

# EARTH SYSTEM SCIENCE

Courses offered by the Department of Earth System Science are listed under the subject code ESS on the Stanford Bulletin's ExploreCourses web site (<https://explorecourses.stanford.edu/search/?view=catalog&academicYear=&page=0&q=ESS&filter-departmentcode=ESS=on&filter-coursestatus=Active=on&filter-term=Summer=on>).

On April 16, 2015, the Senate of the Academic Council approved the change of name for the department to become the Department of Earth System Science. Prior to April 16, the department was named the Department of Environmental Earth System Science.

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 Earth System Science

The University's basic requirements for the M.S. and Ph.D. degrees are discussed in the "Graduate Degrees (<http://www.stanford.edu/dept/registrar/bulletin/4901.htm>)" section of this bulletin. The Department of Earth System Science does not offer coterminal admission to the master's in Earth System Science.

## Learning Objectives (Graduate)

The objectives of the doctoral program in Earth System Science 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 with the ability to teach and communicate effectively with the public.

The objectives of the master's program in Earth System Science 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.

## Master of Science in Earth System Science

The University's requirements for M.S. degrees are outlined in the "Graduate Degrees (<http://www.stanford.edu/dept/registrar/bulletin/4901.htm>)" section of this bulletin.

## Admission

For admission to graduate work in the department, completion of the Aptitude Test (verbal, quantitative, and analytical writing assessment) of the Graduate Record Examination is optional. In keeping with University policy, applicants whose first language is not English must submit TOEFL (Test of English as a Foreign Language) scores from a test taken within the last 18 months. Individuals who have completed a B.S. or two-year M.S. program in the U.S. or other English-speaking country are not required to submit TOEFL scores.

## Degree Requirements

### Unit Requirements

1. A minimum of 45 units of course work at the 100 level or above.
2. 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.
3. No more than 15 units of thesis research may be used to satisfy the 45-unit requirement.
4. Some students may be required to make up background deficiencies in addition to these basic requirements.
5. 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.

### Course Work

|   |   | Units |
|---|---|-------|
| <b>Seminar Requirements</b>   |   |       |
| Each quarter during the first academic year:  |   |       |
| ESS 301   | Topics in Earth System Science  | 1     |
| <b>Required Core Courses (Students are required to take three 2-unit courses during the first year):</b>                                |   |       |
| ESS 305   | Climate Change: An Earth Systems Perspective  | 2     |
| ESS 306   | From Freshwater to Oceans to Land Systems: An Earth System Perspective to Global Challenges | 2     |
| ESS 307   | Research Proposal Development and Delivery  | 2     |
| <b>Distribution Requirements (Students must take one class from each of the following three areas within the first or second year):</b> |   |       |
| Area A: Analysis of the Earth System (Select one course)  |   |       |
| ESS 214   | Introduction to geostatistics and modeling of spatial uncertainty                           | 3-4   |
| GEOLSCI 240   | Data science for geoscience   | 3     |
| CME 106   | Introduction to Probability and Statistics for Engineers                                    | 4     |
| CEE 362A  | Uncertainty Quantification  | 3     |
| STATS 200   | Introduction to Statistical Inference   | 4     |
| STATS 206   | Applied Multivariate Analysis   | 3     |
| STATS 207   | Introduction to Time Series Analysis  | 3     |
| STATS 216   | Introduction to Statistical Learning  | 3     |
| STATS 366   | Modern Statistics for Modern Biology  | 3     |
| Area B: Measurement of the Earth System (Select one course)   |   |       |
| ESS 210   | Techniques in Environmental Microbiology  | 3     |
| ESS 212   | Measurements in Earth Systems   | 3-4   |
| ESS 224   | Remote Sensing of Hydrology   | 3     |
| ESS 241   | Remote Sensing of the Oceans  | 3-4   |
| ESS 243   | Molecular Geomicrobiology Laboratory  | 4     |
| ESS 253S  | Hopkins Microbiology Course   | 3-12  |
| ESS 262   | Remote Sensing of Land  | 4     |
| Area C: Earth System Processes, Models, and Human-Environmental Interactions (Select one course)  |   |       |
| ESS 206   | World Food Economy  | 5     |
| ESS 220   | Physical Hydrogeology   | 4     |
| ESS 221   | Contaminant Hydrogeology and Reactive Transport   | 3     |
| ESS 223   | Biosphere-Atmosphere Interactions   | 4     |
| ESS 227   | Decision Science for Environmental Threats  | 3-5   |

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| ESS 230  | Pursuing Sustainability: Managing Complex Social Environmental Systems | 3   |
| ESS 242  | Antarctic Marine Geology and Geophysics                                | 3   |
| ESS 244  | Marine Ecosystem Modeling  | 3   |
| ESS 246A | Atmosphere, Ocean, and Climate Dynamics: The Atmospheric Circulation   | 3   |
| ESS 246B | Atmosphere, Ocean, and Climate Dynamics: the Ocean Circulation         | 3   |
| ESS 247  | Tropical Meteorology   | 3-4 |
| ESS 258  | Geomicrobiology  | 3   |
| ESS 270  | Analyzing land use in a globalized world                               | 3   |
| ESS 360  | Social Structure and Social Networks                                   | 5   |

## Teaching Assistantship

As a program requirement, advanced degree candidates in ESS complete TA-appointed (25%) quarters at a minimum of: 2 for Ph.D. students and 1 for master's students, to be completed over the course of study. In addition, additional TA quarters may be considered and/or required in consultation with the research advisor, depending on academic goals, funding availability, or the requirements of individual doctoral programs.

## Advising

The department's graduate coordinator, in coordination with the departmental faculty, appoints an academic advisor prior to registration with appropriate consideration of the student's background, interests, and professional goals. In consultation with the advisor, the student plans a program of course work for the first year. The faculty advisor is charged with designing the curriculum in consultation with the student specific to the research topic.

## Thesis

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 advisor appoints a second reader for the thesis who must be approved by the graduate coordinator; the thesis advisor is the first reader. The two readers jointly determine whether the thesis is acceptable for the M.S. degree in the department.

## Master of Science, Course Work Only Option for ESS Ph.D. Students

The course-work-only M.S. for ESS Ph.D. students requires 45 unduplicated units of which all 45 must be course work (non-research, non-independent study, non-thesis units). All required units must be in courses at the 100-level or above, 50 percent of those units must be in graduate-level courses (generally, at the 200-level or above). No units are awarded for course work completed elsewhere (i.e., not eligible to transfer-in units). All 45 units can be applied to the 135 unit requirement for the Ph.D. The remaining 90 units can consist of all research units

## Doctor of Philosophy in Earth System Science

The University's requirements for the Ph.D. degree are outlined in the "Graduate Degrees (<http://www.stanford.edu/dept/registrar/bulletin/4901.htm>)" section of this bulletin.

## Admission

For admission to graduate work in the department, completion of the Aptitude Test (verbal, quantitative, and analytical writing assessment) of the Graduate Record Examination is optional. In keeping with University policy, applicants whose first language is not English must submit TOEFL

(Test of English as a Foreign Language) scores from a test taken within the last 18 months. Individuals who have completed a B.S. or two-year M.S. program in the U.S. or other English-speaking country are not required to submit TOEFL scores.

## Degree Requirements

### Unit Requirements

1. A minimum of 135 units of graduate study at Stanford must be satisfactorily completed.
2. Required courses must be taken for a letter grade, if offered.
3. Ph.D. students registered for 10 units must pass at least 6 units per quarter. Students must maintain at least a 3.0 grade point average.
4. Ph.D. students must complete a minimum of four graduate level, letter-grade courses of at least 3 units each from four different faculty members on the Academic Council in the University.
5. By the end of Spring Quarter of their first year in residence, students must complete at least three graduate level courses taught by a minimum of two different ESS faculty members.

### Course Work

|   |   | Units |
|---|---|-------|
| <b>Seminar Requirements</b>   |   |       |
| Each quarter during the first academic year:  |   |       |
| ESS 301   | Topics in Earth System Science  | 1     |
| <b>Required Core Courses (Students are required to take three 2-unit courses during the first year):</b>                                |   |       |
| ESS 305   | Climate Change: An Earth Systems Perspective  | 2     |
| ESS 306   | From Freshwater to Oceans to Land Systems: An Earth System Perspective to Global Challenges | 2     |
| ESS 307   | Research Proposal Development and Delivery  | 2     |
| <b>Distribution Requirements (Students must take one class from each of the following three areas within the first or second year):</b> |   |       |
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| ESS 214   | Introduction to geostatistics and modeling of spatial uncertainty                           | 3-4   |
| GEOLSCI 240   | Data science for geoscience   | 3     |
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| Area B: Measurement of the Earth System (Select one course)   |   |       |
| ESS 210   | Techniques in Environmental Microbiology  | 3     |
| ESS 212   | Measurements in Earth Systems   | 3-4   |
| ESS 224   | Remote Sensing of Hydrology   | 3     |
| ESS 241   | Remote Sensing of the Oceans  | 3-4   |
| ESS 243   | Molecular Geomicrobiology Laboratory  | 3-4   |
| ESS 253S  | Hopkins Microbiology Course   | 3-12  |
| ESS 262   | Remote Sensing of Land  | 4     |
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| ESS 206   | World Food Economy  | 5     |
| ESS 220   | Physical Hydrogeology   | 4     |

|          |  |     |
|----------|--|-----|
| ESS 221  | Contaminant Hydrogeology and Reactive Transport                        | 3   |
| ESS 223  | Biosphere-Atmosphere Interactions                                      | 3-4 |
| ESS 227  | Decision Science for Environmental Threats                             | 3-5 |
| ESS 230  | Pursuing Sustainability: Managing Complex Social Environmental Systems | 3   |
| ESS 242  | Antarctic Marine Geology and Geophysics                                | 3   |
| ESS 244  | Marine Ecosystem Modeling  | 3   |
| ESS 246A | Atmosphere, Ocean, and Climate Dynamics: The Atmospheric Circulation   | 3   |
| ESS 246B | Atmosphere, Ocean, and Climate Dynamics: the Ocean Circulation         | 3   |
| ESS 247  | Tropical Meteorology   | 3-4 |
| ESS 258  | Geomicrobiology  | 3   |
| ESS 270  | Analyzing land use in a globalized world                               | 3   |
| ESS 360  | Social Structure and Social Networks                                   | 5   |

## Teaching Assistantship

As a program requirement, advanced degree candidates in ESS complete TA-appointed (25%) quarters at a minimum of: 2 for Ph.D. students and 1 for master's students, to be completed over the course of study. In addition, additional TA quarters may be considered and/or required in consultation with the research advisor, depending on academic goals, funding availability, or the requirements of individual doctoral programs.

