GEOPHYSICS

Courses offered by the Department of Geophysics are listed under the subject code GEOPHYS on the (http://explorecourses.stanford.edu/CourseSearch/search/?view=catalog&catalog=&page=0&q=GEOPHYS&filter-catalognumber-GEOPHYS=on) Stanford Bulletin's (http://explorecourses.stanford.edu/CourseSearch/search/?view=catalog&catalog=&page=0&q=GEOPHYS&filter-catalognumber-GEOPHYS=on) ExploreCourses web site (http://explorecourses.stanford.edu/CourseSearch/search/?view=catalog&catalog=&page=0&q=GEOPHYS&filter-catalognumber-GEOPHYS=on).

Geophysics is the branch of Earth sciences which explores and analyzes active processes of the Earth through physical measurement. The undergraduate and graduate programs are designed to provide a background of fundamentals in science, and courses to coordinate these fundamentals with the principles of geophysics. The program leading to the Bachelor of Science (B.S.) in Geophysics permits many electives and a high degree of flexibility for each student. Graduate programs provide specialized training for professional work in resource exploration, research, and education, and lead to the degrees of Master of Science and Doctor of Philosophy.

The Department of Geophysics is housed in the Ruth Wattis Mitchell Earth Sciences Building. It has numerous research facilities, among which are a state-of-the-art broadband seismic recording station, high pressure and temperature rock properties and rock deformation laboratories, various instruments for field measurements including seismic recorders, nine dual frequency GPS receivers, and field equipment for measuring in-situ stress at great depth. Current research activities include crustal deformation, earthquake seismology and earthquake mechanics, reflection, refraction, and tomographic seismology, rock mechanics, rock physics, seismic studies of the continental lithosphere, remote sensing, environmental geophysics, and synthetic aperture radar studies.

Mission of the Undergraduate Program in Geophysics

The mission of the undergraduate program in Geophysics is to expose students to a broad spectrum of geophysics, including resource exploration, environmental geophysics, seismology, and tectonics. Students in the major obtain a solid foundation in the essentials of mathematics, physics, and geology, and build upon that foundation with advanced course work in geophysics to develop the in-depth knowledge they need to pursue advanced graduate study and professional careers in government or the private sector.

Learning Outcomes (Undergraduate)

The Geophysics Department expects its undergraduate majors to demonstrate certain learning outcomes. These learning outcomes are used to evaluate students' progress, as well as the undergraduate program itself. Students are expected to:

1. demonstrate a fundamental understanding of the physical processes governing the structure and evolution of Earth and planetary systems, including geophysical fluids, environmental hazards, and energy and freshwater resources.
2. demonstrate the ability to quantitatively describe the behavior of natural systems and the principles of geophysical measurements with physics-based mathematical models.
3. demonstrate the ability to make observations using a variety of geophysical instruments and laboratory experiments and to reduce, model, and interpret their data and uncertainties
4. demonstrate the ability to effectively communicate original scientific results as was as evaluate the published and presented results of others.

Graduate Programs in Geophysics

University requirements for the M.S. and Ph.D. are described in the "Graduate Degrees (http://www.stanford.edu/dept/registrar/bulletin/4901.htm)" section of this bulletin.

Learning Outcomes (Graduate)

The objective of the graduate program in Geophysics is to prepare students to be leaders in the geophysics industry, academia, and research organizations through completion of fundamental courses in their major field and related sciences, as well as through independent research. Students are expected to:

1. apply skills developed in fundamental courses to geophysical problems.
2. research, analyze, and synthesize solutions to an original and contemporary geophysics problem.
3. work independently and as part of a team to develop and improve geophysics solutions.
4. apply written, visual, and oral presentation skills to communicate scientific knowledge.
5. master's students are expected to develop an in-depth technical understanding of geophysics problems at an advanced level.
6. doctoral students are expected to complete a scientific investigation that is significant, challenging and original.

Bachelor of Science in Geophysics

Undergraduates in Geophysics are exposed to a broad spectrum of topics in the Earth sciences that describe and predict our planet's evolution. Majors are built on a solid foundation of mathematics and natural sciences with advanced coursework in geophysics to develop the in-depth knowledge needed to pursue advanced graduate study and professional careers in government or the private sector.

A primary focus of the Geophysics major, both as a primary and secondary major, is the senior research project. Students work closely with a faculty mentor to complete an original research paper that can result in published literature. Students selecting Geophysics as a primary major generally pursue specialized skills in areas such as resource exploration, environmental geophysics, seismology, or tectonics. For students pursuing Geophysics as a secondary major, the department encourages a multidisciplinary approach involving the application of broad knowledge to achieve a better understanding of the Earth and its future. Declared majors must maintain a cumulative grade point average (GPA) of at least 2.0.

The following courses are required for the B.S. degree in Geophysics. A written report on original research or an honors thesis is also required through participation in and GEOPHYS 199 Senior Seminar: Issues in Earth Sciences in Autumn Quarter of the senior year.

Geophysics Core Courses

Students must take all of the following:

		Units
GEOPHYS 101	Frontiers of Geophysical Research at Stanford	3
GEOPHYS 110	Introduction to the Foundations of Contemporary Geophysics	3
GEOPHYS 120	Ice, Water, Fire	3

GEOPHYS 162		3
Total Units		12

Geophysics Research

		Units
GEOPHYS 199	Senior Seminar: Issues in Earth Sciences	3
GEOPHYS 196	Undergraduate Research in Geophysics	9
Total Units		12

Supporting Mathematics Courses

		Units
CME 100	Vector Calculus for Engineers	5
or MATH 51	Linear Algebra, Multivariable Calculus, and Modern Applications	
or MATH 52	Integral Calculus of Several Variables	
CME 102	Ordinary Differential Equations for Engineers	5
or MATH 53	Ordinary Differential Equations with Linear Algebra	
CME 104	Linear Algebra and Partial Differential Equations for Engineers	5
or MATH 131P	Partial Differential Equations	
Total Units		15

Supporting Physics Courses

		Units
PHYSICS 41	Mechanics	4
or PHYSICS 61	Mechanics and Special Relativity	
PHYSICS 43	Electricity and Magnetism	4
or PHYSICS 63	Electricity, Magnetism, and Waves	
PHYSICS 45	Light and Heat	4
or PHYSICS 65	Quantum and Thermal Physics	
Total Units		12

Supporting Electives (18 units)

18 units of geophysics-relevant upper-level electives to be approved by the Director of Undergraduate Studies and selected from offerings across the University including, but not limited to courses in mathematics, Earth and other natural sciences, and engineering.

Substitutions allowed with the consent of Director of Undergraduate Studies; classes to be taken for a letter grade if offered, grade 'C' or better.

Honors Program

The department offers a program leading to the B.S. degree in Geophysics with honors. The honors program is open to students with a grade point average (GPA) of at least 3.5 in all courses required for the Geophysics major and minimum of 3.0 in all University course work. The guidelines are:

1. Select a research project, either theoretical, field, or experimental, that has the approval of an adviser.
2. Submit a proposal to the department, which decides on its suitability as an honors project. Qualified students intending to pursue honors are encouraged to apply to the program during Winter quarter of their junior year.
3. Course credit for the project is assigned by the adviser within the framework of GEOPHYS 198 Honors Program.
4. The decision whether a given independent study project does or does not merit an award of honors is made jointly by the department and the student's adviser. This decision is based on the quality of both the honors work and the student's other work in Earth Sciences.
5. The work done on the honors program cannot be used as a substitute for regularly required courses.

