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&g=ESS&filter-departmentcode-ESS=on&filter-coursesstatus-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.

On April 16, 2015, the Senate of the Academic Council approved the Master of Science in Earth System Science. Students who matriculated into the Master of Science in Environmental Earth System Science have the option of changing the name of their degree to Earth System Science. Degree requirements remain the same.

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, the applicant must have taken the Aptitude Test (verbal, quantitative, and analytical writing assessment) of the Graduate Record Examination. 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.

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

Seminar Requirements

Each quarter during the first academic year:

ESS 301 Topics in Earth System Science 1

Required Core Courses (Students are required to take three 2-unit courses during the first year):

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

Distribution Requirements (Students must take one class each of the following three areas within the first or second year): 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 3

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 1-3

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 242 Antarctic Marine Geology and Geophysics 3

ESS 244 Marine Ecosystem Modeling 3
Department of Earth System Science: Admission Requirements

University policy, applicants whose first language is not English must have taken the Aptitude Test (verbal, quantitative, and analytical writing assessment) of the Graduate Record Examination. In keeping with the University's requirements for the Ph.D. degree, candidates must be proficient in English. Students who have taken the TOEFL (Test of English as a Foreign Language) in the last 2 years must meet the University's minimum score of 100. The program also accepts the IELTS (International English Language Testing System). Students who have completed a B.S. or M.S. program in the U.S. or other English-speaking country are not required to submit TOEFL scores.

Admission

For admission to graduate work in the department, the applicant must have taken the Aptitude Test (verbal, quantitative, and analytical writing assessment) of the Graduate Record Examination. In keeping with University policy, applicants whose first language is not English must present evidence of English proficiency. The University policy requires a minimum score of 100 on the TOEFL for admission to the program. Students who have completed a B.S. or M.S. program in the U.S. or other English-speaking country are not required to submit TOEFL scores.

Course Work

Required Core Courses (Students are required to take three 2-unit courses during the first year):

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESS 301</td>
<td>Topics in Earth System Science</td>
<td>1</td>
</tr>
<tr>
<td>ESS 305</td>
<td>Climate Change: An Earth Systems Perspective</td>
<td>2</td>
</tr>
<tr>
<td>ESS 306</td>
<td>From Freshwater to Oceans to Land Systems: An Earth System Perspective Global Challenges</td>
<td>2</td>
</tr>
<tr>
<td>ESS 307</td>
<td>Research Proposal Development and Delivery</td>
<td>2</td>
</tr>
</tbody>
</table>

Distribution Requirements (Students must take one class from each of the following three areas within the first or second year):

Area A: Analysis of the Earth System (Select one course)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESS 214</td>
<td>Introduction to geostatistics and modeling of spatial uncertainty</td>
<td>3-4</td>
</tr>
<tr>
<td>GEOLSCI 240</td>
<td>Data science for geoscience</td>
<td>3</td>
</tr>
<tr>
<td>CME 106</td>
<td>Introduction to Probability and Statistics for Engineers</td>
<td>4</td>
</tr>
<tr>
<td>CEE 362A</td>
<td>Uncertainty Quantification</td>
<td>3</td>
</tr>
<tr>
<td>STATS 200</td>
<td>Introduction to Statistical Inference</td>
<td>3</td>
</tr>
<tr>
<td>STATS 206</td>
<td>Applied Multivariate Analysis</td>
<td>3</td>
</tr>
<tr>
<td>STATS 207</td>
<td>Introduction to Time Series Analysis</td>
<td>3</td>
</tr>
<tr>
<td>STATS 216</td>
<td>Introduction to Statistical Learning</td>
<td>3</td>
</tr>
<tr>
<td>STATS 366</td>
<td>Modern Statistics for Modern Biology</td>
<td>1-3</td>
</tr>
</tbody>
</table>

Area B: Measurement of the Earth System (Select one course)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESS 210</td>
<td>Techniques in Environmental Microbiology</td>
<td>3</td>
</tr>
<tr>
<td>ESS 212</td>
<td>Measurements in Environmental Systems</td>
<td>3-4</td>
</tr>
<tr>
<td>ESS 224</td>
<td>Remote Sensing of Hydrology</td>
<td>3</td>
</tr>
<tr>
<td>ESS 241</td>
<td>Remote Sensing of the Oceans</td>
<td>3-4</td>
</tr>
<tr>
<td>ESS 243</td>
<td>Molecular Geomicrobiology Laboratory</td>
<td>3-4</td>
</tr>
<tr>
<td>ESS 253S</td>
<td>Hopkins Microbiology Course</td>
<td>3-12</td>
</tr>
<tr>
<td>ESS 262</td>
<td>Remote Sensing of Land</td>
<td>4</td>
</tr>
</tbody>
</table>

Area C: Earth System Processes, Models, and Human-Environment Interactions (Select one course)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESS 206</td>
<td>World Food Economy</td>
<td>5</td>
</tr>
<tr>
<td>ESS 220</td>
<td>Physical Hydrogeology</td>
<td>4</td>
</tr>
<tr>
<td>ESS 221</td>
<td>Contaminant Hydrogeology and Reactive Transport</td>
<td>3</td>
</tr>
</tbody>
</table>

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.html)" section of this bulletin.
Therefore, it is strongly advised that the qualifying exam be passed by the end of the second year in the Ph.D. program. The department policy requires completion of the department qualifying procedures and forming a doctoral committee (for example, for unsatisfactory progress). University policy permits students to retain candidacy until the end of the quarter in which candidacy expires), unless terminated by review meeting with their adviser(s) in Spring Quarter).

Teaching Assistantship
As a program requirement, advanced degree candidates in ESS complete Teaching Assistantship (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 adviser 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. adviser(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 adviser.

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

For a statement of University policy on graduate advising, see the “Graduate Advising and Credentialing” 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 adviser and the advisee. As a best practice, advising expectations should be periodically discussed and reviewed to ensure mutual
understanding. Both the adviser and the advisee are expected to maintain professionalism and integrity.

**Purpose of Advising**

Faculty advisers 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://exploredegrees.stanford.edu/graduatedegrees/#advisingandcredentials)" section of this bulletin.

**Expectations**

- Students are paired with a primary adviser at the time of admission to the Earth System Science graduate program. A secondary adviser 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, adviser, and department. As part of this process, advisers 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 adviser frequently enough that if they are not making sufficient progress, they ideally receive such feedback sooner than at an annual meeting.

- Students can expect advisers 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
  - Admire the students
  - Exercise high professional standards in their academic work, research, and mentoring partnerships

- Be pro-active in seeking advice and keeping the adviser informed about academic and research progress
- Consult with the adviser, 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 adviser 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, Robert Dunbar, Scott Fendorf, Christopher Field, Christopher Francis, Steven Gorelick, Robert Jackson, Eric Lambin, David Lobell, Pamela Matson, Rosamond Naylor

**Associate Professors:** Karen Casciotti, James Holland Jones, Kate Maher, Leif Thomas

**Assistant Professors:** Marshall Burke, Anne Dekas, Alexandra Konings, Morgan O’Neill, Aditi Sheshadri, Paula Welander, Gabrielle Wong-Parodi

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

**Visiting Professors:**

1. Joint appointment with Biology
2. Joint appointment with the Precourt Institute for Energy
3. Joint appointment with the Woods Institute for the Environment
4. Joint appointment with the Freeman Spogli Institute for International Studies