## Annual Review

Each year, the department evaluates students to assess progress to degree, identify areas of strength, provide helpful resources, and note potential issues or areas of concern. This annual review includes a record of accomplishments presented by the student, written evaluations by the faculty advisor of the student's progress, and committee feedback on the academic and research progress of the student. The student should have no 'I' grades in core courses, must maintain at least a 3.0 grade-point average, and show evidence of productive and sustained research progress, with no conflict of interest or conflict of commitment.

Possible outcomes of the annual review include: (1) continuation of the student in good standing, and (2) placing the student on probation, with specific written guidelines of the period of probation and the necessary steps for reinstatement to good standing.

Annual reviews are required for all Ph.D. students, including first-year Ph.D. students. In the first year, the annual review is conducted between the student and the Ph.D. advisor(s) (prior to forming a doctoral committee). After the first year, the annual review must be conducted between the student and the student's doctoral committee. In all years, the written annual review form must be completed and signed by both the student and the advisor.

In the year in which students are undertaking their candidacy exam (research qualifying exam), that exam serves as the annual review. In addition, any student who has scheduled the dissertation defense and petitioned to graduate in Axess may elect not to hold an additional annual review meeting. Annual reviews that are not the qualifying exam or dissertation defense should take place in the Autumn or Winter Quarter (with the exception of first-year students, who may hold their annual review meeting with their advisor(s) in Spring Quarter).

## Candidacy and Qualification Exam

Admission to a doctoral degree program is preliminary to, and distinct from, admission to candidacy. Admission to candidacy for the doctoral degree is a judgment by the faculty in the department or school of the student's potential to successfully complete the requirements of the degree program. Candidacy is valid for five calendar years (through the

end of the quarter in which candidacy expires), unless terminated by the department (for example, for unsatisfactory progress). University policy requires completion of the department qualifying procedures and application for candidacy by the end of the second year in the Ph.D. program. Therefore, it is strongly advised that the qualifying exam be taken during the fifth (non-Summer) quarter so that the student may retake the exam in the case of inadequate performance and still advance to candidacy by the end of the sixth (non-Summer) quarter.

Students must present a draft proposal to their advisor in a timely fashion, and take account of the advisor's comments and require revisions before preparing a final draft. The student submits a copy of the final draft of the research proposal to each member of the examining committee at least two weeks before the scheduled date of the examination.

The qualifying exam is an oral exam based on the candidate's written research proposal. The exam is a test of the student's ability to recognize, evaluate, and plan a significant research project and his/her mastery of fields essential to the completion of research. The research proposal must provide a concise review of the background literature, and must discuss the proposed problem, its importance, and the methods to be applied to its examination. The methods should be made clear. The proposal must contain a timetable and, if appropriate, the student should discuss such matters as funding, field logistics, laboratory scheduling, and availability of equipment. The proposal must be well thought out, carefully written and edited, and finished with appropriate references and illustrations. It must not exceed 15 double-spaced pages in length, exclusive of figures and bibliography. The qualifying exam is oral and consists of three parts:

1. A presentation of the proposed research (no more than 30 minutes duration);
2. An examination of the candidate on the merits of the proposal, touching on but not limited to the aspects listed in the proposal; and
3. An examination of any subject matter judged by committee members to be relevant to the student's ability to carry out the proposed research.

It is recognized that, in practice, parts 1# 3 may not be entirely separate and distinct. The entire examination lasts no less than 2 hours and no more than 3 hours; the examination under part 3 is at least one hour. No part of examination is public.

## Doctoral Dissertation and Oral Defense

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 advisor 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.

## COVID-19 Policies

On July 30, the Academic Senate adopted grading policies effective for all undergraduate and graduate programs, excepting the professional Graduate School of Business, School of Law, and the School of Medicine M.D. Program. For a complete list of those and other academic

policies relating to the pandemic, see the "COVID-19 and Academic Continuity (<http://exploreddegrees.stanford.edu/covid-19-policy-changes/#tempdeptemplatetabtext>)" section of this bulletin.

The Senate decided that all undergraduate and graduate courses offered for a letter grade must also offer students the option of taking the course for a "credit" or "no credit" grade and recommended that deans, departments, and programs consider adopting local policies to count courses taken for a "credit" or "satisfactory" grade toward the fulfillment of degree-program requirements and/or alter program requirements as appropriate.

## Graduate Degree Requirements

### Grading

For all courses taken during the 2020-21 academic year, the Earth System Science department will allow grades of 'CR' (credit) (or 'S' (satisfactory) grades in classes retaining the S/NC basis), in addition to letter grades, to count towards fulfillment of requirements for the Ph.D and M.S. degrees.

For a statement of University policy on graduate advising, see the "Graduate Advising (<https://exploreddegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext>)" section of this bulletin.

## Graduate Advising Expectations

The Department of Earth System Science is committed to providing academic advising in support of graduate student scholarly and professional development. When most effective, this advising relationship entails collaborative and sustained engagement by both the advisor and the advisee. As a best practice, advising expectations should be periodically discussed and reviewed to ensure mutual understanding. Both the advisor and the advisee are expected to maintain professionalism and integrity.

### Purpose of Advising

Faculty advisors guide students in key areas such as selecting courses, designing and conducting research, developing of teaching pedagogy, navigating policies and degree requirements, and exploring academic opportunities and professional pathways.

Graduate students are active contributors to the advising relationship, proactively seeking academic and professional guidance and taking responsibility for informing themselves of policies and degree requirements for their graduate program.

For a statement of University policy on graduate advising, see the "Graduate Advising (<https://exploreddegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext>)" section of this bulletin.

### Expectations

- Students are paired with a primary advisor at the time of admission to the Earth System Science graduate program. A secondary advisor may also be designated at the time of admission.
- Beginning with the first quarter, and at least annually thereafter, a shared expectations conversation occurs. This clarifies educational philosophies and individual responsibilities, and generates a written record for student, advisor, and department. As part of this process, advisors provide clear statements of their expectations, discuss those expectations with the student, and articulate which areas may be open to amendment based on student input. Broad areas in which to align expectations include:
  - Course selection and other academic development
  - Navigating policies and degree requirements
  - Financial support
  - Identifying research opportunities and level of independence

- Research milestones, publications, co-authorship, outside collaborations, and timeline
- Frequency of individual and group meetings, expectations for campus and departmental presence, vacations
- Frequency of and funding for off-campus research and professional development activities (such as conferences, workshops, short courses, and field work)
- Preparation for future employment and exploration of professional pathways
- There is an annual review of progress that generates a written record. This review is documented by the thesis committee as part of the annual review meeting. In addition, students should be meeting with their advisor frequently enough that if they are not making sufficient progress, they ideally receive such feedback sooner than at an annual meeting.
- Students can expect advisors to:
  - Exercise high professional standards in their academic work, research, and mentoring partnerships
  - Serve as intellectual and professional mentors
  - Understand University and department policies pertinent to graduate students
  - Provide timely, regular, and constructive feedback on progress
  - Provide insights into career options and pathways and/or point students toward relevant career and professional development resources
- Advisors can expect students to:
  - Exercise high professional standards in their academic work, research, and mentoring partnerships
  - Be pro-active in seeking advice and keeping the advisor informed about academic and research progress
  - Consult with the advisor, and others as necessary, to resolve problems
  - Take primary responsibility for meeting timelines, policies, and milestones that impact degree progress

## Additional Resources and Pathways

- The thesis committee is convened by the student's second year. Once convened, the thesis committee:
  - Meets annually with the student to discuss research progress, research plans, coursework, and professional/career goals, and to provide verbal and written feedback on degree progress
  - For Ph.D. students, the thesis committee conducts the qualifying exam and the oral exam (i.e., dissertation defense), and approves the written dissertation
  - In some cases, members of the thesis committee may also be research collaborators, and may also serve as mentors and/or letter writers for applications
- As part of their advising network, students are encouraged to consult departmental resources (such as department and school student services staff, the thesis committee, the department Director of Graduate Studies, and the department Chair), Stanford institutional resources (such as VPGE, the Office of Graduate Life, CAPS, and the campus Ombuds), as well as individuals and networks in the broader scientific community (such as the American Geophysical Union and the Earth Sciences Women's Network).
- In the event that a student has a formal concern or complaint about their advising experience, they are encouraged to contact the department Director of Graduate Studies, the department Chair, the school Associate Dean for Educational Affairs, and/or the school Associate Dean for Human Resources and Faculty Affairs.



- In the event that either the student or advisor feels that the advising relationship is not effective, the school process for formally evaluating student/advisor assignments may be activated.

*Chair:* Kevin Arrigo

*Directors of Graduate Studies:* Pamela Matson, Rosamond Naylor

*Professors:* Kevin Arrigo, Noah Diffenbaugh<sup>3</sup>, Robert Dunbar, Scott Fendorf, Christopher Field<sup>1,3</sup>, Christopher Francis, Steven Gorelick, Robert Jackson<sup>2,3</sup>, Eric Lambin<sup>3</sup>, David Lobell<sup>3,4</sup>, Pamela Matson, Rosamond Naylor

*Associate Professors:* Marshall Burke<sup>4</sup>, Karen Casciotti, James Holland Jones, Kate Maher, Leif Thomas, Paula Welander

*Assistant Professors:* Anne Dekas, Alexandra Konings, Morgan O'Neill, Aditi Sheshadri, Gabrielle Wong-Parodi

*Courtesy Professors:* Gregory Asner, Ken Caldeira, Anna Michalak, Peter Vitousek

*Visiting Professors:*

<sup>1</sup> Joint appointment with Biology

<sup>2</sup> Joint appointment with the Precourt Institute for Energy

<sup>3</sup> Joint appointment with the Woods Institute for the Environment

<sup>4</sup> Joint appointment with the Freeman Spogli Institute for International Studies

## Courses

### ESS 8. The Oceans: An Introduction to the Marine Environment. 4 Units.

The course will provide a basic understanding of how the ocean functions as a suite of interconnected ecosystems, both naturally and under the influence of human activities. Emphasis is on the interactions between the physical and chemical environment and the dominant organisms of each ecosystem. The types of ecosystems discussed include coral reefs, deep-sea hydrothermal vents, coastal upwelling systems, blue-water oceans, estuaries, and near-shore dead zones. Lectures, multimedia presentations, group activities, and tide-pooling day trip.

Same as: EARTHSYS 8

### ESS 38N. The Worst Journey in the World: The Science, Literature, and History of Polar Exploration. 3 Units.

This course examines the motivations and experiences of polar explorers under the harshest conditions on Earth, as well as the chronicles of their explorations and hardships, dating to the 1500s for the Arctic and the 1700s for the Antarctic. Materials include *The Worst Journey in the World* by Aspley Cherry-Garrard who in 1911 participated in a midwinter Antarctic sledging trip to recover emperor penguin eggs. Optional field trip into the high Sierra in March.