Minor in Geophysics

The Geophysics minor provides students with a general knowledge of geophysics. The minor consists of :

- Four courses in Geophysics numbered 100 or higher
- Supporting math: CME 100 Vector Calculus for Engineers (or MATH 51 Linear Algebra, Multivariable Calculus, and Modern Applications)
- Supporting physics: PHYSICS 21 Mechanics, Fluids, and Heat (or PHYSICS 41 or PHYSICS 61), PHYSICS 23 Electricity, Magnetism, and Optics (or PHYSICS 43 or PHYSICS 63), and PHYSICS 25 Modern Physics (or PHYSICS 45 or PHYSICS 65).

Coterminal Master of Science Program in Geophysics

The department offers a coterminal M.S. degree for students wishing to obtain more specialized training in Geophysics than is normally possible during study for the B.S. degree alone. A M.S. degree should be considered as the professional degree in Geophysics and is aimed at students wishing to work in a related industry, or students desiring a more focused academic study in the field than the B.S. program allows.

The coterminal M.S. degree in Geophysics is offered in conjunction with any relevant undergraduate program at Stanford. Geophysics students often enter the department with degrees in Earth Sciences, Mathematics, Physics, Chemistry, or other natural science or engineering fields. Any of these are suitable for the coterminal Geophysics program, and students interested are encouraged to discuss their own background with a Geophysics faculty member.

Admission

To apply for admission to the Geophysics coterminal M.S. program, students must submit the Coterminal Online Application (https://applyweb.com/stanterm/), including submission of a transcript, a statement of purpose, and at least two letters of recommendation. Applications with a letter of recommendation from a Geophysics faculty are generally considered the strongest. Additional letters from other academic or work-related persons also strengthen the application. There are no specific GPA requirements for entry, but the department looks for proven performance in a rigorous undergraduate curriculum as a prerequisite for admission.

Undergraduates with at least junior-level standing may apply, and applications should be submitted by the Autumn Quarter of the senior year.

The graduation requirements to obtain the degree are identical to those for the regular Geophysics master's degree.

University Coterminal Requirements

Coterminal master's degree candidates are expected to complete all master's degree requirements as described in this bulletin. University requirements for the coterminal master's degree are described in the “Coterminal Master's Program (http://exploredegrees.stanford.edu/cotermdegrees/)” section. University requirements for the master's degree are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/#masterstext)" section of this bulletin.

After accepting admission to this coterminal master's degree program, students may request transfer of courses from the undergraduate to the graduate career to satisfy requirements for the master's degree. Transfer of courses to the graduate career requires review and approval of both the undergraduate and graduate programs on a case by case basis.

In this master's program, courses taken during or after the first quarter of the sophomore year are eligible for consideration for transfer to the graduate career; the timing of the first graduate quarter is not a factor. No courses taken prior to the first quarter of the sophomore year may be used to meet master's degree requirements.

Course transfers are not possible after the bachelor's degree has been conferred.

The University requires that the graduate advisor be assigned in the student's first graduate quarter even though the undergraduate career may still be open. The University also requires that the Master's Degree Program Proposal be completed by the student and approved by the department by the end of the student's first graduate quarter.

Master of Science in Geophysics

Objectives

To enhance the student's training for professional work in geophysics through the completion of fundamental courses, both in the major fields and in related sciences, and independent research.

Degree Requirements

The candidate must complete 45 units from the following groups of courses:

1. Complete 15 units of Geophysics lecture courses with at least 9 units numbered 200 or higher.
2. Complete 9 units of non-Geophysics lecture courses in the School of Earth, Energy, and Environmental Sciences, with at least 3 units numbered 200 level or higher.
3. Complete 1-4 electives selected from courses numbered 100 or higher from mathematics, chemistry, engineering, physics, relevant biology, computer science, ecology, hydrology, or within the School of Earth, Energy, and Environmental Sciences. At least one course must be numbered 200 or higher. (GEOPHYS 201 excluded.)
4. Enroll for at least three quarters of research seminar (GEOPHYS 385 series).
5. At least 6, but not more than 15, of the 45 units must be earned by enrollment in GEOPHYS 400 Research in Geophysics for independent work on a research problem resulting in a written report accepted and archived by the candidate's faculty. A summer internship is encouraged as a venue for research, but no academic credit is given.
6. Submit a program proposal for approval by a faculty adviser in the first quarter of enrollment.
7. Each candidate must present and defend the results of his or her research at a public oral presentation attended by at least two faculty members, and turn in a thesis/report to the adviser.
8. Students are required to attend department seminars.
9. Required courses used to fulfill requirements for the M.S. in Geophysics must be lecture courses (component LEC) taken for a letter grade (unless S/NC is the only option offered).

Doctor of Philosophy in Geophysics

Objectives

The Ph.D. degree is conferred upon evidence of high attainment in Geophysics and the ability to conduct an independent investigation and present the results of such research.

Transfer Credit

An incoming student with a relevant master of science degree may apply for a departmental waiver of up to 12 units of the 30 lecture units required for the Ph.D. degree, for certain courses as approved by the departmental graduate faculty adviser. Credit for courses generally requires that students identify an equivalent Stanford course and obtain the signature of the Stanford faculty responsible for that course, stating its equivalence.

Degree Requirements

A minimum of 135 units of graduate study at Stanford must be satisfactorily completed. Required courses used to fulfill requirements for the Ph.D. in Geophysics must be lecture courses (component LEC) taken for a letter grade (unless S/NC is the only option offered). Geophysics courses used to fulfill requirements for the Ph.D. must be taught by Geophysics faculty (or senior academic staff if supervised by a faculty member). Lecture courses on geophysical topics taught by visiting faculty can only be counted as fulfilling a Geophysics requirement if approved in advance by the Department Chair and the Director of Graduate Studies. Students are required to attend the department seminars and to complete sufficient units of independent work on a research problem to meet the 135-unit University requirement. 12 units must be met by participation in the GEOPHYS 385 series, or equivalent series in other departments with the approval of the adviser and graduate coordinator. Students are encouraged to participate in the GEOPHYS 385 series from more than one faculty member or group and relevant equivalent series in other departments.

ENGR 202W Technical Communication, is recommended but not required.

The student's record must indicate outstanding scholarship, and deficiencies in previous training must be removed. Experience as a teaching assistant (quarter-time for at least two academic quarters) is required for the Ph.D. degree. For more information, see the Geophysics Administrative Guide, section 1.4.1.

The student must pass the departmental qualifying examination by the end of the sixth academic quarter; prepare under faculty supervision a dissertation that is a contribution to knowledge and the result of independent work expressed in satisfactory form; and pass the University oral examination.

The Ph.D. dissertation must be submitted in its final form within five calendar years from the date of admission to candidacy. Upon formal acceptance into a research group, the student and faculty adviser form a supervising committee consisting of at least three members who are responsible for overseeing satisfactory progress toward the Ph.D. degree. At least two committee members must be Geophysics faculty members. The committee conducts the department oral examination, and meets thereafter annually with the student to review degree progress. The Geophysics faculty monitors the progress of all students who have not yet passed their department oral examination by carrying out an annual performance appraisal at a closed faculty meeting.

Course requirements

1. *Geophysics:* 12 units, lecture courses numbered 200 and above, from 4 different Geophysics faculty with different research specializations. These units cannot be waived.
2. *Additional Geophysics:* 3 units, lecture courses numbered 120 and above
3. *School of Earth, Energy & Environmental Sciences (non-Geophysics):* 3 units, lecture courses numbered 100 or above
4. *Mathematics (numbered 100 or above), Science, and Engineering (non-School of Earth, Energy & Environmental Sciences):* 6 units, lecture courses numbered 200 or above

5. *Any of the above categories:* 6 units, lecture courses numbered 200 or above
6. *Total required units:* 30 units.

