic requirements.
6. By the end of Winter Quarter of the first year in residence, a student must complete at least three courses taught by a minimum of two different department faculty members.

Each student must have a research adviser who is a faculty member in the department and is within the student's thesis topic area or specialized area of study. The faculty adviser is charged with designing the curriculum in consultation with the student specific to the research topic. Each student must complete a thesis describing his or her research. Thesis research should begin during the first year of study at Stanford and should be completed before the end of the second year of residence. Early during the thesis research period, and after consultation with the student, the thesis adviser appoints a second reader for the thesis who must be approved by the graduate coordinator; the thesis adviser is the first reader. The two readers jointly determine whether the thesis is acceptable for the M.S. degree in the department.

DOCTOR OF PHILOSOPHY IN ENVIRONMENTAL EARTH SYSTEM SCIENCE

The objectives of the doctoral program are to enable students to develop the skills needed to conduct original investigations in environmental and earth system sciences, to interpret the results, and to present the data and conclusions in a publishable manner. Graduates should develop strong communication skills and leadership skills with the ability to teach and communicate effectively with the public.

The University's requirements for the Ph.D. degree are outlined in the "Graduate Degrees" section of this bulletin. A summary of additional department requirements follows:

1. Students must complete the required courses in their individual program or in their specialized area of study with a grade point average (GPA) of 3.0 (B) or higher, or demonstrate that they have completed the equivalents elsewhere.
2. Students must complete a minimum of four letter grade courses of at least 3 units each from four different faculty members on the Academic Council in the University.
3. Students must complete EESS 300, Earth Sciences Seminar, in their first quarter at Stanford.
4. By the end of Winter Quarter of their first year in residence, students must complete at least three courses taught by a minimum of two different departmental faculty members.
5. Each student must qualify for candidacy for the Ph.D. by the end of the sixth quarter in residence, excluding summers. Department procedures require selection of a faculty thesis adviser, preparation of a written research proposal, approval of this proposal by the thesis adviser, selection of a committee for the Ph.D. qualifying examination, and approval of the membership by the graduate coordinator and chair of the department. The research examination consists of three parts: oral presentation of a research proposal; examination on the research proposal; and examination on subject matter relevant to the proposed research. The exam should take place prior to May 1 so that its

outcome is known at the time of the annual spring evaluation of graduate students.

Upon qualifying for Ph.D. candidacy, the student and thesis adviser, who must be a department faculty member, choose a research committee that includes a minimum of two faculty members in the University in addition to the adviser. Annually, in the month of March or April, the candidate must organize a meeting of the full research committee to present a progress report covering the past year and provide expected goals for the coming year.

Under the supervision of the research advisory committee, the candidate must prepare a doctoral dissertation that is a contribution to knowledge and is the result of independent research; curriculum must also be developed with the supervision of the committee, which should be designed to provide a rigorous foundation for the research area. The format of the dissertation must meet University guidelines. The student is urged to prepare dissertation chapters that, in scientific content and format, are readily publishable.

The doctoral dissertation is defended in the University oral examination. The department appoints the research adviser and two other members of the research committee to be readers of the draft dissertation. The readers are charged to read the draft and to certify in writing to the department that it is adequate to serve as a basis for the University oral examination. Upon obtaining this written certification, the student is permitted to schedule the University oral examination.

ENVIRONMENTAL EARTH SYSTEM SCIENCE (EESS)

UNDERGRADUATE COURSES IN ENVIRONMENTAL EARTH SYSTEM SCIENCE

EESS 2. Earth System History
The evolution of Earth's systems from formation to the present. Couplings and relationships among biosphere, lithosphere, hydrosphere, and atmosphere. Topics include the evolution of life, origin of the oceans, atmosphere and continents, and changes in climate. Modern climate change and anthropogenic effects. GER: DB-NatSci
3 units, Win (Chamberlain, P)

EESS 8. The Oceans: An Introduction to the Marine Environment
For non-majors and majors in earth science or environmental science. Students will learn about the major ocean ecosystems and how they function both naturally and under the influence of human activities. Emphasis will be placed on the dominant organisms of each ecosystem and how they interact with each other and their physical and chemical environment. The types of ecosystems discussed will include coral reefs, deep-sea hydrothermal vents, coastal upwelling systems, blue-water oceans, estuaries, near-shore dead zones, etc. The course will incorporate a mix of lectures, multi-media presentations, and group activities.
4 units, Spr (Staff)