Same as: EARTHSYS 38N, GEOLSCI 38N

### ESS 40. Approaching Palau: Preparation and Research Ideation and Development. 1 Unit.

This class is a seminar designed to prepare students participating in the 2019 Palau Seminar for possible research activities. Enrollment by approval of the instructors.

Same as: CEE 40

### ESS 46N. Exploring the Critical Interface between the Land and Monterey Bay: Elkhorn Slough. 3 Units.

Preference to freshmen. Field trips to sites in the Elkhorn Slough, a small agriculturally impacted estuary that opens into Monterey Bay, a model ecosystem for understanding the complexity of estuaries, and one of California's last remaining coastal wetlands. Readings include Jane Caffrey's *Changes in a California Estuary: A Profile of Elkhorn Slough*. Basics of biogeochemistry, microbiology, oceanography, ecology, pollution, and environmental management.

Same as: EARTHSYS 46N

### ESS 60. Food, Water and War: Life on the Mekong. 1 Unit.

Preparatory course for Bing Overseas Studies summer course in Cambodia. Prerequisite: Requires instructor consent.

### ESS 61Q. Food and security. 3 Units.

The course will provide a broad overview of key policy issues concerning agricultural development and food security, and will assess how global governance is addressing the problem of food security. At the same time the course will provide an overview of the field of international security, and examine how governments and international institutions are beginning to include food in discussions of security.

Same as: EARTHSYS 61Q, INTNLREL 61Q

### ESS 86N. The Most Rational People in the World. 4 Units.

Humans, broadly construed, emerged as bipedal apes in the African mixed savanna-woodlands approximately two million years ago. From humble beginnings, humans have gone on to become the ecologically dominant species in most biomes and grown to a global population in excess of seven billion. This dominance arises from a combination of features of the human organism including its extreme degree of behavioral flexibility and flexible social organization. The prima facie evidence of human evolutionary and ecological success raises a paradox with respect to recent work in economics and psychology which increasingly argues for pervasive irrationality in human decision-making in a wide array of behavioral contexts. How is it possible for an organism with such seemingly flawed software supporting decision-making to become the globally dominant species? We will use this contradiction as the launching point for understanding what rationality means in a broad ecological and cross-cultural context. What do we mean by 'rationality'? How do different disciplines conceive of rationality in different ways? Is there such a thing as a rationality that transcends cultural differences or is the very idea of rationality a cultural construction that is used to justify imperialism and other modes of paternalism? Are there systematic factors that promote or impede rational decision-making? The seminar will provide a gentle introduction to the formal approaches of decision theory which we will apply to an unusual array of topics centered on the subsistence and reproductive decisions of hunter-gatherers, horticulturalists, pastoralists, and agrarian peasants, in short, people living in face-to-face, subsistence societies. In addition to doing reading from a broad array of social and natural science disciplines around the topic of rationality, students will regularly engage in exercises to assess their own approaches to decision-making.

### ESS 101. Environmental and Geological Field Studies in the Rocky Mountains. 3 Units.

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.

Same as: EARTHSYS 100

**ESS 102. Scientific Basis of Climate Change. 3-5 Units.**

This course explores the scientific basis of anthropogenic climate change. We will read the original papers that established the scientific foundation for the climate change forecast. Starting with Fourier's description of the greenhouse effect, we trace the history of the key insights into how humanity is perturbing the climate system. The course is based on *The Warming Papers*, edited by David Archer and Raymond Pierrehumbert. Participants take turns presenting and leading a discussion of the papers and of Archer and Pierrehumbert's commentary.

Same as: ESS 202

**ESS 103. Planetary Atmospheres: Dynamics. 3-5 Units.**

This course describes the physics and general circulation of planetary atmospheres in the Solar System and among the growing zoo of exoplanets. Topics include observations, energy balance, composition, radiation and convection, with emphasis on giant/fluid planets. Prerequisites: Math 51 or CME 100 or equivalent, and ESS 246A and ESS 246B, or consent of the instructor.

Same as: ESS 203

**ESS 106. World Food Economy. 5 Units.**

The economics of food production, consumption, and trade. The micro- and macro- determinants of food supply and demand, including the interrelationship among food, income, population, and public-sector decision making. Emphasis on the role of agriculture in poverty alleviation, economic development, and environmental outcomes. Grades based on mid-term exam and group modeling project and presentation. Enrollment is by application only and will be capped at 25, with priority given to upper level undergraduates in Economics and Earth Systems and graduate students (graduate students enroll in 206). Application found at <https://economics.stanford.edu/academics/undergraduate-program/forms>.

Same as: EARTHSYS 106, EARTHSYS 206, ECON 106, ECON 206, ESS 206

**ESS 107. Control of Nature. 3 Units.**

Think controlling the earth's climate is science fiction? It is when you watch *Snowpiercer* or *Dune*, but scientists are already devising geoengineering schemes to slow climate change. Will we ever resurrect the woolly mammoth or even a T. Rex (think *Jurassic Park*)? Based on current research, that day will come in your lifetime. Who gets to decide what species to save? And more generally, what scientific and ethical principles should guide our decisions to control nature? In this course, we will examine the science behind ways that people alter and engineer the earth, critically examining the positive and negative consequences. We'll explore these issues first through popular movies and books and then, more substantively, in scientific research.

Same as: EARTHSYS 107

**ESS 108. Research Preparation for Undergraduates. 1 Unit.**

For undergraduates planning to conduct research during the summer with faculty through the MUIR and SUPER programs. Readings, oral presentations, proposal development. May be repeated for credit.

**ESS 109. Biological and Social Networks. 3-5 Units.**

This course introduces the analysis of social and biological networks with a focus on field data collected by interdisciplinary environmental and health scientists. Beginning from the premise that structure emerges from relationships between individual entities, we will concentrate in particular on the measurement of relationships, emphasizing especially practical methodology for mixed-method fieldwork suitable for interdisciplinary biosocial sciences (e.g., earth system science, epidemiology, demography, anthropology, conservation science). Topics include: social relationships in humans and other animals, ecological networks (e.g., trophic and mutualistic interactions), epidemiological networks, research design for collecting relational data, naturalistic observation, ethnographic network methods, sampling, data quality, missing data, graphs and graph theory, structural measures (e.g., density, centrality and centralization, clustering and community detection, embeddedness), network evolution, network diffusion, emergence, egocentric networks, multi-mode/multi-layer networks, inference for sampled networks. All computation and visualization will be done in R so some familiarity is assumed.

Same as: ESS 209

**ESS 111. Biology and Global Change. 4 Units.**

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. Prerequisite: Biology or Human Biology core or BIO 81 or graduate standing.

Same as: BIO 117, EARTHSYS 111, EARTHSYS 217

**ESS 112. Human Society and Environmental Change. 4 Units.**

Interdisciplinary approaches to understanding human-environment interactions with a focus on economics, policy, culture, history, and the role of the state. Prerequisite: ECON 1.

Same as: EARTHSYS 112, EARTHSYS 212, HISTORY 103D

**ESS 115. Approaching Nepal: Coupled Human-Natural Systems of the Solokhumbu. 1-2 Unit.**

This class designed to prepare students participating in the 2020 BOSP Nepal Seminar. Through readings, lectures, and class discussions, students will acquire a working knowledge of coupled human-natural system theory and examine case studies of CHNS analysis in the region. We will also provide content on the history of Nepal and the Sherpa people, Buddhist and Hindu thoughts on nature and resources, agricultural systems across Himalayan ecotones, and geology, glaciology, water, and energy issues relevant to the course itinerary. The class will meet weekly through the Spring quarter. We may switch the time to accommodate the schedules of all enrolled students. The class is mandatory for students participating in BOSP Nepal 2020.

Same as: ESS 215

**ESS 117. Earth Sciences of the Hawaiian Islands. 4 Units.**

Progression from volcanic processes through rock weathering and soil-ecosystem development to landscape evolution. The course starts with an investigation of volcanic processes, including the volcano structure, origin of magmas, physical-chemical factors of eruptions. Factors controlling rock weathering and soil development, including depth and nutrient levels impacting plant ecosystems, are explored next. Geomorphic processes of landscape evolution including erosion rates, tectonic/volcanic activity, and hillslope stability conclude the course. Methods for monitoring and predicting eruptions, defining spatial changes in landform, landform stability, soil production rates, and measuring biogeochemical processes are covered throughout the course. This course is restricted to students accepted into the Earth Systems of Hawaii Program.

Same as: EARTH 117, EARTHSYS 117

**ESS 118X. Shaping the Future of the Bay Area. 3-5 Units.**

The complex urban problems affecting quality of life in the Bay Area, from housing affordability and transportation congestion to economic vitality and social justice, are already perceived by many to be intractable, and will likely be exacerbated by climate change and other emerging environmental and technological forces. Changing urban systems to improve the equity, resilience and sustainability of communities will require new collaborative methods of assessment, goal setting, and problem solving across governments, markets, and communities. It will also require academic institutions to develop new models of co-production of knowledge across research, education, and practice. This XYZ course series is designed to immerse students in co-production for social change. The course sequence covers scientific research and ethical reasoning, skillsets in data-driven and qualitative analysis, and practical experience working with local partners on urban challenges that can empower students to drive responsible systems change in their future careers. The Autumn (X) course is specifically focused on concepts and skills, and completion is a prerequisite for participation in the Winter (Y) and/or Spring (Z) practicum quarters, which engage teams in real-world projects with Bay Area local governments or community groups. X is composed of four modules: (A) participation in two weekly classes which prominently feature experts in research and practice related to urban systems; (B) reading and writing assignments designed to deepen thinking on class topics; (C) fundamental data analysis skills, particularly focused on Excel and ArcGIS, taught in lab sessions through basic exercises; (D) advanced data analysis skills, particularly focused on geocomputation in R, taught through longer and more intensive assignments. X can be taken for 3 units (ABC), 4 units (ACD), or 5 units (ABCD). Open to undergraduate and graduate students in any major. For more information, visit <http://bay.stanford.edu>.