Ph.D. Qualifying Examination Requirement

1. One research proposal (10-20 pages) with a component that outlines a plan of research for 2 -3 years
2. An oral presentation with the student's advising committee on both the research proposal (~30-40 min) with questions by the committee constituting the qualifying exam.
3. The exam can include a (~5 page) second project proposal and second project presentation but is not required. A completed second project or a second project proposal (~5 pages) must be presented at the time of the first annual review following the qualifying exam.
4. The duration of the exam time should not exceed three hours. Consult with your faculty advisor for guidance on the structure of the qualifying exam.

Breadth Requirement

The purpose of the Breadth Requirement is to provide students with opportunities to develop the confidence to carry out research in multiple areas. Students cannot advance to TGR status or receive the Ph.D. degree before completion of the Breadth Requirement.

The Breadth Requirement can be met with either secondary research or secondary coursework:

1. Secondary Research (12 or more graded units)

- The secondary project must stand alone from the primary project as a separate piece of work. The following three scenarios are all acceptable: (1) new problem, new method; (2) new problem, primary project method; (3) primary project problem, new method
- The topic of the secondary project must be in Geophysics or a related discipline within the School of Earth, Energy, and Environmental Sciences (SE3).
- The secondary project must be supervised by a SE3 faculty member (academic council or research faculty), i.e., not the primary adviser or from the primary advisor's research group.
- Completion of the secondary project must result in a publication in a refereed journal, a presentation at a scientific conference or workshop, or a chapter and/or appendix in the PhD. thesis.
- Students must complete the "Geophysics Secondary Project Advising Expectations Agreement" which must be approved by the primary and secondary advisers.
- Exceptions to the above require the approval of the DGS.

2. Secondary Coursework (12 or more graded units)

- Secondary Coursework is a program of graded (or Instructor-mandated S/NC) lecture courses at the 200 level or higher.
- The secondary coursework must be in Geophysics or the School of Earth, Energy, and Environmental Sciences.
- At least 6 units must come from the Department of Geophysics. The remaining courses may be chosen from courses offered by the School of Earth, Energy and Environmental Sciences.
- Secondary coursework cannot be used to meet other degree requirements at Stanford.
- No transfer credit may be used to meet the secondary course requirement.
- Students must complete the "Geophysics Secondary Course Requirement Plan" which must be approved by the primary adviser.
- Exceptions to the above require the approval of the DGS.

Exceptions

Any exceptions to the above rules must be approved and signed by the student's adviser, by all members of the student's academic committee, by the Director of Graduate Studies and Chair.

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://exploredegrees.stanford.edu/covid-19-policy-changes/#tempdepttemplatetabtext)" 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.

Undergraduate Degree Requirements

Grading

Under normal circumstances, all courses credited to the Geophysics degree have been required to be taken for a letter grade. For all courses taken during the 2020-21 academic year, the Geophysics department will accept letter grades or 'CR' (credit) or 'S' (satisfactory) grades in classes offered on a S/NC basis as fulfillment of requirements for the Geophysics undergraduate degree.

Graduate Degree Requirements

Grading

Under normal circumstances, all courses credited to the Geophysics degree have been required to be taken for a letter grade. For all courses taken during the 2020-21 academic year, the Geophysics department will accept letter grades or 'CR' (credit) or 'S' (satisfactory) grades in classes offered on a S/NC basis as fulfillment of requirements for the Ph.D and M.S. degrees.

Graduate Advising Expectations

The Department of Geophysics is committed to providing academic advising in support of graduate student scholarly and professional development. For a statement of University policy on graduate advising, see the "Graduate Advising (http://exploredegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext)" section of this bulletin.

Minimum Advising Expectations for the Department of Geophysics

1. Each adviser meets with each advisee in Autumn or Winter quarter, beginning in the advisee's first year, to develop/update a document entitled "the expectations agreement" that records the agreed upon approach to the following for each individual advisee:

- Courses: the process and responsibility for selecting courses
- Thesis topic: the process and responsibility for selecting the topic
- Members of advising committee: the process and responsibility for selection
- Meetings of adviser and advisee: structure and frequency
- Conducting the research: the level of independence and progress expected, the involvement of the adviser (level of participation, nature

of oversight), involvement of other collaborators (both inside and outside of research group)

- Thesis content, including expectations with respect to publications
- Writing of publications: style of interaction, policy on co-authorship, publication costs
- Conference travel/presentations: who attends/presents, frequency, financial support
- Funding (stipend, tuition, research costs): source, responsibilities, requirements for ongoing support
- In-the-office hours
- Vacations and other absences
- Expectations for Summer Quarter
- Preparing for career interests, plans after Stanford

The document, signed by both the adviser and advisee, is submitted to the Assistant Director of Student Services. If the adviser-advisee discussion would benefit from the involvement of an additional person, either the adviser or advisee can request the presence of a faculty or staff member of the school.

The expectations agreement is reviewed by the Assistant Director of Student Services and the Director of Graduate Studies, with follow-up as needed.

If there is change in adviser, the expectations agreement must be completed with the new adviser within the first quarter after the change.

2. A one-hour annual review, focused on academic progress, is held every year; in the first year this is deferred to Autumn of the second year. This meeting includes the advisee, the adviser, and at least two other faculty. Time is designated in every annual review to review the expectations agreement, circulated in advance to all those in attendance at the review.

At any time, a student with questions or concerns can approach any one of the following individuals in the school:

- Other faculty members of advisory committee
- Assistant Director of Student Services in their home department (Rachael Madison in Geophysics) or program
- Director of Graduate Studies in their home department (Jerry Harris in Geophysics) or another department
- Associate Chair for Diversity and Inclusion (Sonia Tikoo in Geophysics)
- Department Chair (Biondo Biondi in Geophysics)
- Alyssa Ferree, Assistant Dean of Student Services
- Robyn Dunbar, Associate Dean for Educational Affairs
- Sue Crutcher, Associate Dean for Human Resources and Faculty Affairs

Chair: Biondo Biondi

Associate Chair: Howard Zebker

Director of Graduate Studies: Jerry Harris

Director of Undergraduate Studies: Dustin Schroeder

Professors: Greg Beroza, Biondo Biondi, Simon Klemperer, Rosemary J. Knight, Paul Segall, Norman H. Sleep, Howard Zebker*

Associate Professor: Eric Dunham, Tiziana Vanorio

Assistant Professors: Lucia Gualtieri, Jenny Suckale, Dustin Schroeder, Sonia Tikoo-Schantz

Professor (Research): William Ellsworth

Emeriti: Jon Claerbout, Robert Kovach, Gerald M. Mavko, Amos Nur, Jerry Harris, Mark D. Zoback

Courtesy Professors: Stephan A. Graham, Tapan Mukerji, Alexandra Konings, Mathieu Lapotre, Ayla Pamukcu, Laura Schaefer

* Joint appointment with Electrical Engineering

Courses

GEOPHYS 20N. Predicting Volcanic Eruptions. 3 Units.
The physics and chemistry of volcanic processes and modern methods of volcano monitoring. Volcanoes as manifestations of the Earth's internal energy and hazards to society. How earth scientists better forecast eruptive activity by monitoring seismic activity, bulging of the ground surface, and the discharge of volcanic gases, and by studying deposits from past eruptions. Focus is on the interface between scientists and policy makers and the challenges of decision making with incomplete information. Field trip to Mt. St. Helens, site of the 1980 eruption.