EESS 37N. Energy and the Environment on the Back of an Envelope
(F,Sem) Stanford Introductory Seminar. Preference to freshmen. How quantitative understanding of the Earth helps inform decisions about energy supply. How can enough energy be provided to support future growth and development throughout the world without damaging the natural environment? Focus is on simple quantitative observations and calculations that facilitate evaluation of potential solutions to this problem; algebra only, no calculus. GER: DB-NatSci
3 units, Aut (Staff)

EESS 39N. The Carbon Cycle: Reducing Your Impact
(F,Sem) Stanford Introductory Seminar. Preference to freshmen. Changes in the long- and short-term carbon cycle and global climate through the burning of fossil fuels since the Industrial Revolution. How people can shrink their carbon footprints. Long-term sources and sinks of carbon and how they are controlled by tectonics and short-term sources and sinks and the interaction between the biosphere and ocean. How people can shrink their carbon footprints. Held at the Stanford Community Farm. GER: DB-NatSci
3 units, Spr (Chamberlain, P)

EESS 57Q. Climate Change from the Past to the Future
(S,Sem) Stanford Introductory Seminar. Preference to sophomores. Numeric models to predict how climate responds to increase of greenhouse gases. Paleoclimate during times in Earth's history when greenhouse gas concentrations were elevated with respect to current concentrations. Predicted scenarios of climate models and how these models compare to known hyperthermal events in Earth history. Interactions and feedbacks among biosphere, hydrosphere, atmosphere, and lithosphere. Topics include long- and short-term carbon cycle, coupled biogeochemical cycles affected by and controlling climate change, and how the biosphere responds to climate change. Possible remediation strategies.
3 units, Spr (Staff)

EESS 101. Environmental and Geological Field Studies in the Rocky Mountains
(Same as GES 101) Three-week, field-based program in the Greater Yellowstone/Teton and Wind River Mountains of Wyoming. Field-based exercises covering topics including: basics of structural geology and petrology; glacial geology; western cordillera geology; paleoclimatology; chemical weathering; aqueous geochemistry; and environmental issues such as acid mine drainage and changing land-use patterns.
3 units, Aut (Chamberlain, P; Graham, S)

EESS 134. Stable Isotopes in Biogeochemistry
(Same as EESS 234) Light stable isotopes and their application to geological, ecological, and environmental problems. Isotopic systematics of hydrogen, carbon, nitrogen, oxygen, and sulfur; chemical and biogenic fractionation of light isotopes in the atmosphere, hydrosphere, and rocks and minerals. GER: DB-NatSci
3 units, not given this year

EESS 141. Remote Sensing of the Oceans
(Same as EESS 241, EARTHSYS 141, EARTHSYS 241) How to observe and interpret physical and biological changes in the oceans using satellite technologies. Topics: principles of satellite remote sensing, classes of satellite remote sensors, converting radiometric data into biological and physical quantities, sensor calibration and validation, interpreting large-scale oceanographic features. GER: DB-NatSci
3-4 units, Win (Arrigo, K)

EESS 143. Marine Biogeochemistry
(Same as EESS 243) (Graduate students register for 243.) Processes that control the mean concentration and distribution of biologically utilized elements and compounds in the ocean. Processes at the air-sea interface, production of organic matter in the upper ocean, remineralization of organic matter in the water column, and processing of organic matter in the sediments. Cycles of carbon, oxygen, and nutrients; the role of the ocean carbon cycle in interannual to decadal variability, paleoclimatology, and the anthropogenic carbon budget. GER: DB-NatSci
3-4 units, Spr (Arrigo, K)

EESS 146A. Atmosphere, Ocean, and Climate Dynamics: The Atmospheric Circulation
(Same as EESS 246A) Introduction to the physics governing the circulation of the atmosphere and ocean and their control on climate with emphasis on the atmospheric circulation. Topics include the global energy balance, the greenhouse effect, the vertical and meridional structure of the atmosphere, dry and moist convection, the equations of motion for the atmosphere and ocean, including the effects of rotation, and the poleward transport of heat by the large-scale atmospheric circulation and storm systems. Prerequisites: MATH 51 or CME100 and PHYSICS 41.
3 units, Win (Staff)

EESS 155. Science of Soils
Physical, chemical, and biological processes within soil systems. Emphasis is on factors governing nutrient availability, plant growth and production, land-resource management, and pollution within soils. How to classify soils and assess nutrient cycling and contaminant fate. Recommended: introductory chemistry and biology. GER: DB-NatSci
4 units, Spr (Fendorf, S)