Same as: CEE 118X, CEE 218X, ESS 218X, GEOLSCI 118X, GEOLSCI 218X, GEOPHYS 118X, GEOPHYS 218X, POLISCI 218X, PUBLPOL 118X, PUBLPOL 218X

**ESS 118Y. Shaping the Future of the Bay Area. 3-5 Units.**

Students are placed in small interdisciplinary teams (engineers and non-engineers, undergraduate and graduate level) to work on complex design, engineering, and policy problems presented by external partners in a real urban setting. Multiple projects are offered and may span both Winter and Spring quarters; students are welcome to participate in one or both quarters. Students are expected to interact professionally with government and community stakeholders, conduct independent team work outside of class sessions, and submit deliverables over a series of milestones. Prerequisite: the Autumn (X) skills course or approval of instructors. For information about the projects and application process, visit <http://bay.stanford.edu>.

Same as: CEE 118Y, CEE 218Y, ESS 218Y, GEOLSCI 118Y, GEOLSCI 218Y, GEOPHYS 118Y, GEOPHYS 218Y, POLISCI 218Y, PUBLPOL 118Y, PUBLPOL 218Y

**ESS 118Z. Shaping the Future of the Bay Area. 3-5 Units.**

Students are placed in small interdisciplinary teams (engineers and non-engineers, undergraduate and graduate level) to work on complex design, engineering, and policy problems presented by external partners in a real urban setting. Multiple projects are offered and may span both Winter and Spring quarters; students are welcome to participate in one or both quarters. Students are expected to interact professionally with government and community stakeholders, conduct independent team work outside of class sessions, and submit deliverables over a series of milestones. Prerequisite: the Autumn (X) skills course or approval of instructors. For information about the projects and application process, visit <http://bay.stanford.edu>.

Same as: CEE 118Z, CEE 218Z, ESS 218Z, GEOLSCI 118Z, GEOLSCI 218Z, GEOPHYS 118Z, GEOPHYS 218Z, POLISCI 218Z

**ESS 123. Biosphere-Atmosphere Interactions. 3-4 Units.**

How do ecosystems respond to climate, and how do ecosystems influence climate? Covers the role of the terrestrial land surface in earth's climate system, including among others photosynthesis, transpiration, greenhouse gasses, radiation, and atmospheric water vapor. For each of these topics, attention is paid to both the underlying processes and how they can be mathematically represented in earth system models. Instruments and techniques used to measure these processes are also discussed, and, where appropriate, demonstrated.

Same as: EARTHSYS 123A, EARTHSYS 223, ESS 223

**ESS 125. INTRODUCTION TO PLANETARY SCIENCE. 3-4 Units.**

This course provides an introduction to planetary science through the exploration of processes that formed and modified planetary bodies within the Solar System and beyond. Each lecture will be given by an expert in a specific subfield of planetary sciences, with topics ranging from planetary materials and formation, planetary dynamics, planetary structure and tectonics, planetary atmospheres, impact cratering, surface processes, and astrobiology. We will also discuss how scientists investigate planets both near and far through sample analysis, telescopic and orbital remote sensing as well as in situ through robotic instruments. Although there are no prerequisites for this course, it is primarily directed towards undergraduate students who are majoring (or plan to) in the sciences or engineering. A minimum level of mathematics equivalent to high school algebra and introductory calculus will be necessary.

Same as: GEOLSCI 124, GEOPHYS 124

**ESS 132. Evolution of Earth Systems. 4 Units.**

This course examines biogeochemical cycles and how they developed through the interaction between the atmosphere, hydrosphere, biosphere, and lithosphere. Emphasis is on the long-term carbon cycle and how it is connected to other biogeochemical cycles on Earth. The course consists of lectures, discussion of research papers, and quantitative modeling of biogeochemical cycles. Students produce a model on some aspect of the cycles discussed in this course. Grades based on class interaction, student presentations, and the modeling project.

Same as: EARTHSYS 132, EARTHSYS 232, ESS 232, GEOLSCI 132, GEOLSCI 232

**ESS 135. Community Leadership. 1-2 Unit.**

Offered through Residential Education to residents of Castano House, Manzanita Park. Topics include: emotional intelligence, leadership styles, listening, facilitating meetings, group dynamics and motivation, finding purpose, fostering resilience. Students will lead discussions on personal development, relationships, risky behaviors, race, ethnicity, spirituality, integrity.

**ESS 141. Remote Sensing of the Oceans. 3-4 Units.**

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.

Same as: EARTHSYS 141, EARTHSYS 241, ESS 241, GEOPHYS 141

**ESS 143. Molecular Geomicrobiology Laboratory. 3-4 Units.**

In this course, students will be studying the biosynthesis of cyclic lipid biomarkers, molecules that are produced by modern microbes that can be preserved in rocks that are over a billion years old and which geologists use as molecular fossils. Students will be tasked with identifying potential biomarker lipid synthesis genes in environmental genomic databases, expressing those genes in a model bacterial expression system in the lab, and then analyzing the lipid products that are produced. The overall goal is for students to experience the scientific research process including generating hypotheses, testing these hypotheses in laboratory experiments, and communicating their results through a publication style paper. Prerequisites: BIO83 and CHEM 121 or permission of the instructor.

Same as: BIO 142, EARTHSYS 143, ESS 243

**ESS 148. Introduction to Physical Oceanography. 4 Units.**

The dynamic basis of oceanography. Topics: physical environment; conservation equations for salt, heat, and momentum; geostrophic flows; wind-driven flows; the Gulf Stream; equatorial dynamics and ENSO; thermohaline circulation of the deep oceans; and tides. Prerequisite: PHYSICS 41.

Same as: CEE 162D, CEE 262D, EARTHSYS 164

**ESS 151. Biological Oceanography. 3-4 Units.**

Required for Earth Systems students in the oceans track. Interdisciplinary look at how oceanic environments control the form and function of marine life. Topics include distributions of planktonic production and abundance, nutrient cycling, the role of ocean biology in the climate system, expected effects of climate changes on ocean biology. Local weekend field trips. Designed to be taken concurrently with Marine Chemistry (ESS/EARTHSYS 152/252). Prerequisites: BIO 43 and ESS 8 or equivalent.

Same as: EARTHSYS 151, EARTHSYS 251, ESS 251

**ESS 152. Marine Chemistry. 3-4 Units.**

Introduction to the interdisciplinary knowledge and skills required to critically evaluate problems in marine chemistry and related disciplines. Physical, chemical, and biological processes that determine the chemical composition of seawater. Air-sea gas exchange, carbonate chemistry, and chemical equilibria, nutrient and trace element cycling, particle reactivity, sediment chemistry, and diagenesis. Examination of chemical tracers of mixing and circulation and feedbacks of ocean processes on atmospheric chemistry and climate. Designed to be taken concurrently with Biological Oceanography (ESS/EARTHSYS 151/251).

Same as: EARTHSYS 152, EARTHSYS 252, ESS 252

**ESS 155. Science of Soils. 3-4 Units.**

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.

Same as: EARTHSYS 155

**ESS 158. Geomicrobiology. 3 Units.**

How microorganisms shape the geochemistry of the Earth's crust including oceans, lakes, estuaries, subsurface environments, sediments, soils, mineral deposits, and rocks. Topics include mineral formation and dissolution; biogeochemical cycling of elements (carbon, nitrogen, sulfur, and metals); geochemical and mineralogical controls on microbial activity, diversity, and evolution; life in extreme environments; and the application of new techniques to geomicrobial systems. Recommended: introductory chemistry and microbiology such as CEE 274A.

Same as: EARTHSYS 158, EARTHSYS 258, ESS 258

**ESS 162. Remote Sensing of Land. 4 Units.**

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.

Same as: EARTHSYS 142, EARTHSYS 242, ESS 262

**ESS 163. Demography and Life History Theory. 5 Units.**

Life history theory is the branch of evolutionary biology that attempts to understand patterns of investment in growth, reproduction, and survival across the life cycle. It is the theory that explains the major transitions that mark individual organisms' life cycles from conception to death. In this class, we will focus on the central themes of life history theory and how they relate to specific problems of the human life cycle. In addition to the classic questions of life history theory (e.g., evolution of reproductive effort, size vs. quality, etc.), we will discuss some peculiar issues that relate specifically to humans. In particular, we will explore the intersection of life history theory and more classical economic approaches to decision theory and rational choice. This will include an exploration of the evolution of economic transfers and their implications for demographic transitions, ecological resilience, and the consumption of natural resources. This discussion will explore how an understanding of life history theory might help in promoting investments in future welfare or developing policies that promote sustainability.

Same as: ESS 363

**ESS 164. Fundamentals of Geographic Information Science (GIS). 1-4 Unit.**

"Everything is somewhere, and that somewhere matters." The rapid growth and maturity of spatial data technologies over the past decade represent a paradigm shift in the applied use of location data from high-level overviews of administrative interests, to highly personalized location-based services that place the individual at the center of the map, at all times. The use of spatial data and related technology continues to grow in fields ranging from environmental sciences to epidemiology to market prediction. This course will present an overview of current approaches to the use of spatial data and its creation, capture, management, analysis and presentation, in a research context. Topics will include modeling of geographic objects and associated data, modeling of geographic space and the conceptual foundations of "spatial thinking," field data collection, basic spatial statistical analysis, remote sensing & the use of satellite-based imagery, "Big Data" and machine learning approaches to spatial data, and cartographic design and presentation including the use of web-based "Storymap" platforms. The course will consist of weekly lectures, guest speakers, computer lab assignments and an individual final project requirement. This course must be taken for a minimum of 3 units and a letter grade to be eligible for Ways credit. In AY 2020-21, a letter grade or 'CR' grade satisfies the Ways requirement. Same as: EARTHSYS 144

**ESS 165. Advanced Geographic Information Systems. 4 Units.**

Building on the Fundamentals of Geographic Information Systems course, this class delves deeper into geospatial analysis and mapping techniques. The class is heavily project-based and students are encouraged to bring their own research questions. Topics include topographic analysis, interpolation, spatial statistics, network analysis, and scripting using Python and Arcpy. All students are required to attend a weekly lab. ESS 164 or equivalent is a prerequisite.

Same as: ESS 265

**ESS 170. Analyzing land use in a globalized world. 3 Units.**

This course examines the dynamics of land use in relation to globalization. The objective is to understand how the expansion of global trade, and public and private regulations affect land use changes. The course will enable students to better understand how to effectively influence land use change, from different vantage points (government, NGO, corporate actor). The main emphasis is on tropical regions. Lectures introduce theories, practical cases, and evaluation tools to better understand contemporary land use dynamics.

Same as: ESS 270



**ESS 171. Climate Models and Data. 3 Units.**

Overview of key concepts necessary to develop familiarity with climate modeling and data. Topics covered will include components of the climate system, climate change and global warming, and model mechanics, their evaluation and usability, and predictability. Assessments will involve the use of datasets and model output, so some knowledge of programming is a pre-requisite.