GEOPHYS 30N. Science Fiction Worlds. 3 Units.
Science fiction writers, with limited knowledge of what technologies or discoveries about space might exist in the future, must build entire worlds in their minds and craft underlying physical laws about how these fantastical places might operate and the types of environments that they could sustain. In this course, we will use popular works of science fiction from film, television, and literature as conversation starters to discuss real discoveries that have been made about how planets form and evolve over time. The class will focus on the following overarching questions: (1) What conditions are required for habitable planets to form? (2) What types of planets may actually exist, including desert worlds, lava planets, ice planets, and ocean worlds? (3) What kids of life could inhabit such diverse worlds? (3) What types of catastrophic events such as supernovas, asteroid impacts, climate changes can nurture or destroy planetary habitability?.
Same as: GEOLSCI 30N

GEOPHYS 50N. Planetary Habitability, World View, and Sustainability. 3 Units.
Sustainability lessons from the geological past Life on Earth has partially perished in sudden mass extinctions several time over the Earth's history. Threats include actions of our own volition, including fossil fuel burning as well as natural events, including the impact of large asteroids. The end Permian 250 million years ago and end Paleocene 55 million years ago extinctions involved natural burning of fossil fuels. The 65 million year ago end Cretaceous extinction involved the impact of and asteroid and possibly fossil fuel burning. Related sustainability topics in the popular press will be discussed as they arise. Student pairs lead discussions on topics on how humanity might avert these catastrophes. Offered occasionally.

GEOPHYS 54N. The Space Mission to Europa. 3 Units.
Jupiter's icy moon Europa is a leading candidate in the search for life in our solar system outside of Earth. NASA's upcoming Europa Clipper mission would investigate the habitability of the moon using a suite of nine geophysical instruments. In this course, we will use the mission as a central text around which to explore the intersection of science, engineering, management, economics, culture, and politics involved in any modern big science enterprise.

GEOPHYS 60N. Man versus Nature: Coping with Disasters Using Space Technology. 4 Units.
Preference to freshman. Natural hazards, earthquakes, volcanoes, floods, hurricanes, and fires, and how they affect people and society; great disasters such as asteroid impacts that periodically obliterate many species of life. Scientific issues, political and social consequences, costs of disaster mitigation, and how scientific knowledge affects policy. How spaceborne imaging technology makes it possible to respond quickly and mitigate consequences; how it is applied to natural disasters; and remote sensing data manipulation and analysis. GER:DB-EngrAppSci.
Same as: EE 60N

GEOPHYS 90. Earthquakes and Volcanoes. 3 Units.
Is the "Big One" overdue in California? What kind of damage would that cause? What can we do to reduce the impact of such hazards in urban environments? Does "fracking" cause earthquakes and are we at risk? Is the United States vulnerable to a giant tsunami? The geologic record contains evidence of volcanic super eruptions throughout Earth's history. What causes these gigantic explosive eruptions, and can they be predicted in the future? This course will address these and related issues. For non-majors and potential Earth scientists. No prerequisites. More information at: https://stanford.box.com/s/zr8ar28efmuo5wtlj6gj2jbxle76r4lu.
Same as: EARTHSYS 113

GEOPHYS 100. Directed Reading. 1-2 Unit.
(Staff).

GEOPHYS 101. Frontiers of Geophysical Research at Stanford. 1-3 Unit.
Required for new students entering the department and undergraduate majors. Department faculty introduce the frontiers of research problems and methods being employed or developed in the department and unique to department faculty and students: what the current research is, why the research is important, what methodologies and technologies are being used, and what the potential impact of the results might be. Graduate students register for 1 unit (Mondays only), undergraduates for 3 units which include a discussion section (Mondays and Wednesdays). Offered every year, autumn quarter.
Same as: GEOPHYS 201

GEOPHYS 104. The Water Course. 4 Units.
The Central Valley of California provides a third of the produce grown in the U.S., but recent droughts and increasing demand have raised concerns about both food and water security. The pathway that water takes from rainfall to the irrigation of fields or household taps (¿the water course¿) determines the quantity and quality of the available water. Working with various data sources (measurements made on the ground, in wells, and from satellites) allows us to model the water budget in the valley and explore the recent impacts on freshwater supplies.
Same as: EARTHSYS 104, EARTHSYS 204, GEOPHYS 204

GEOPHYS 106. Sustainable and Equitable Water Management. 3-4 Units.
California has committed itself to sustainable groundwater management, with passage of the Sustainable Groundwater Management Act in 2014, and safe drinking water access for all, with California's Human Right to Water Act in 2012. Yet, groundwater overdraft continues while over 1 million residents lack access to safe drinking water. Working with a water agency in the San Joaquin Valley, we will explore feedback loops between the two Acts and develop a plan for water management that meet the co-equal objectives of sustainable and equitable resource governance. We will work with "big" and "small" data, exploring the possibilities but also the limitations of using publicly available data for assessment and monitoring. The course will include guest speakers and interaction with public agencies and other key stakeholders.nThis is a Cardinal Course certified by the Haas Center.
Same as: EARTHSYS 106B, EARTHSYS 206B, GEOPHYS 206

GEOPHYS 108. Tectonics Field Trip. 1-3 Unit.
What does an earthquake fault look like near Earth's surface? How about the inside of, or beneath, a volcano? Why does California experience earthquakes and volcanic eruptions? Learn about thermo-physico-chemical evolution (mass transport, heat transport) in Earth's crust through a required long-weekend field trip (in 2019: evening Thurs 5/30 evening Mon 6/3, beginning of Dead Week) to eastern California and Sierra Nevada. May be repeated for credit (future destinations likely include San Andreas fault, Mendocino Triple Junction, Crater Lake, Lava Tubes, and western Basin and Range province. Lectures (typically one per week) provide context for planned trip.

GEOPHYS 109. Formation and Dynamics of Planets. 3-4 Units.
This course will cover formation of planets within a protoplanetary disk, dynamical evolution of planetary systems (Grand Tack and Nice models, planet migration), condensation chemistry within the solar nebula and meteorite classification, classical accretion models and pebble accretion, melting, magma ocean formation and core formation on rocky objects. Topics will be discussed in the context of both the Solar system and extrasolar planet observations.
Same as: GEOLSCI 119, GEOLSCI 219, GEOPHYS 209

GEOPHYS 110. Introduction to the Foundations of Contemporary Geophysics. 3 Units.
Introduction to the foundations of contemporary geophysics. Topics drawn from broad themes in: whole Earth geodynamics, geohazards, natural resources, and environment. In each case the focus is on how the interpretation of a variety of geophysical measurements (e.g., gravity, seismology, heat flow, electromagnetics, and remote sensing) can be used to provide fundamental insight into the behavior of the Earth. The course will include a weekend field trip. Prerequisite: CME 100 or MATH 51, or co-registration in either.
Same as: EARTHSYS 110

GEOPHYS 112. Exploring Geosciences with MATLAB. 1-3 Unit.
How to use MATLAB as a tool for research and technical computing, including 2-D and 3-D visualization features, numerical capabilities, and toolboxes. Practical skills in areas such as data analysis, regressions, optimization, spectral analysis, differential equations, image analysis, computational statistics, and Monte Carlo simulations. Emphasis is on scientific and engineering applications. Offered every year, autumn quarter.
Same as: ENERGY 112

GEOPHYS 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 118X, ESS 218X, GEOLSCI 118X, GEOLSCI 218X, GEOPHYS 218X, POLISCI 218X, PUBLPOL 118X, PUBLPOL 218X

GEOPHYS 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 118Y, ESS 218Y, GEOLSCI 118Y, GEOLSCI 218Y, GEOPHYS 218Y, POLISCI 218Y, PUBLPOL 118Y, PUBLPOL 218Y

GEOPHYS 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 118Z, ESS 218Z, GEOLSCI 118Z, GEOLSCI 218Z, GEOPHYS 218Z, POLISCI 218Z