EESS 156. Soil Chemistry
(Same as EESS 256) (Graduate students register for 256.) Practical and quantitative treatment of soil processes affecting chemical reactivity, transformation, retention, and bioavailability. Principles of primary areas of soil chemistry: inorganic and organic soil components, complex equilibria in soil solutions, and adsorption phenomena at the solid-water interface. Processes and remediation of acid, saline, and wetland soils. Recommended: soil science and introductory chemistry and microbiology. GER: DB-NatSci
4 units, Win (Fendorf, S)

EESS 160. Statistical Methods for Earth and Environmental Sciences: General Introduction
Extracting information from data using statistical summaries and graphical visualization, statistical measures of association and correlation, distribution models, sampling, error estimation and confidence intervals, linear models and regression analysis, introduction to time-series and spatial data with geostatistics, applications including environmental monitoring, natural hazards, and experimental design. GER:DB-Math
3 units, Spr (Switzer, P)

EESS 162. Remote Sensing of Land Use and Land Cover
(Same as EARTHSYS 142, EARTHSYS 242) The use of satellite remote sensing to monitor land use and land cover, with emphasis on terrestrial changes. Topics include pre-processing data, biophysical properties of vegetation observable by satellite, accuracy assessment of maps derived from remote sensing, and methodologies to detect changes such as urbanization, deforestation, vegetation health, and wildfires.
4 units, not given this year

EESS 164. Fundamentals of Geographic Information Science (GIS)
(Same as EARTHSYS 144) Survey of geographic information including maps, satellite imagery, and census data, approaches to spatial data, and tools for integrating and examining spatially-explicit data. Emphasis is on fundamental concepts of geographic information science and associated technologies. Topics include geographic data structure, cartography, remotely sensed data, statistical analysis of geographic data, spatial analysis, map design, and geographic information system software. Computer lab assignments. GER: DB-NatSci
4 units, Aut (Staff)

EESS 180. Fundamentals of Sustainable Agriculture
(Same as EARTHSYS 180, EARTHSYS 280, EESS 280) Ecological, economic, and social dimensions of sustainable agriculture in the context of a growing world population. Focus is on management and technological approaches, and historical content of agricultural growth and change, organic agriculture, soil and water resource management, nutrient and pest management, biotechnology, ecosystem services, and climate change. GER: DB-NatSci
3 units, alternate years, not given this year

EESS 241. Remote Sensing of the Oceans
(Same as EESS 141, EARTHSYS 141, EARTHSYS 241) How to observe and interpret physical and biological changes in the oceans using satellite technologies. Topics: principles of satellite remote sensing, classes of satellite remote sensors, converting radiometric data into biological and physical quantities, sensor calibration and validation, interpreting large-scale oceanographic features. GER: DB-NatSci
3-4 units, Win (Arrigo, K)

GRADUATE COURSES IN ENVIRONMENTAL EARTH SYSTEM SCIENCE

EESS 211. Fundamentals of Modeling
Simulation models are a powerful tool for environmental research, if used properly. This course covers the major concepts and techniques for building and evaluating models. Topics include model calibration, model selection, uncertainty and sensitivity analysis, and Monte Carlo and bootstrap methods. Emphasis will be placed on gaining hands-on experience using the R programming language. Basic knowledge of statistics is required.
3 units, Aut (Lobell, D)

EESS 217. Climate of the Cenozoic
For upper-division undergraduate and graduate students. The paleoclimate of the Cenozoic and how climate changes in the past link to the carbon cycle. Topics include long- and short-term records of climate on continents and oceans, evidence for and causes of hyperthermal events, how the Earth's climate has responded in increased carbon dioxide in the atmosphere. Guest speakers, student presentations.
3 units, not given this year

EESS 220. Physical Hydrogeology
(Same as CEE 260A) Theory of underground water occurrence and flow, analysis of field data and aquifer tests, geologic groundwater environments, solution of field problems, and groundwater modeling. Introduction to groundwater contaminant transport and unsaturated flow. Lab. Prerequisite: elementary calculus.
4 units, Aut (Gorelick, S; Walker, K; Erban, L)

EESS 221. Contaminant Hydrogeology
(Same as CEE 260C) (Formerly GES 231.) For earth scientists and engineers. Environmental and water resource problems involving contaminated groundwater. The processes affecting contaminant migration through porous media including interactions between dissolved substances and solid media. Conceptual and quantitative treatment of advective-dispersive transport with reacting solutes. Predictive models of contaminant behavior controlled by local equilibrium and kinetics. Modern methods of contaminant transport simulation and optimal aquifer remediation. Prerequisite: GES 230 or CEE 260A or equivalent.
4 units, not given this year