Same as: ESS 271

**ESS 179S. Seminar: Issues in Environmental Science, Technology and Sustainability. 1-2 Unit.**

Invited faculty, researchers and professionals share their insights and perspectives on a broad range of environmental and sustainability issues. Students critique seminar presentations and associated readings.

Same as: CEE 179S, CEE 279S, EARTHSYS 179S

**ESS 181. Urban Agroecology. 3 Units.**

The United Nations estimates that up to 15% of the world's food is produced in and around cities. Urban populations are projected to continue rising and urban agriculture in its many forms has been shown to provide multiple benefits to urban communities. This class will survey urban agriculture around the world while training you in small-scale food production practices. The emphasis will be on ecological approaches to the design and stewardship of urban farms and gardens. nnnlf permitted, given the challenges of COVID-19, the course will be taught in-person, outdoors at the Stanford Educational Farm. nn nThis is a 3-unit, Earth Systems practicum course that meets on Wednesdays from noon to 3pm. Space is limited and applications are due by Friday 8/28. Students will be notified if they are admitted to the course by 9/4. For the course application go to: [https://stanforduniversity.qualtrics.com/jfe/form/SV\\_86udp8aEuWUCnNH](https://stanforduniversity.qualtrics.com/jfe/form/SV_86udp8aEuWUCnNH).

Same as: EARTHSYS 181, EARTHSYS 281, ESS 281, URBANST 181

**ESS 185. Adaptation. 3 Units.**

Adaptation is the process by which organisms or societies become better suited to their environments. In this class, we will explore three distinct but related notions of adaptation. Biological adaptations arise through natural selection, while cultural adaptations arise from a variety of processes, some of which closely resemble natural selection. A newer notion of adaptation has emerged in the context of climate change where adaptation takes on a highly instrumental, and often planned, quality as a response to the negative impacts of environmental change. We will discuss each of these ideas, using their commonalities and subtle differences to develop a broader understanding of the dynamic interplay between people and their environments. Topics covered will include, among others: evolution, natural selection, levels of selection, formal models of cultural evolution, replicator dynamics, resilience, rationality and its limits, complexity, adaptive management.

Same as: EARTHSYS 183

**ESS 202. Scientific Basis of Climate Change. 3-5 Units.**

This course explores the scientific basis of anthropogenic climate change. We will read the original papers that established the scientific foundation for the climate change forecast. Starting with Fourier's description of the greenhouse effect, we trace the history of the key insights into how humanity is perturbing the climate system. The course is based on *The Warming Papers*, edited by David Archer and Raymond Pierrehumbert. Participants take turns presenting and leading a discussion of the papers and of Archer and Pierrehumbert's commentary.

Same as: ESS 102

**ESS 203. Planetary Atmospheres: Dynamics. 3-5 Units.**

This course describes the physics and general circulation of planetary atmospheres in the Solar System and among the growing zoo of exoplanets. Topics include observations, energy balance, composition, radiation and convection, with emphasis on giant/fluid planets.

Prerequisites: Math 51 or CME 100 or equivalent, and ESS 246A and ESS 246B, or consent of the instructor.

Same as: ESS 103

**ESS 204. Virtual Scientific Presentation and Public Speaking. 2 Units.**

The ability to present your research in a compelling, concise, and engaging manner will enhance your professional career. Virtual presentations make it harder to connect and interact with the audience, and to overcome this requires new skills, including video, sound, lighting, live vs. pre-recorded content, and virtual posters. These elements will be the focus of this class. But regardless of format, I will work to convince you that the best way to capture an audience and leave a lasting impression is to tell a story, do a demo, or pick a fight. The course is taught as a series of stand-and-deliver exercises with class feedback and revision on the fly, supplemented by one-on-one coaching. We will have sessions on virtual conference presentations, virtual job interviews and job talks, departmental seminars, webinars, press interviews, and funding pitches. My pledge is that everyone will come away a more skilled and confident speaker than they were before. Grades are optional: 70% in-class exercises, 30% final project, such as your upcoming AGU, GSA, or SEG presentation. It's best to take the course when you have research to present. (<http://syllabus.stanford.edu>).

Same as: GEOLSCI 306, GEOPHYS 205

**ESS 205. Fundamentals of Geobiology. 3 Units.**

Lecture and discussion covering key topics in the history of life on Earth, as well as basic principles that apply to life in the universe. Co-evolution of Earth and life; critical intervals of environmental and biological change; geomicrobiology; paleobiology; global biogeochemical cycles; scaling of geobiological processes in space and time.

Same as: EARTHSYS 205A, GEOLSCI 205

**ESS 206. World Food Economy. 5 Units.**

The economics of food production, consumption, and trade. The micro- and macro- determinants of food supply and demand, including the interrelationship among food, income, population, and public-sector decision making. Emphasis on the role of agriculture in poverty alleviation, economic development, and environmental outcomes. Grades based on mid-term exam and group modeling project and presentation. Enrollment is by application only and will be capped at 25, with priority given to upper level undergraduates in Economics and Earth Systems and graduate students (graduate students enroll in 206). Application found at <https://economics.stanford.edu/academics/undergraduate-program/forms>.

Same as: EARTHSYS 106, EARTHSYS 206, ECON 106, ECON 206, ESS 106

**ESS 208. Topics in Geobiology. 1 Unit.**

Reading course addressing current topics in geobiology. Topics will vary from year to year, but will generally cover areas of current debate in the primary literature, such as the origin of life, the origin and consequences of oxygenic photosynthesis, environmental controls on and consequences of metabolic innovations in microbes, the early evolution of animals and plants, and the causes and consequences of major extinction events. Participants will be expected to read and present on current papers in the primary literature.

Same as: GEOLSCI 208

**ESS 209. Biological and Social Networks. 3-5 Units.**

This course introduces the analysis of social and biological networks with a focus on field data collected by interdisciplinary environmental and health scientists. Beginning from the premise that structure emerges from relationships between individual entities, we will concentrate in particular on the measurement of relationships, emphasizing especially practical methodology for mixed-method fieldwork suitable for interdisciplinary biosocial sciences (e.g., earth system science, epidemiology, demography, anthropology, conservation science). Topics include: social relationships in humans and other animals, ecological networks (e.g., trophic and mutualistic interactions), epidemiological networks, research design for collecting relational data, naturalistic observation, ethnographic network methods, sampling, data quality, missing data, graphs and graph theory, structural measures (e.g., density, centrality and centralization, clustering and community detection, embeddedness), network evolution, network diffusion, emergence, egocentric networks, multi-mode/multi-layer networks, inference for sampled networks. All computation and visualization will be done in R so some familiarity is assumed.

Same as: ESS 109

**ESS 210. Techniques in Environmental Microbiology. 3-4 Units.**

Fundamentals and application of laboratory techniques to study the diversity and activity of microorganisms in environmental samples, including soil, sediment, and water. Emphasis is on culture-independent approaches, including epifluorescence microscopy, extraction and analysis of major biomolecules (DNA, RNA, protein, lipids), stable isotope probing, and metabolic rate measurements. Format will include lectures, laboratory exercises, and discussions. Students will learn how to collect, analyze, and understand common and cutting-edge datasets in environmental microbiology. Permission from instructor is required to enroll as C/NC or for 3 units.

**ESS 211. Fundamentals of Modeling. 3-5 Units.**

Simulation models are a powerful tool for environmental research, if used properly. 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 is on gaining hands-on experience using the R programming language. Prerequisite: Basic knowledge of statistics.

Same as: EARTHSYS 211

**ESS 212. Measurements in Earth Systems. 3-4 Units.**

A classroom, laboratory, and field class designed to provide students familiarity with techniques and instrumentation used to track biological, chemical, and physical processes operating in earth systems, encompassing upland, aquatic, estuarine, and marine environments. Topics include gas and water flux measurement, nutrient and isotopic analysis, soil and water chemistry determination. Students will develop and test hypotheses, provide scientific evidence and analysis, culminating in a final presentation.

Same as: EARTHSYS 124

**ESS 213. Global Change and Emerging Infectious Disease. 3 Units.**

The changing epidemiological environment. How human-induced environmental changes, such as global warming, deforestation and land-use conversion, urbanization, international commerce, and human migration, are altering the ecology of infectious disease transmission, and promoting their re-emergence as a global public health threat. Case studies of malaria, cholera, hantavirus, plague, and HIV.

Same as: EARTHSYS 114, EARTHSYS 214, HUMBIO 114

**ESS 214. Introduction to geostatistics and modeling of spatial uncertainty. 3-4 Units.**

Introduction of fundamental geostatistical tools for modeling spatial variability and uncertainty, and mapping of environmental attributes. Additional topics include sampling design and incorporation of different types of information (continuous, categorical) in prediction. Assignments consist of small problems to familiarize students with theoretical concepts, and applications dealing with the analysis and interpretation of various data sets (soil, water pollution, atmospheric constituents, remote sensing) primarily using Matlab. No prior programming experience is required. Open to graduates. Open to undergraduates with consent from the instructor. 3-credit option includes midterm/final or student-developed project. 4-credit option requires both. Prerequisite: College-level introductory statistics.

**ESS 215. Approaching Nepal: Coupled Human-Natural Systems of the Solokhumbu. 1-2 Unit.**

This class designed to prepare students participating in the 2020 BOSP Nepal Seminar. Through readings, lectures, and class discussions, students will acquire a working knowledge of coupled human-natural system theory and examine case studies of CHNS analysis in the region. We will also provide content on the history of Nepal and the Sherpa people, Buddhist and Hindu thoughts on nature and resources, agricultural systems across Himalayan ecotones, and geology, glaciology, water, and energy issues relevant to the course itinerary. The class will meet weekly through the Spring quarter. We may switch the time to accommodate the schedules of all enrolled students. The class is mandatory for students participating in BOSP Nepal 2020.

Same as: ESS 115

**ESS 218X. Shaping the Future of the Bay Area. 3-5 Units.**

The complex urban problems affecting quality of life in the Bay Area, from housing affordability and transportation congestion to economic vitality and social justice, are already perceived by many to be intractable, and will likely be exacerbated by climate change and other emerging environmental and technological forces. Changing urban systems to improve the equity, resilience and sustainability of communities will require new collaborative methods of assessment, goal setting, and problem solving across governments, markets, and communities. It will also require academic institutions to develop new models of co-production of knowledge across research, education, and practice. This XYZ course series is designed to immerse students in co-production for social change. The course sequence covers scientific research and ethical reasoning, skillsets in data-driven and qualitative analysis, and practical experience working with local partners on urban challenges that can empower students to drive responsible systems change in their future careers. The Autumn (X) course is specifically focused on concepts and skills, and completion is a prerequisite for participation in the Winter (Y) and/or Spring (Z) practicum quarters, which engage teams in real-world projects with Bay Area local governments or community groups. X is composed of four modules: (A) participation in two weekly classes which prominently feature experts in research and practice related to urban systems; (B) reading and writing assignments designed to deepen thinking on class topics; (C) fundamental data analysis skills, particularly focused on Excel and ArcGIS, taught in lab sessions through basic exercises; (D) advanced data analysis skills, particularly focused on geocomputation in R, taught through longer and more intensive assignments. X can be taken for 3 units (ABC), 4 units (ACD), or 5 units (ABCD). Open to undergraduate and graduate students in any major. For more information, visit <http://bay.stanford.edu>.