GEOPHYS 119. Planetary Surface Processes: Shaping the Landscape of the Solar System. 4 Units.
The surfaces of planets, moons, and other bodies are shaped and modified by a wide array of physical and chemical processes. Understanding these processes allows us to decipher the history of the Solar System. This course offers a quantitative examination of both exogenous processes - such as impact cratering and space weathering - and endogenous processes - such as tectonics, weathering, and volcanic, fluvial, eolian, and periglacial activity - as well as a brief introduction to the fundamentals of remote sensing in the context of planetary exploration. As we develop a basic mechanistic framework for these processes, we will apply our acquired knowledge through thematic discussions of the surfaces of Mercury, Venus, Earth, the Moon, Mars, asteroids, Io, Titan, Europa, Enceladus, Pluto, and comets. For upper-division undergraduates and graduate students.
Same as: GEOLSCI 120, GEOLSCI 220, GEOPHYS 219

GEOPHYS 120. Ice, Water, Fire. 3-5 Units.
Introductory application of continuum mechanics to ice sheets and glaciers, water waves and tsunamis, and volcanoes. Emphasis on physical processes and mathematical description using balance of mass and momentum, combined with constitutive equations for fluids and solids. Designed for undergraduates with no prior geophysics background; also appropriate for beginning graduate students. Prerequisites: CME 100 or MATH 52 and PHYSICS 41 (or equivalent).
Same as: GEOPHYS 220

GEOPHYS 122. Planetary Systems: Dynamics and Origins. 2-4 Units.
(Students with a strong background in mathematics and the physical sciences should register for 222.) Motions of planets and smaller bodies, energy transport in planetary systems, composition, structure and dynamics of planetary atmospheres, cratering on planetary surfaces, properties of meteorites, asteroids and comets, extrasolar planets, and planetary formation. Prerequisite: some background in the physical sciences, especially astronomy, geophysics, or physics. Students need instructor approval to take the course for 2 or 4 units.
Same as: GEOLSCI 122, GEOLSCI 222

GEOPHYS 124. 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: ESS 125, GEOLSCI 124

GEOPHYS 126. PLANETARY SCIENCE READING. 1 Unit.
The course will meet once a week to discuss a recent journal article related to the broad field of planetary science, including but not limited to cosmochemistry, planet formation, planetary geology, planetary atmospheres, Earth history, astrobiology, and exoplanets. Students will be expected to lead the group discussion at least once per quarter. No formal presentations will be required. There are no prerequisites for this course, but students should have some facility with reading scientific literature.
Same as: GEOLSCI 127, GEOLSCI 227, GEOPHYS 226

GEOPHYS 128. MODELING EARTH. 3-4 Units.
Most problems in Earth Science are dazzling and beautifully complex. Abstracting from this natural complexity to identify the essential components and mechanisms of a natural system is perhaps the most important, but commonly overlooked, task for developing testable mathematical models for Earth and Environmental Science. This course focuses on conceptual model development, rather than addressing the variety of formal mathematical techniques available for the analytical analysis or numerical simulation of a model. Recommended Prerequisites: CME 100 or MATH 51 (or equivalent).
Same as: GEOPHYS 228

GEOPHYS 130. Introductory Seismology. 3 Units.
Introduction to seismology including: elasticity and the wave equation, P, S, and surface waves, dispersion, ray theory, reflection and transmission of seismic waves, seismic imaging, large-scale Earth structure, earthquake location, earthquake statistics and forecasting, magnitude scales, seismic source theory.

GEOPHYS 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 141, ESS 241

GEOPHYS 150. Geodynamics: Our Dynamic Earth. 3-5 Units.
What processes determine the large-scale structure and motion of Earth? How does convection deep within Earth drive plate tectonics and the formation of ocean basins and mountain ranges? Drawing from fundamental principles of mechanics and thermodynamics, we develop mathematical theories for heat flow, mantle convection, and the bending and breaking of Earth's brittle crust. Scaling arguments and dimensional analysis provide intuition that is refined through analytical and numerical solution (in MATLAB) of the governing equations and validated through comparison with observations. Prerequisites: differential equations (CME 104 or MATH 53); mechanics and thermodynamics (PHYSICS 41 and 45); prior programming experience (CME 192 or CS 106A) is recommended.
Same as: GEOPHYS 250

GEOPHYS 165. Ice Penetrating Radar. 1-3 Unit.
The purpose of this course is to provide an introduction to the physics, systems, processing, and analysis of ice penetrating radar, preparing students to use it as a quantitative research tool. Target students are graduates or advanced undergraduates in geophysics, glaciology, planetary science, or engineering with an interest in the use of radar to study glaciers, ice sheets, or icy planets.nPrerequisite: EE 142 or EE 242 or PHYS 43 or instructor consent.
Same as: GEOPHYS 230

GEOPHYS 181. Fluids and Flow in the Earth: Computational Methods. 3 Units.
Interdisciplinary problems involving the state and movement of fluids in crustal systems, and computational methods to model these processes. Examples of processes include: nonlinear, time-dependent flow in porous rocks; coupling in porous rocks between fluid flow, stress, deformation, and heat and chemical transport; percolation of partial melt; diagenetic processes; pressure solution and the formation of stylolites; and transient pore pressure in fault zones. MATLAB, Lattice-Boltzmann, and COMSOL Multiphysics. Term project. No experience with COMSOL Multiphysics required. Offered every other year, winter quarter.
Same as: GEOPHYS 203

GEOPHYS 182. Reflection Seismology. 3 Units.
The principles of seismic reflection profiling, focusing on methods of seismic data acquisition and seismic data processing for hydrocarbon exploration.
Same as: GEOPHYS 222

GEOPHYS 183. Reflection Seismology Interpretation. 1-4 Unit.
The structural and stratigraphic interpretation of seismic reflection data, emphasizing hydrocarbon traps in two and three dimensions on industry data, including workstation-based interpretation. Lectures only, 1 unit. Prerequisite: 222, or consent of instructor. (Geophys 183 must be taken for a minimum of 3 units to be eligible for Ways credit).
Same as: GEOLSCI 223, GEOPHYS 223

GEOPHYS 184. Journey to the Center of the Earth. 3 Units.
The interconnected set of dynamic systems that make up the Earth. Focus is on fundamental geophysical observations of the Earth and the laboratory experiments to understand and interpret them. What earthquakes, volcanoes, gravity, magnetic fields, and rocks reveal about the Earth's formation and evolution.
Same as: GEOLSCI 107, GEOLSCI 207, GEOPHYS 274

GEOPHYS 185. Rock Physics for Reservoir Characterization. 3 Units.
How to integrate well log and laboratory data to determine and theoretically generalize rock physics transforms between sediment wave properties (acoustic and elastic impendence), bulk properties (porosity, lithology, texture, permeability), and pore fluid conditions (pore fluid and pore pressure). These transforms are used in seismic interpretation for reservoir properties, and seismic forward modeling in what-if scenarios.
Same as: GEOPHYS 260

GEOPHYS 186. Tectonophysics. 3 Units.
The physics of faulting and plate tectonics. Topics: plate driving forces, lithospheric rheology, crustal faulting, and the state of stress in the lithosphere. Exercises: lithospheric temperature and strength profiles, calculation of seismic strain from summation of earthquake moment tensors, slip on faults in 3D, and stress triggering and inversion of stress from earthquake focal mechanisms. Offered every other year, winter quarter.
Same as: GEOPHYS 290

GEOPHYS 188. Basic Earth Imaging. 2-3 Units.
Echo seismogram recording geometry, head waves, moveout, velocity estimation, making images of complex shaped reflectors, migration by Fourier and integral methods. Anti-aliasing. Dip moveout. Computer labs. See http://sep.stanford.edu/sep/prof/. Offered every year, autumn quarter. *The Geophys180 cross-listing is considered an advanced undergraduate course.
Same as: GEOPHYS 210

GEOPHYS 190. Near-Surface Geophysics: Imaging Groundwater Systems. 3 Units.
Groundwater systems in important agricultural areas of the U.S. The effects of climate change on water availability and crop production. Introduction to methodologies for describing and modeling the integrated surface and groundwater system. The use of geophysical methods to support sustainable groundwater management: airborne method for regional-scale imaging, ground-based and borehole methods for site-specific assessment. Each week includes two hours of class time, some of which will involve computer modeling/analysis of data. Pre-requisite: CME 100 or Math 51, or co-registration in either.
Same as: GEOPHYS 275

GEOPHYS 191. Observing Freshwater. 3 Units.
We will study estimates of the components of the land hydrological cycle using in-situ and satellite observations and model output. Hydrological variables are rainfall, snow, water vapor, soil moisture, stream discharge and groundwater; other variables are vegetation, surface temperature, soil types, land use and surface topography. We focus on observations and their role in the water balance of the land surface. In-class lab experience working with data. Group/individual term project & paper & presentation; no final. Pre-requisite: basic familiarity with MATLAB.