EESS 234. Stable Isotopes in Biogeochemistry
(Same as EESS 134) Light stable isotopes and their application to geological, ecological, and environmental problems. Isotopic systematics of hydrogen, carbon, nitrogen, oxygen, and sulfur; chemical and biogenic fractionation of light isotopes in the atmosphere, hydrosphere, and rocks and minerals.
3 units, not given this year

EESS 240. Advanced Oceanography
For upper-division undergraduates and graduate . Topical issues in marine science/oceanography. Topics vary each year following or anticipating research trends in oceanographic research. Focus is on links between the circulation and physics of the ocean with climate in the N. Pacific region, and marine ecologic responses. Participation by marine scientists from research groups and organizations including the Monterey Bay Aquarium Research Institute.
3 units, not given this year

EESS 242. Antarctic Marine Geology
(Same as EARTHSYS 272) For upper-division undergraduates and graduate students. Intermediate and advanced topics in marine geology and geophysics, focusing on examples from the Antarctic continental margin and adjacent Southern Ocean. Topics: glaciers, icebergs, and sea ice as geologic agents (glacial and glacial marine sedimentology, Southern Ocean current systems and deep ocean sedimentation), Antarctic biostratigraphy and chronostratigraphy (continental margin evolution). Seismic lines and sediment core/well log data. Examples from a recent scientific drilling expedition to Prydz Bay, Antarctica. Up to two students may have an opportunity to study at sea in Antarctica during Winter Quarter.
3 units, Aut (Dunbar, R)

EESS 243. Marine Biogeochemistry
(Same as EESS 143) (Graduate students register for 243.) Processes that control the mean concentration and distribution of biologically utilized elements and compounds in the ocean. Processes at the air-sea interface, production of organic matter in the upper ocean, remineralization of organic matter in the water column, and processing of organic matter in the sediments. Cycles of carbon, oxygen, and nutrients; the role of the ocean carbon cycle in interannual to decadal variability, paleoclimatology, and the anthropogenic carbon budget.
3-4 units, Spr (Arrigo, K)

EESS 244. Marine Ecosystem Modeling
Practical background necessary to construct and implement a 2-dimensional (space and time) numerical model of a simple marine ecosystem. Computer programming, model design and parameterization, and model evaluation. Students develop and refine their own multi-component marine ecosystem model.
3 units, Spr (Staff)

EESS 245. Advanced Biological Oceanography
Themes vary annually but include topics such as marine bio-optics, marine ecological modeling, and phytoplankton primary production. Hands-on laboratory and computer activities, and field trips into local waters. May be repeated for credit.
3-4 units, not given this year

EESS 246A. Atmosphere, Ocean, and Climate Dynamics: The Atmospheric Circulation
(Same as EESS 146A) Introduction to the physics governing the circulation of the atmosphere and ocean and their control on climate with emphasis on the atmospheric circulation. Topics include the global energy balance, the greenhouse effect, the vertical and meridional structure of the atmosphere, dry and moist convection, the equations of motion for the atmosphere and ocean, including the effects of rotation, and the poleward transport of heat by the large-scale atmospheric circulation and storm systems. Prerequisites: MATH 51 or CME100 and PHYSICS 41.
3 units, Win (Staff)

EESS 250. Elkhorn Slough Microbiology
(Formerly GES 270.) The microbial ecology and biogeochemistry of Elkhorn Slough, an agriculturally-impacted coastal estuary draining into Monterey Bay. The diversity of microbial lifestyles associated with estuarine physical/chemical gradients, and the influence of microbial activity on the geochemistry of the Slough, including the cycling of carbon, nitrogen, sulfur, and metals. Labs and field work. Location: Hopkins Marine Station.
3 units, Sum (Staff)

EESS 253S. Hopkins Microbiology Course
(Same as BIO 274S, BIOHOPK 274, CEE 274S) (Formerly GES 274S.) Four-week, intensive. The interplay between molecular, physiological, ecological, evolutionary, and geochemical processes that constitute, cause, and maintain microbial diversity. How to isolate key microorganisms driving marine biological and geochemical diversity, interpret culture-independent molecular characterization of microbial species, and predict causes and consequences. Laboratory component: what constitutes physiological and metabolic microbial diversity; how evolutionary and ecological processes diversify individual cells into physiologically heterogeneous populations; and the principles of interactions between individuals, their population, and other biological entities in a dynamically changing microbial ecosystem. Prerequisites: CEE 274A,B, or equivalents.
9-12 units, Sum (Spormann, A; Francis, C)

EESS 256. Soil Chemistry
(Same as EESS 156) (Graduate students register for 256.) Practical and quantitative treatment of soil processes affecting chemical reactivity, transformation, retention, and bioavailability. Principles of primary areas of soil chemistry: inorganic and organic soil components, complex equilibria in soil solutions, and adsorption phenomena at the solid-water interface. Processes and remediation of acid, saline, and wetland soils. Recommended: soil science and introductory chemistry and microbiology.
4 units, Win (Fendorf, S)