Same as: CEE 118X, CEE 218X, ESS 118X, GEOLSCI 118X, GEOLSCI 218X, GEOPHYS 118X, GEOPHYS 218X, POLISCI 218X, PUBLPOL 118X, PUBLPOL 218X

**ESS 218Y. Shaping the Future of the Bay Area. 3-5 Units.**

Students are placed in small interdisciplinary teams (engineers and non-engineers, undergraduate and graduate level) to work on complex design, engineering, and policy problems presented by external partners in a real urban setting. Multiple projects are offered and may span both Winter and Spring quarters; students are welcome to participate in one or both quarters. Students are expected to interact professionally with government and community stakeholders, conduct independent team work outside of class sessions, and submit deliverables over a series of milestones. Prerequisite: the Autumn (X) skills course or approval of instructors. For information about the projects and application process, visit <http://bay.stanford.edu>.

Same as: CEE 118Y, CEE 218Y, ESS 118Y, GEOLSCI 118Y, GEOLSCI 218Y, GEOPHYS 118Y, GEOPHYS 218Y, POLISCI 218Y, PUBLPOL 118Y, PUBLPOL 218Y

**ESS 218Z. Shaping the Future of the Bay Area. 3-5 Units.**

Students are placed in small interdisciplinary teams (engineers and non-engineers, undergraduate and graduate level) to work on complex design, engineering, and policy problems presented by external partners in a real urban setting. Multiple projects are offered and may span both Winter and Spring quarters; students are welcome to participate in one or both quarters. Students are expected to interact professionally with government and community stakeholders, conduct independent team work outside of class sessions, and submit deliverables over a series of milestones. Prerequisite: the Autumn (X) skills course or approval of instructors. For information about the projects and application process, visit <http://bay.stanford.edu>.

Same as: CEE 118Z, CEE 218Z, ESS 118Z, GEOLSCI 118Z, GEOLSCI 218Z, GEOPHYS 118Z, GEOPHYS 218Z, POLISCI 218Z

**ESS 220. Physical Hydrogeology. 4 Units.**

(Formerly GES 230.) 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.

Same as: CEE 260A

**ESS 221. Contaminant Hydrogeology and Reactive Transport. 3 Units.**

Decades of industrial activity have released vast quantities of contaminants to groundwater, threatening water resources, ecosystems and human health. What processes control the fate and transport of contaminants in the subsurface? What remediation strategies are effective and what are the tradeoffs among them? How are these processes represented in models used for regulatory and decision-making purposes? This course will address these and related issues by focusing on the conceptual and quantitative treatment of advective-dispersive transport with reacting solutes, including modern methods of contaminant transport simulation. Some Matlab programming / program modification required. Prerequisite: Physical Hydrogeology ESS 220 / CEE 260A (Gorelick) or equivalent and college-level course work in chemistry. Same as: CEE 260C

**ESS 223. Biosphere-Atmosphere Interactions. 3-4 Units.**

How do ecosystems respond to climate, and how do ecosystems influence climate? Covers the role of the terrestrial land surface in earth's climate system, including among others photosynthesis, transpiration, greenhouse gasses, radiation, and atmospheric water vapor. For each of these topics, attention is paid to both the underlying processes and how they can be mathematically represented in earth system models. Instruments and techniques used to measure these processes are also discussed, and, where appropriate, demonstrated.

Same as: EARTHSYS 123A, EARTHSYS 223, ESS 123

**ESS 224. Remote Sensing of Hydrology. 3 Units.**

This class discusses the methods available for remote sensing of the components of the terrestrial hydrologic cycle and how to use them. Topics include the hydrologic cycle, relevant sensor types and the electromagnetic spectrum, active/passive microwave remote sensing (snow, soil moisture, canopy water content, rainfall), thermal sensing of evapotranspiration, gravity and hyperspectral methods, as well as an introduction to data assimilation and calibration/validation approaches for hydrologic variables. Pre-requisite: programming experience.

Same as: CEE 260D

**ESS 225. Rivers: The Arteries of Earth's Continents. 3 Units.**

Rivers are the arteries of Earth's continents, conveying water, sediments, and solutes from the headwaters to the oceans. They provide a haven for life and have been at the heart of the world's economy by generating fertile floodplains, human habitats, as well as by facilitating international commerce. This course offers a quantitative examination of rivers, from headwaters to deltas. We will first develop a basic mechanistic understanding of fluvial processes, including flow hydraulics, erosion, sediment transport, and deposition. We will then apply our acquired knowledge through thematic discussions of relevant issues. Possible themes include deltas and climate change, rivers and human activity (damming, sand mining, deforestation), rivers and the evolution of land plants, rivers and biogeochemical cycles, submarine channels, and the alien rivers of Mars and Titan.

Same as: GEOLSCI 224, GEOPHYS 221

**ESS 227. Decision Science for Environmental Threats. 3-5 Units.**

Decision science is the study of how people make decisions. It aims to describe these processes in ways that will help people make better or more well-informed decisions. It is an interdisciplinary field that draws upon psychology, economics, political science, and management, among other disciplines. It is being used in a number of domain areas and for a variety of applications, including managing freshwater resources, designing decision support tools to aid in coastal adaptation to sea-level rise, and creating "nudges" to enhance energy efficiency behaviors. This course covers behavioral theories of probabilistic inference, intuitive prediction, preference, and decision making. Topics include heuristics and biases, risk perceptions and attitudes, strategies for combining different sources of information and dealing with conflicting objectives, and the roles of group and emotional processes in decision making. This course will introduce students to foundational theories of decision science, and will involve applying these theories to understand decisions about environmental threats.

Same as: EARTHSYS 227

**ESS 230. Pursuing Sustainability: Managing Complex Social Environmental Systems. 3 Units.**

This course provides a systems framework for understanding and managing social-environmental systems, with the ultimate goal of inclusive, equitable, intra- and intergenerational human well-being. It explores the roles of natural, human, social, technological and knowledge resources in supporting efforts toward sustainability, and examines the trade-offs, feedbacks, non-linearities and other interactions among different parts of complex systems that must be addressed to avoid unintended negative consequences for people and environment. Finally, it provides an overview of the tools, approaches, and strategies that assist with management of assets for sustainability goals. The course draws on readings from a variety of on-line sources as well as chapters and case studies provided in the required text. Priority given to SUST students. Enrollment open to seniors and graduate students only. Please contact program staff at [rachelx@stanford.edu](mailto:rachelx@stanford.edu) for permission code.

Same as: SUST 210

**ESS 231. Coral Reefs of the Western Pacific: Interdisciplinary perspectives, emerging crises, and solutions. 3 Units.**

This new graduate-level course focuses on the complex interplay of biology, physics, chemistry, and human activities that both promotes and limits the development of coral reefs. We will examine the ecology of these biodiverse systems as well as the service they provide in terms of rapid nutrient recycling, coastal protection, and maintenance of large populations of fish. New advances in our understanding of coral reefs will be highlighted, including the role of climate variability and micro- and mesoscale fluid flow in controlling reef growth and persistence, the physiology, genomics, and physics underpinning thermal resilience in corals, contributing and mitigating factors involved in the current decline of coral reefs, ocean acidification, fishing, reef-scale trophic modeling, ecological interactions and trophic cascades, and reefs as part of complex seascapes and linkages with other marine ecosystems. The course will conclude with an analysis of science to policy case studies and future opportunities. The faculty leaders collectively have over 100 years of field experience working in coral reefs of the Pacific and despite our forced online teaching and learning format will endeavor to bring the coral reef field experience to life for this class.

**ESS 232. Evolution of Earth Systems. 4 Units.**

This course examines biogeochemical cycles and how they developed through the interaction between the atmosphere, hydrosphere, biosphere, and lithosphere. Emphasis is on the long-term carbon cycle and how it is connected to other biogeochemical cycles on Earth. The course consists of lectures, discussion of research papers, and quantitative modeling of biogeochemical cycles. Students produce a model on some aspect of the cycles discussed in this course. Grades based on class interaction, student presentations, and the modeling project.

Same as: EARTHSYS 132, EARTHSYS 232, ESS 132, GEOLSCI 132, GEOLSCI 232

**ESS 233. Mitigating Climate Change through Soil Management. 2 Units.**

Climate change is one of the greatest crises facing our world. Increasing soil organic carbon storage may be a key strategy for mitigating global climate change, with the potential to offset approximately 20% of annual global fossil fuel emissions. In this course, we will learn about soil carbon cycling, its contribution to the global carbon cycle, how carbon is stored in soil, and land management practices that can increase or decrease soil carbon stocks, thereby mitigating or exacerbating climate change. Although the content is centered on soil carbon, the processes and skills learned in this course can be applied to design solutions to any environmental problem. Prerequisites: Some knowledge of soils, introductory chemistry, and introductory biology would be useful but not necessary. Please email the instructor if you have any concerns or questions.

Same as: EARTHSYS 233

**ESS 239. Data science for geoscience. 3 Units.**

This course provides an overview of the most relevant areas of data science (applied statistics, machine learning & computer vision) to address geoscience challenges, questions and problems. Using actual geoscientific research questions as background, principles and methods of data scientific analysis, modeling, and prediction are covered. Data science areas covered are: extreme value statistics, multi-variate analysis, factor analysis, compositional data analysis, spatial information aggregation models, spatial estimation, geostatistical simulation, treating data of different scales of observation, spatio-temporal modeling (geostatistics). Application areas covered are: process geology, hazards, natural resources. Students are encouraged to participate actively in this course by means of their own data science research challenge or question.

Same as: EARTHSYS 240, ENERGY 240, GEOLSCI 240

**ESS 240. Advanced Oceanography. 3 Units.**

For upper-division undergraduates and graduate students in the natural sciences and engineering. Topical issues in marine science/oceanography. Topics vary each year following or anticipating research trends in ocean research and issues. For 2018, the focus is on the Arctic Ocean, including Arctic Oceanography, Ecosystems, Resource Utilization and Geopolitics, and Environmental Change.

**ESS 241. Remote Sensing of the Oceans. 3-4 Units.**

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.