GEOPHYS 196. Undergraduate Research in Geophysics. 1-10 Unit.
Field-, lab-, or computer-based. Faculty supervision. Written reports.

GEOPHYS 197. Senior Thesis in Geophysics. 3-5 Units.
For seniors writing a thesis based on Geophysics research in 196 or as a summer research fellow. Seniors defend the results of their research at a public oral presentation.

GEOPHYS 198. Honors Program. 1-3 Unit.
Experimental, observational, or theoretical honors project and thesis in geophysics under supervision of a faculty member. Students who elect to do an honors thesis should begin planning it no later than Winter Quarter of the junior year. Prerequisites: department approval. Seniors defend the results of their research at a public oral presentation.

GEOPHYS 199. Senior Seminar: Issues in Earth Sciences. 3 Units.
Focus is on written and oral communication in a topical context. Topics from current frontiers in earth science research and issues of concern to the public. Readings, oral presentations, written work, and peer review.
Same as: GEOLSCI 150

GEOPHYS 201. Frontiers of Geophysical Research at Stanford. 1-3 Unit.
Required for new students entering the department and undergraduate majors. Department faculty introduce the frontiers of research problems and methods being employed or developed in the department and unique to department faculty and students: what the current research is, why the research is important, what methodologies and technologies are being used, and what the potential impact of the results might be. Graduate students register for 1 unit (Mondays only), undergraduates for 3 units which include a discussion section (Mondays and Wednesdays). Offered every year, autumn quarter.
Same as: GEOPHYS 101

GEOPHYS 202. Reservoir Geomechanics. 3 Units.
Basic principles of rock mechanics and the state of stress and pore pressure in sedimentary basins related to exploitation of hydrocarbon and geothermal reservoirs. Mechanisms of hydrocarbon migration, exploitation of fractured reservoirs, reservoir compaction and subsidence, hydraulic fracturing, utilization of directional and horizontal drilling to optimize well stability.Given alternate years.

GEOPHYS 203. Fluids and Flow in the Earth: Computational Methods. 3 Units.
Interdisciplinary problems involving the state and movement of fluids in crustal systems, and computational methods to model these processes. Examples of processes include: nonlinear, time-dependent flow in porous rocks; coupling in porous rocks between fluid flow, stress, deformation, and heat and chemical transport; percolation of partial melt; diagenetic processes; pressure solution and the formation of stylolites; and transient pore pressure in fault zones. MATLAB, Lattice-Boltzmann, and COMSOL Multiphysics. Term project. No experience with COMSOL Multiphysics required. Offered every other year, winter quarter.
Same as: GEOPHYS 181

GEOPHYS 204. The Water Course. 4 Units.
The Central Valley of California provides a third of the produce grown in the U.S., but recent droughts and increasing demand have raised concerns about both food and water security. The pathway that water takes from rainfall to the irrigation of fields or household taps (¿the water course¿) determines the quantity and quality of the available water. Working with various data sources (measurements made on the ground, in wells, and from satellites) allows us to model the water budget in the valley and explore the recent impacts on freshwater supplies.
Same as: EARTHSYS 104, EARTHSYS 204, GEOPHYS 104

GEOPHYS 205. 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: ESS 204, GEOLSCI 306

GEOPHYS 206. Sustainable and Equitable Water Management. 3-4 Units.
California has committed itself to sustainable groundwater management, with passage of the Sustainable Groundwater Management Act in 2014, and safe drinking water access for all, with California's Human Right to Water Act in 2012. Yet, groundwater overdraft continues while over 1 million residents lack access to safe drinking water. Working with a water agency in the San Joaquin Valley, we will explore feedback loops between the two Acts and develop a plan for water management that meet the co-equal objectives of sustainable and equitable resource governance. We will work with "big" and "small" data, exploring the possibilities but also the limitations of using publicly available data for assessment and monitoring. The course will include guest speakers and interaction with public agencies and other key stakeholders.nThis is a Cardinal Course certified by the Haas Center.
Same as: EARTHSYS 106B, EARTHSYS 206B, GEOPHYS 106

GEOPHYS 208. Unconventional Reservoir Geomechanics. 3 Units.
This course will investigate oil and gas production from extremely low permeability reservoirs. Lectures and exercises will address 1) the physical and fluid transport properties of unconventional reservoir formations, 2) stimulation techniques such as hydraulic fracturing and 3) understanding microseismicity associated with hydraulic stimulation and induced seismicity associated with wastewater injection. Prerequisite: GEOPHYS 202 or concurrent enrollment in GEOPHYS 202 is strongly recommended.

GEOPHYS 209. Formation and Dynamics of Planets. 3-4 Units.
This course will cover formation of planets within a protoplanetary disk, dynamical evolution of planetary systems (Grand Tack and Nice models, planet migration), condensation chemistry within the solar nebula and meteorite classification, classical accretion models and pebble accretion, melting, magma ocean formation and core formation on rocky objects. Topics will be discussed in the context of both the Solar system and extrasolar planet observations.
Same as: GEOLSCI 119, GEOLSCI 219, GEOPHYS 109

GEOPHYS 210. Basic Earth Imaging. 2-3 Units.
Echo seismogram recording geometry, head waves, moveout, velocity estimation, making images of complex shaped reflectors, migration by Fourier and integral methods. Anti-aliasing. Dip moveout. Computer labs. See http://sep.stanford.edu/sep/prof/. Offered every year, autumn quarter. *The Geophys180 cross-listing is considered an advanced undergraduate course.
Same as: GEOPHYS 188

GEOPHYS 211. Environmental Soundings Image Estimation. 3 Units.
Imaging principles exemplified by means of imaging geophysical data of various uncomplicated types (bathymetry, altimetry, velocity, reflectivity). Adjoints, back projection, conjugate-gradient inversion, preconditioning, multidimensional autoregression and spectral factorization, the helical coordinate, and object-based programming. Common recurring issues such as limited aperture, missing data, signal/noise segregation, and nonstationary spectra. See http://sep.stanford.edu/sep/prof/.

GEOPHYS 212. Topics in Climate Change. 2 Units.
This introductory classroom course presents Earth's climate system and explores the science and politics of global climate change. Students will learn how the climate system works, the factors that cause climate to change across different time scales, the use of models and observations to make predictions about future climate. The course will discuss possible consequences of climate change in the Earth, and it will explore the evidence for changes due to global warming. There are no prerequisites.

GEOPHYS 213. Quantitative Analysis of Geopressure for Geoscientists and Engineers. 2 Units.
In these lectures we will have a dialogue that addresses how to predict, detect and quantify subsurface fluid pressure regimes (geopressure) with more emphasis on fundamental than empiricism that is so common in this field. Rock physics and basin history modeling are important tools to develop an earth model. So is the seismic. Rock physics guided velocity and amplitude modeling tools such as velocity analysis, reflection tomography and inversion as well as basin modeling would be used to establish a common velocity model that not only yields reasonably correct description of geopressure but also an improved subsurface velocity model that yields better seismic image at correct depths.