EESS 259. Environmental Microbial Genomics
The application of molecular and environmental genomic approaches to the study of biogeochemically-important microorganisms in the environment without the need for cultivation. Emphasis is on genomic analysis of microorganisms by direct extraction and cloning of DNA from natural microbial assemblages. Topics include microbial energy generation and nutrient cycling, genome structure, gene function, physiology, phylogenetic and functional diversity, evolution, and population dynamics of uncultured communities.
1-3 units, Win (Francis, C)

EESS 263. Topics in Advanced Geostatistics
(Same as ENERGY 242) Conditional expectation theory and projections in Hilbert spaces; parametric versus non-parametric geostatistics; Boolean, Gaussian, fractal, indicator, and annealing approaches to stochastic imaging; multiple point statistics inference and reproduction; neural net geostatistics; Bayesian methods for data integration; techniques for upscaling hydrodynamic properties. May be repeated for credit. Prerequisites: 240, advanced calculus, C++/Fortran.
3-4 units, not given this year

EESS 280. Fundamentals of Sustainable Agriculture
(Same as EARTHSYS 180, EARTHSYS 280, EESS 180) Ecological, economic, and social dimensions of sustainable agriculture in the context of a growing world population. Focus is on management and technological approaches, and historical content of agricultural growth and change, organic agriculture, soil and water resource management, nutrient and pest management, biotechnology, ecosystem services, and climate change.
3 units, alternate years, not given this year

EESS 301. Topics in Environmental Earth System Science
Current topics, issues, and research related to interactions that link the oceans, atmosphere, land surfaces and freshwater systems. May be repeated for credit.
1 unit, Aut (Thomas, L), Win (Thomas, L), Spr (Thomas, L)

EESS 322A. Seminar in Hydrogeology
Current topics. May be repeated for credit. Autumn Quarter has open enrollment, For Winter Quarter, consent of instructor is required.
1 unit, not given this year

EESS 322B. Seminar in Hydrogeology
Current topics. May be repeated for credit. Prerequisite: consent of instructor.
1 unit, Win (Gorelick, S)

EESS 323. Stanford at Sea
(Same as BIOHOPK 182H, BIOHOPK 323H, EARTHSYS 323) (Graduate students register for 323H.) Five weeks of marine science including oceanography, marine physiology, policy, maritime studies, conservation, and nautical science at Hopkins Marine Station, followed by five weeks at sea aboard a sailing research vessel in the Pacific Ocean. Shore component comprised of three multidisciplinary courses meeting daily and continuing aboard ship. Students develop an independent research project plan while ashore, and carry out the research at sea. In collaboration with the Sea Education Association of Woods Hole, MA. Only 6 units may count towards the Biology major.
16 units, alternate years, not given this year

EESS 330. Advanced Topics in Hydrogeology
Topics: questioning classic explanations of physical processes; coupled physical, chemical, and biological processes affecting heat and solute transport. May be repeated for credit.
1-2 units, Aut (Gorelick, S), Win (Gorelick, S), Spr (Gorelick, S)

EESS 342. Geostatistics
Classic results and current research. Topics based on interest and timeliness. May be repeated for credit.
1-2 units, Aut (Boucher, A)

EESS 342B. Geostatistics
Classic results and current research. Topics based on interest and timeliness. May be repeated for credit.
1-2 units, not given this year

EESS 342C. Geostatistics
Classic results and current research. Topics based on interest and timeliness. May be repeated for credit.
1-2 units, not given this year

EESS 363F. Oceanic Fluid Dynamics
(Same as CEE 363F) Dynamics of rotating stratified fluids with application to oceanic flows. Topics include: inertia-gravity waves; geostrophic and cyclogeostrophic balance; vorticity and potential vorticity dynamics; quasi-geostrophic motions; planetary and topographic Rossby waves; inertial, symmetric, barotropic and baroclinic instability; Ekman layers; and the frictional spin-down of geostrophic flows. Prerequisite: CEE 262A or graduate fluid mechanics.
3 units, alternate years, not given this year

EESS 385. Practical Experience in the Geosciences
On-the-job training, that may include summer internship, in applied aspects of the geosciences, and technical, organizational, and communication dimensions. Meets USCIS requirements for F-1 curricular practical training. May be repeated for credit.
1 unit, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

EESS 400. Graduate Research
May be repeated for credit. Prerequisite: consent of instructor.
1-15 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)