Same as: EARTHSYS 141, EARTHSYS 241, ESS 141, GEOPHYS 141

**ESS 242. Antarctic Marine Geology and Geophysics. 3 Units.**

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). Students interpret seismic lines and sediment core/well log data. Examples from a recent scientific drilling expedition to Prydz Bay, Antarctica.

Same as: EARTHSYS 272

**ESS 243. Molecular Geomicrobiology Laboratory. 3-4 Units.**

In this course, students will be studying the biosynthesis of cyclic lipid biomarkers, molecules that are produced by modern microbes that can be preserved in rocks that are over a billion years old and which geologists use as molecular fossils. Students will be tasked with identifying potential biomarker lipid synthesis genes in environmental genomic databases, expressing those genes in a model bacterial expression system in the lab, and then analyzing the lipid products that are produced. The overall goal is for students to experience the scientific research process including generating hypotheses, testing these hypotheses in laboratory experiments, and communicating their results through a publication style paper. Prerequisites: BIO83 and CHEM 121 or permission of the instructor.

Same as: BIO 142, EARTHSYS 143, ESS 143

**ESS 244. Marine Ecosystem Modeling. 3 Units.**

This course will provide the practical background necessary to construct and implement a 2-dimensional (space and time) numerical model of a simple marine ecosystem. Instruction on computer programming, model design and parameterization, and model evaluation will be provided. Throughout the 10-week course, each student will develop and refine their own multi-component marine ecosystem model. Instructor consent required.

**ESS 245. Advanced Biological Oceanography. 2-3 Units.**

For upper-division undergraduate and graduate students. For upper-division undergraduate and graduate students interested in an in-depth look at biological processes in the world's oceans. Themes will vary from year to year but will include such topics as marine bio-optics, marine ecological modeling, phytoplankton primary production, and others. Hands-on laboratory and computer activities will be an integral part of the course, as will field trips into local waters. May be repeated for credit. Enrollment by instructor consent only.



**ESS 246A. Atmosphere, Ocean, and Climate Dynamics: The Atmospheric Circulation. 3 Units.**

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.

Same as: CEE 161I, CEE 261I, EARTHSYS 146A

**ESS 246B. Atmosphere, Ocean, and Climate Dynamics: the Ocean Circulation. 3 Units.**

Introduction to the physics governing the circulation of the atmosphere and ocean and their control on climate with emphasis on the large-scale ocean circulation. This course will give an overview of the structure and dynamics of the major ocean current systems that contribute to the meridional overturning circulation, the transport of heat, salt, and biogeochemical tracers, and the regulation of climate. Topics include the tropical ocean circulation, the wind-driven gyres and western boundary currents, the thermohaline circulation, the Antarctic Circumpolar Current, water mass formation, atmosphere-ocean coupling, and climate variability. Prerequisites: MATH 51 or CME100; and PHYSICS 41; and a course that introduces the equations of fluid motion (e.g. ESS 246A, ESS 148, or CEE 101B).

Same as: CEE 162I, CEE 262I, EARTHSYS 146B

**ESS 247. Tropical Meteorology. 3-4 Units.**

Introduction to tropical meteorology and climate. Topics include radiative-convective equilibrium, Hadley and Walker circulations, equatorial waves, El Nino/Southern Oscillation, the Madden-Julian Oscillation, monsoons and tropical cyclones. Prerequisites: Math 51 or CME100; and (concurrent is acceptable) ESS 246A and ESS 246B, or consent of the instructor.

**ESS 249. Marine Stable Isotopes. 3 Units.**

This course will provide an introduction to stable isotopes biogeochemistry with emphasis on applications in marine science. We will cover fundamental concepts of nuclear structure and origin of elements and isotopes, and stable isotopic fractionation. We will discuss mass spectrometry techniques, mass independent fractionation, clumped isotopes, mass balance and box models. Applications of these concepts to studies of ocean circulation, marine carbon and nitrogen cycles, primary productivity, and particle scavenging will also be discussed.

**ESS 251. Biological Oceanography. 3-4 Units.**

Required for Earth Systems students in the oceans track. Interdisciplinary look at how oceanic environments control the form and function of marine life. Topics include distributions of planktonic production and abundance, nutrient cycling, the role of ocean biology in the climate system, expected effects of climate changes on ocean biology. Local weekend field trips. Designed to be taken concurrently with Marine Chemistry (ESS/EARTHSYS 152/252). Prerequisites: BIO 43 and ESS 8 or equivalent.

Same as: EARTHSYS 151, EARTHSYS 251, ESS 151

**ESS 252. Marine Chemistry. 3-4 Units.**

Introduction to the interdisciplinary knowledge and skills required to critically evaluate problems in marine chemistry and related disciplines. Physical, chemical, and biological processes that determine the chemical composition of seawater. Air-sea gas exchange, carbonate chemistry, and chemical equilibria, nutrient and trace element cycling, particle reactivity, sediment chemistry, and diagenesis. Examination of chemical tracers of mixing and circulation and feedbacks of ocean processes on atmospheric chemistry and climate. Designed to be taken concurrently with Biological Oceanography (ESS/EARTHSYS 151/251).

Same as: EARTHSYS 152, EARTHSYS 252, ESS 152

**ESS 253S. Hopkins Microbiology Course. 3-12 Units.**

(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 and CEE 274B, or equivalents.

Same as: BIO 274S, BIOHOPK 274, CEE 274S

**ESS 255. Microbial Physiology. 3 Units.**

Introduction to the physiology of microbes including cellular structure, transcription and translation, growth and metabolism, mechanisms for stress resistance and the formation of microbial communities. These topics will be covered in relation to the evolution of early life on Earth, ancient ecosystems, and the interpretation of the rock record. Recommended: introductory biology and chemistry.

Same as: BIO 180, EARTHSYS 255, GEOLSCI 233A

**ESS 256. Soil and Water Chemistry. 3 Units.**

(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.

Same as: EARTHSYS 256

**ESS 258. Geomicrobiology. 3 Units.**

How microorganisms shape the geochemistry of the Earth's crust including oceans, lakes, estuaries, subsurface environments, sediments, soils, mineral deposits, and rocks. Topics include mineral formation and dissolution; biogeochemical cycling of elements (carbon, nitrogen, sulfur, and metals); geochemical and mineralogical controls on microbial activity, diversity, and evolution; life in extreme environments; and the application of new techniques to geomicrobial systems. Recommended: introductory chemistry and microbiology such as CEE 274A.

Same as: EARTHSYS 158, EARTHSYS 258, ESS 158

**ESS 259. Environmental Microbial Genomics. 1-3 Unit.**

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.

**ESS 260. Advanced Statistical Methods for Earth System Analysis. 3 Units.**

Introduction for graduate students to important issues in data analysis relevant to earth system studies. Emphasis on methodology, concepts and implementation (in R), rather than formal proofs. Likely topics include the bootstrap, non-parametric methods, regression in the presence of spatial and temporal correlation, extreme value analysis, time-series analysis, high-dimensional regressions and change-point models. Topics subject to change each year. Prerequisites: STATS 110 or equivalent.

Same as: STATS 360

**ESS 262. Remote Sensing of Land. 4 Units.**

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.

Same as: EARTHSYS 142, EARTHSYS 242, ESS 162

**ESS 264. Poverty, Infrastructure and Climate. 2-3 Units.**

Lack of access to physical infrastructure such as roads, water supply and electricity is a key element of how 'poverty' is often defined. At the same time, the causal pathways that link infrastructure and economic development are not well understood, and are likely being re-shaped by a changing climate. Students in this course will contribute to a new initiative on poverty, infrastructure and climate change by (1) reviewing and synthesizing literature from relevant scholarly communities, (2) co-creating a conceptual causal model of the ways in which infrastructure (particularly roads and water assets) contributes to poverty alleviation, and (3) contributing to the design of applied research effort on these topics in sub-Saharan Africa. Students who opt for the 3-unit enrollment will have an additional supervised project that could take the form of a review paper, research proposal, or analysis of secondary data. There are no formal pre-requisites for the class; students from all schools and departments are welcome. Enrollment requires permission of the instructors. Interested students are invited to submit an application at <https://tiny.cc/EPIC-Stanford>.

Same as: CEE 265I

**ESS 265. Advanced Geographic Information Systems. 4 Units.**

Building on the Fundamentals of Geographic Information Systems course, this class delves deeper into geospatial analysis and mapping techniques. The class is heavily project-based and students are encouraged to bring their own research questions. Topics include topographic analysis, interpolation, spatial statistics, network analysis, and scripting using Python and Arcpy. All students are required to attend a weekly lab. ESS 164 or equivalent is a prerequisite.

Same as: ESS 165

**ESS 268. Empirical Methods in Sustainable Development. 3-5 Units.**

The determinants of human well-being over the short and long-run, including the role of environmental factors in shaping development outcomes. A focus on the empirical literature across both social and natural sciences, with discussion and assignments emphasizing empirical analysis of environment-development linkages, application of methods in causal inference, and data visualization.

Same as: INTLPOL 272

**ESS 270. Analyzing land use in a globalized world. 3 Units.**

This course examines the dynamics of land use in relation to globalization. The objective is to understand how the expansion of global trade, and public and private regulations affect land use changes. The course will enable students to better understand how to effectively influence land use change, from different vantage points (government, NGO, corporate actor). The main emphasis is on tropical regions. Lectures introduce theories, practical cases, and evaluation tools to better understand contemporary land use dynamics.

Same as: ESS 170

**ESS 271. Climate Models and Data. 3 Units.**

Overview of key concepts necessary to develop familiarity with climate modeling and data. Topics covered will include components of the climate system, climate change and global warming, and model mechanics, their evaluation and usability, and predictability. Assessments will involve the use of datasets and model output, so some knowledge of programming is a pre-requisite.

Same as: ESS 171

**ESS 275. Nitrogen in the Marine Environment. 1-2 Unit.**

The goal of this seminar course is to explore current topics in marine nitrogen cycle. We will explore a variety of processes, including primary production, nitrogen fixation, nitrification, denitrification, and anaerobic ammonia oxidation, and their controls. We will use the book *Nitrogen in the Marine Environment* and supplement with student-led discussions of recent literature. A variety of biomes, spatial and temporal scales, and methodologies for investigation will be discussed.

**ESS 280. Principles and Practices of Sustainable Agriculture. 3-4 Units.**

Field-based training in ecologically sound agricultural practices at the Stanford Community Farm. Weekly lessons, field work, and group projects. Field trips to educational farms in the area. Topics include: soils, composting, irrigation techniques, IPM, basic plant anatomy and physiology, weeds, greenhouse management, and marketing. Application required. Deadline: September 10 for Autumn and March 10 for Spring. [nnApplication: https://stanforduniversity.qualtrics.com/jfe/form/SV\\_244JnBoEP7zs8Dz](https://stanforduniversity.qualtrics.com/jfe/form/SV_244JnBoEP7zs8Dz).