GEOPHYS 214. Water Management in Agricultural Areas. 2 Units.
The course will introduce the new generation of methods used for investigating groundwater systems. The primary focus would be on methods for estimating the components of the aquifer water balance, which are critical elements needed for reliable projections of future conditions. The structure of the course will be lectures followed by student presentations based on follow-up readings and working with the extensive dataset from the High Plains aquifer in Kansas. The course will draw heavily on the short courses and workshops Dr. Butler has presented to practicing professionals and students over the last 15 years.

GEOPHYS 216. Chemical Kinetics and Basin Modeling. 2-3 Units.
Students will explore the structure of sedimentary organic matter and the chemical and thermodynamic requirements for generating petroleum. A wide variety of thermal maturity indicators will be explored, paying particular attention to optical indicators and predictive kinetics of Tmax and %Ro. Students will understand the advantages and pitfalls of kinetic measurements in the lab. Hands-on exercises reinforce learning targets. An optional class project allows students to take the class for 3 units instead of 2. Course readings come from the literature and Burnham's textbook.
Same as: ENERGY 282, GEOLSCI 216

GEOPHYS 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, ESS 218X, GEOLSCI 118X, GEOLSCI 218X, GEOPHYS 118X, POLISCI 218X, PUBLPOL 118X, PUBLPOL 218X

GEOPHYS 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, ESS 218Y, GEOLSCI 118Y, GEOLSCI 218Y, GEOPHYS 118Y, POLISCI 218Y, PUBLPOL 118Y, PUBLPOL 218Y

GEOPHYS 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, ESS 218Z, GEOLSCI 118Z, GEOLSCI 218Z, GEOPHYS 118Z, POLISCI 218Z

GEOPHYS 219. Planetary Surface Processes: Shaping the Landscape of the Solar System. 4 Units.
The surfaces of planets, moons, and other bodies are shaped and modified by a wide array of physical and chemical processes. Understanding these processes allows us to decipher the history of the Solar System. This course offers a quantitative examination of both exogenous processes - such as impact cratering and space weathering - and endogenous processes - such as tectonics, weathering, and volcanic, fluvial, eolian, and periglacial activity - as well as a brief introduction to the fundamentals of remote sensing in the context of planetary exploration. As we develop a basic mechanistic framework for these processes, we will apply our acquired knowledge through thematic discussions of the surfaces of Mercury, Venus, Earth, the Moon, Mars, asteroids, Io, Titan, Europa, Enceladus, Pluto, and comets. For upper-division undergraduates and graduate students.
Same as: GEOLSCI 120, GEOLSCI 220, GEOPHYS 119

GEOPHYS 220. Ice, Water, Fire. 3-5 Units.
Introductory application of continuum mechanics to ice sheets and glaciers, water waves and tsunamis, and volcanoes. Emphasis on physical processes and mathematical description using balance of mass and momentum, combined with constitutive equations for fluids and solids. Designed for undergraduates with no prior geophysics background; also appropriate for beginning graduate students. Prerequisites: CME 100 or MATH 52 and PHYSICS 41 (or equivalent).
Same as: GEOPHYS 120

GEOPHYS 221. 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: ESS 225, GEOLSCI 224

GEOPHYS 222. Reflection Seismology. 3 Units.
The principles of seismic reflection profiling, focusing on methods of seismic data acquisition and seismic data processing for hydrocarbon exploration.
Same as: GEOPHYS 182

GEOPHYS 223. Reflection Seismology Interpretation. 1-4 Unit.
The structural and stratigraphic interpretation of seismic reflection data, emphasizing hydrocarbon traps in two and three dimensions on industry data, including workstation-based interpretation. Lectures only, 1 unit. Prerequisite: 222, or consent of instructor. (Geophys 183 must be taken for a minimum of 3 units to be eligible for Ways credit).
Same as: GEOLSCI 223, GEOPHYS 183

GEOPHYS 224. Seismic Reflection Processing. 2-3 Units.
Workshop in computer processing of 2D and 3D seismic reflection data. Students individually process a seismic reflection profile (of their own choice or instructor-provided) from field recordings to migrated sections and subsurface images, using interactive software (OpenCPS from OpenGeophysical.com). Prerequisite: GEOPHYS 222 or consent of instructor.

GEOPHYS 225. Multiphase Instabilities and Extreme Events. 4 Units.
How fast can ice sheets disintegrate? Why do volcanoes erupt? Which processes govern thenoccurrence of landslides? And can we reduce the destructive reach of tsunamis and storm surges?nThe common denominator of what at first glance might seem like disparate systems isnmultiphase flow. The dynamic interactions between multiple solid and fluid phases, such as icenand melt-water; lava and gas; vegetation and waves, give rise to drastic nonlinearities that governnabrupt change. This class explores the role of multiphase instabilities in the onset and evolutionnof extreme events. We will explore the different types of instabilities that arise in differentnmultiphase aggregates and why they might be critical for understanding the nonlinear behaviornof natural systems.

GEOPHYS 226. PLANETARY SCIENCE READING. 1 Unit.
The course will meet once a week to discuss a recent journal article related to the broad field of planetary science, including but not limited to cosmochemistry, planet formation, planetary geology, planetary atmospheres, Earth history, astrobiology, and exoplanets. Students will be expected to lead the group discussion at least once per quarter. No formal presentations will be required. There are no prerequisites for this course, but students should have some facility with reading scientific literature.
Same as: GEOLSCI 127, GEOLSCI 227, GEOPHYS 126

GEOPHYS 227. Global Seismology. 3 Units.
Fundamentals of global-scale seismic wave propagation, including a review of the basic structure of the Earth; body waves in terms of ray-theory representation; surface waves as traveling waves and normal modes; free-oscillations of the Earth and ray-mode duality; normal mode summation, the spectral element method and synthetic seismograms; adjoint methods; seismic sources within the Earth and at the surface of the Earth (e.g. in the ocean). Recommended prerequisite: GEOPHYS 130.

GEOPHYS 228. MODELING EARTH. 3-4 Units.
Most problems in Earth Science are dazzling and beautifully complex. Abstracting from this natural complexity to identify the essential components and mechanisms of a natural system is perhaps the most important, but commonly overlooked, task for developing testable mathematical models for Earth and Environmental Science. This course focuses on conceptual model development, rather than addressing the variety of formal mathematical techniques available for the analytical analysis or numerical simulation of a model. Recommended Prerequisites: CME 100 or MATH 51 (or equivalent).
Same as: GEOPHYS 128

GEOPHYS 229. Earthquake Rupture Dynamics. 3 Units.
Physics of earthquakes, including nucleation, propagation, and arrest; slip-weakening and rate-and-state friction laws; thermal pressurization and dynamic weakening mechanisms; off-fault plasticity; dynamic fracture mechanics; earthquake energy balance. Problem sets involve numerical simulations on CEES cluster. Prerequisites: GEOPHYS 287. Offered occasionally.

GEOPHYS 230. Ice Penetrating Radar. 1-3 Unit.
The purpose of this course is to provide an introduction to the physics, systems, processing, and analysis of ice penetrating radar, preparing students to use it as a quantitative research tool. Target students are graduates or advanced undergraduates in geophysics, glaciology, planetary science, or engineering with an interest in the use of radar to study glaciers, ice sheets, or icy planets.nPrerequisite: EE 142 or EE 242 or PHYS 43 or instructor consent.
Same as: GEOPHYS 165

GEOPHYS 235. Waves and Fields in Geophysics. 3 Units.
Basic topics and approaches (theory and numerical simulations) on acoustic, electromagnetic, and elastic waves and fields for geophysical applications: dispersion, phase and group velocities, attenuation, reflection and transmission at planar interfaces, high frequency and low frequency approximations, heterogeneous media. Prerequisites: UG level class on waves or consent of instructor.