Same as: EARTHSYS 180

**ESS 281. Urban Agroecology. 3 Units.**

The United Nations estimates that up to 15% of the world's food is produced in and around cities. Urban populations are projected to continue rising and urban agriculture in its many forms has been shown to provide multiple benefits to urban communities. This class will survey urban agriculture around the world while training you in small-scale food production practices. The emphasis will be on ecological approaches to the design and stewardship of urban farms and gardens. ~~nnlf~~ permitted, given the challenges of COVID-19, the course will be taught in-person, outdoors at the Stanford Educational Farm. ~~nn~~ This is a 3-unit, Earth Systems practicum course that meets on Wednesdays from noon to 3pm. Space is limited and applications are due by Friday 8/28. Students will be notified if they are admitted to the course by 9/4. For the course application go to: [https://stanforduniversity.qualtrics.com/jfe/form/SV\\_86udp8aEuWUCnNH](https://stanforduniversity.qualtrics.com/jfe/form/SV_86udp8aEuWUCnNH).

Same as: EARTHSYS 181, EARTHSYS 281, ESS 181, URBANST 181

**ESS 282. Designing Educational Gardens. 2 Units.**

A project-based course emphasizing 'ways of doing 's sustainable agricultural systems based at the new Stanford Educational Farm. Students will work individually and in small groups on the design of a new educational garden and related programs for the Stanford Educational Farm. The class will meet on 6 Fridays over the course of winter quarter. Class meetings will include an introduction to designing learning gardens and affiliated programs, 3 field trips to exemplary educational gardens in the bay area that will include tours and discussions with garden educators, and work sessions for student projects. By application only. Same as: EARTHSYS 182

**ESS 292. Directed Individual Study in Earth System Science. 1-10 Unit.**

Under supervision of an Earth System Science faculty member on a subject of mutual interest.

**ESS 300. Climate studies of terrestrial environments. 3 Units.**

This course will consist of a weekly seminar covering topics of interest in Cenozoic climate. The course examines the interactions between the biosphere, atmosphere and geosphere and how these interactions influence climate. The course will cover classic and seminal papers on the controls of the oxygen, hydrogen, and carbon isotopes of the hydrosphere, atmosphere and biosphere and how they are expressed in paleoclimate proxies. Seminar will consist of reading and discussion of these papers. Students will be responsible for presenting papers. Grades will be determined by class participation. (Chamberlain).

**ESS 301. Topics in Earth System Science. 1 Unit.**

Current topics, issues, and research related to interactions that link the oceans, atmosphere, land surfaces and freshwater systems. May be repeated for credit.

**ESS 305. Climate Change: An Earth Systems Perspective. 1-2 Unit.**

This is an introductory graduate-level course that is intended to provide an overview of leading-edge research topics in the area of climate change. Lectures introduce the physical, biogeochemical, ecological, and human dimensions of climate change, with emphasis on understanding climate change from an Earth System perspective (e.g., nonlinearities, feedbacks, thresholds, tipping points, resilience, vulnerability, risk). The emphasis is on providing an initial introduction to the process by which researchers pose questions and analyze and interpret results.

**ESS 306. From Freshwater to Oceans to Land Systems: An Earth System Perspective to Global Challenges. 2 Units.**

Within this class we will have cover Earth System processes ranging from nutrient cycles to ocean circulation. We will also address global environmental challenges of the twenty-first century that include maintaining freshwater resources, land degradation, health of our oceans, and the balance between food production and environmental degradation. Weekly readings and problem sets on specific topics will be followed by presentations of Earth System Science faculty and an in-depth class discussion. ESS first year students have priority enrollment.

**ESS 307. Research Proposal Development and Delivery. 2 Units.**

In this class students will learn how to write rigorous, high yield, multidisciplinary proposals targeting major funding agencies. The skills gained in this class are essential to any professional career, particularly in research science. Students will write a National Science Foundation style proposal involving testable hypotheses, pilot data or calculations, and broader impact. Restricted to ESS and GS first-year graduate students. Same as: GEOLSCI 307

**ESS 308. Carbon Dioxide and Methane Removal, Utilization, and Sequestration. 1 Unit.**

This is a seminar on carbon dioxide and methane removal, utilization, and sequestration options, and their role in decarbonizing the global energy system. This course will cover topics including the global carbon balance, utilizing atmospheric carbon in engineered solutions, recycling and sequestering fossil-based carbon, and enhancing natural carbon sinks. The multidisciplinary lectures and discussions will cover elements of technology, economics, policy and social acceptance, and will be led by a series of guest lecturers. Short group project on carbon solutions. Same as: EARTHSYS 308, ENERGY 308, ENVRES 295, ME 308

**ESS 322B. Seminar in Hydrology. 1 Unit.**

Current topics. May be repeated for credit. Prerequisite: consent of instructor.

**ESS 323. Stanford at Sea. 16 Units.**

(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. 2020-21 academic year offering of this course is dependent on COVID-19 regulations. Same as: BIOHOPK 182H, BIOHOPK 323H, EARTHSYS 323

**ESS 325. Vortex Dynamics. 3-4 Units.**

This course will be a combination of lectures and reading + discussion, covering a focused subset of fundamental topics in vortex dynamics with application to geophysical fluid dynamics. The class will begin with two-dimensional vortex behavior and move to three-dimensional vortex dynamics in stratified flow. Topics include the equations of motion, two-dimensional circulation and vorticity, potential vorticity and inversion, asymmetric vortex dynamics in stratified flow, and balanced vortex dynamics (e.g. hurricanes and tornadoes).

**ESS 328. Environmental Change and Human Resiliency. 3-4 Units.**

Unprecedented environmental change increasingly threatens human settlements in the U.S. and around the globe. This environmental change renders communities vulnerable to poor health outcomes, property loss, and displacement. This confluence of interrelated disaster events challenges people's ability to adapt, with profound impacts on health and resiliency. This course is designed to help students think broadly about the factors that promote or inhibit individual and community-level adaptation to environmental change through case studies such as the 2018 Camp Fire in Northern California to the 2017 Hurricane Maria in Puerto Rico. Through this process, the class will consider the role of social and behavioral psychology, health, information, state and non-state actors, and the larger climate community on resiliency outcomes.

**ESS 330. Advanced Topics in Hydrogeology. 1-2 Unit.**

Topics: questioning classic explanations of physical processes; coupled physical, chemical, and biological processes affecting heat and solute transport. May be repeated for credit.

**ESS 348. Dynamics of the Atmosphere. 3-5 Units.**

Overview of large-scale atmospheric dynamics. Topics include the circulation of a zonally symmetric atmosphere, internal gravity waves, Rossby waves, the instability of zonal flows, and the role of eddies in the general circulation. Class participation in terms of summarizing papers and making presentations will be required.

**ESS 355. Coral Reefs of the Western Pacific: Interdisciplinary Perspectives, Emerging Crises, and Solutions. 1 Unit.**

This new graduate-level course focusses on the complex interplay of biology, physics, chemistry, and human activities that both promotes and limits the development of coral reefs. We will examine the ecology of these biodiverse systems as well as the service they provide in terms of rapid nutrient recycling, coastal protection, and maintenance of large populations of fish. New advances in our understanding of coral reefs will be highlighted, including the role of climate variability and micro- and mesoscale fluid flow in controlling reef growth and persistence, the physiology, genomics, and physics underpinning thermal resilience in corals, contributing and mitigating factors involved in the current decline of coral reefs, ocean acidification, fishing, reef-scale trophic modeling, ecological interactions and trophic cascades, and reefs as part of complex seascapes and linkages with other marine ecosystems. The course will conclude with an analysis of science to policy case studies and future opportunities. The faculty leaders collectively have over 100 years of field experience working in coral reefs of the Pacific and despite our forced online teaching and learning format will endeavor to bring the coral reef field experience to life for this class.

Same as: BIO 355, BIOHOPK 355, CEE 363I

**ESS 360. Social Structure and Social Networks. 5 Units.**

In this course, we will explore social network analysis, a set of methods and theories used in the analysis of social structure. The fundamental conceit underlying social network analysis is that social structure emerges from relationships between individuals. We will therefore concentrate in particular on the measurement of relationships, emphasizing especially practical methodology for anthropological fieldwork. This is a somewhat unusual course because of its focus on social network research coming out of anthropological and ethological traditions. While most current practitioners of social network analysis are (probably) sociologists, many of both the methodological antecedents and theoretical justifications for the field can be found in these two traditions. A major goal of this course is to understand how the methods and perspectives of social network analysis can be usefully incorporated into contemporary approaches to ethnography and other anthropological modes of investigation. Prerequisite: graduate standing or consent of instructor.

**ESS 363. Demography and Life History Theory. 5 Units.**

Life history theory is the branch of evolutionary biology that attempts to understand patterns of investment in growth, reproduction, and survival across the life cycle. It is the theory that explains the major transitions that mark individual organisms' life cycles from conception to death.

In this class, we will focus on the central themes of life history theory and how they relate to specific problems of the human life cycle. In addition to the classic questions of life history theory (e.g., evolution of reproductive effort, size vs. quality, etc.), we will discuss some peculiar issues that relate specifically to humans. In particular, we will explore the intersection of life history theory and more classical economic approaches to decision theory and rational choice. This will include an exploration of the evolution of economic transfers and their implications for demographic transitions, ecological resilience, and the consumption of natural resources. This discussion will explore how an understanding of life history theory might help in promoting investments in future welfare or developing policies that promote sustainability.

Same as: ESS 163

**ESS 363F. Geophysical Fluid Dynamics. 3 Units.**

The fundamental dynamics of rotating stratified fluids. 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. Prerequisites: CEE 262A or a graduate class in fluid mechanics. Recommended math background: vector calculus, ordinary differential equations, and partial differential equations.

Same as: CEE 363F

**ESS 400. Graduate Research. 1-15 Unit.**

Independent study and thesis research under the supervision of a faculty member in the Earth System Science department. On registration, students designate faculty member and agreed-upon units. The course involves regular meetings with the faculty advisor both in person and remotely. May be repeated for credit. Prerequisite: consent of instructor.

**ESS 401. Curricular Practical Training. 1-3 Unit.**

CPT course required for international students completing degree.

Prerequisite: Earth System Science Ph.D. candidate.

**ESS 801. TGR Project. 0 Units.**

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**ESS 802. TGR Dissertation. 0 Units.**

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