GEOPHYS 237. Evolution of Terrestrial Planets. 3 Units.
Despite forming in the inner solar system from broadly similar starting materials, Mercury, Venus, Earth, Mars, and the Moon each represent a unique outcome of the planetary formation process. Processes occurring deep inside planets drive the evolution of planetary crusts and atmospheres, which both control planetary habitability. This course explores how geophysical approaches such as gravity, topography, seismology, heat flow, and magnetism provide insight into the thermal and chemical histories of each rocky world. We cover how planetary scientists study ancient processes such as core formation, impact cratering, magnetic field generation, mantle convection, and tectonics by a combination of spacecraft measurements, modeling, and laboratory analyses of extraterrestrial materials. Recommended prerequisites: PHYSICS 41, 43, and MATH 51 or CME 100, or instructor consent.

GEOPHYS 238. Waves in Solids and Fluids. 3 Units.
Wave propagation and sources in elastic solids and compressible fluids; body, surface, and interface waves in homogeneous and plane layered media; dispersion, phase and group velocities; reflection and transmission; near-field, far-field, and static limits; effects of gravity, surface and internal gravity waves; Fourier methods and solutions in the time and frequency domains; Green's functions; reciprocity; adjoint methods and full-waveform inversion; point and line sources, finite sources, moving sources and directivity effects; multipole expansions; source representation in solids using transformation strain; application to earthquakes, volcanoes, and tsunamis. Prerequisites: Graduate-level background in continuum mechanics.
Same as: ME 347

GEOPHYS 240. Borehole Seismic Modeling and Imaging. 3 Units.
Borehole seismic imaging for applications to subsurface reservoir characterization and monitoring. Topics include data acquisition, data processing, imaging and inversion. Analysis and processing of synthetic and field datasets. Prerequisites: Waves class equivalent to GP 230, Matlab or other computer programming.

GEOPHYS 241A. Seismic Reservoir Characterization. 3-4 Units.
(Same as GP241) Practical methods for quantitative characterization and uncertainty assessment of subsurface reservoir models integrating well-log and seismic data. Multidisciplinary combination of rock-physics, seismic attributes, sedimentological information and spatial statistical modeling techniques. Student teams build reservoir models using limited well data and seismic attributes typically available in practice, comparing alternative approaches. Software provided (SGEMS, Petrel, Matlab). Offered every other year.nRecommended: ERE240/260, or GP222/223, or GP260/262 or GES253/257; ERE246, GP112.
Same as: ENERGY 141, ENERGY 241

GEOPHYS 250. Geodynamics: Our Dynamic Earth. 3-5 Units.
What processes determine the large-scale structure and motion of Earth? How does convection deep within Earth drive plate tectonics and the formation of ocean basins and mountain ranges? Drawing from fundamental principles of mechanics and thermodynamics, we develop mathematical theories for heat flow, mantle convection, and the bending and breaking of Earth's brittle crust. Scaling arguments and dimensional analysis provide intuition that is refined through analytical and numerical solution (in MATLAB) of the governing equations and validated through comparison with observations. Prerequisites: differential equations (CME 104 or MATH 53); mechanics and thermodynamics (PHYSICS 41 and 45); prior programming experience (CME 192 or CS 106A) is recommended.
Same as: GEOPHYS 150

GEOPHYS 254. Sedimentology and Rock Physics of Carbonates. 3-4 Units.
Processes of precipitation and sedimentation of carbonate minerals as well as their post-depositional alteration with emphasis on marine systems. Topics include: geographic and bathymetric distribution of carbonates in modern and ancient oceans; genesis and environmental significance of carbonate grains and sedimentary textures; carbonate diagenesis; changes in styles of carbonate deposition through Earth history; reservoir quality and properties defined by storage capacity, flow (permeability) and connectivity of pores (effective porosity); the interplay between these properties, the original depositional characteristics of the carbonate sediments and post-depositional alteration; relationships between dissolution processes, cementation processes, and the resulting connectivity of the flow pathways. Lab exercises emphasize petrographic and rock physics analysis of carbonate rocks at scales ranging from map and outcrop to hand sample and thin section.
Same as: GEOLSCI 254

GEOPHYS 255. Report on Energy Industry Training. 1-3 Unit.
On-the-job-training for master's and doctoral degree students under the guidance of on-site supervisors. Students submit a report detailing work activities, problems, assignment, and key results. May be repeated for credit. Prerequisite: written consent of adviser.

GEOPHYS 257. Introduction to Computational Earth Sciences. 1-4 Unit.
Techniques for mapping numerically intensive algorithms to modern high performance computers such as the Center for Computational Earth and Environmental Science's (CEES) . Topics include computer architecture performance analysis, and parallel programming. Topics covered include pthreads OpenMP; MPI, Cilk++, and CUDA.. Exercises using SMP and cluster computers. May be repeated for credit. Offered every other year, winter quarter.

GEOPHYS 259. Properties of Rocks and Geomaterials. 3-4 Units.
Lectures and laboratory experiments. Properties of rocks and geomaterials and how they relate to chemo-mechanical processes in crustal settings, reservoirs, and man-made materials. Focus is on properties such as porosity, permeability, acoustic wave velocity, and electrical resistivity. Students may investigate a scientific problem to support their own research (4 units). Prerequisites: Physics 41 (or equivalent) and CME 100.
Same as: CEE 192

GEOPHYS 260. Rock Physics for Reservoir Characterization. 3 Units.
How to integrate well log and laboratory data to determine and theoretically generalize rock physics transforms between sediment wave properties (acoustic and elastic impendence), bulk properties (porosity, lithology, texture, permeability), and pore fluid conditions (pore fluid and pore pressure). These transforms are used in seismic interpretation for reservoir properties, and seismic forward modeling in what-if scenarios.
Same as: GEOPHYS 185

GEOPHYS 261. Advanced Rock Physics Topics. 1-3 Unit.
This course will present advanced topics in elastic effective medium theory, as applied to porous rocks.

GEOPHYS 262. Rock Physics. 3 Units.
Geophysical methods are used to image and characterize regions of the subsurface to explore for, evaluate and manage Earth resources (water and energy). A rock physics relationship is required to transform measured geophysical properties to the material properties of interest. Starting with the theoretical framework, we will explore the development of the rock physics transform from the laboratory to the field scale. Electrical and elastic properties and NMR. Grading based on four 2-week assignments.
Same as: ENERGY 252

GEOPHYS 264. Three-Dimensional Imaging. 3 Units.
Multidimensional time and frequency representations, generalization of Fourier transform methods to non-Cartesian coordinate systems, Hankel and Abel transforms, line integrals, impulses and sampling, reconstruction tomography, imaging radar. The projection-slice and layergram reconstruction methods as developed in radio interferometry. Radar imaging and backprojection algorithms for 3- and 4-D imaging. In weekly labs students create software to form images using these techniques with actual data. Final project consists of design, analysis and simulation of an advanced imaging system. Prerequisites: None required, but recommend EE103, EE261, EE278, some inverse method concepts such as from Geophys281.
Same as: EE 262

GEOPHYS 265. Imaging Radar and Applications. 3 Units.
Radar remote sensing, radar image characteristics, viewing geometry, range coding, synthetic aperture processing, correlation, range migration, range/Doppler algorithms, wave domain algorithms, polar algorithm, polarimetric processing, interferometric measurements. Applications: surfafe deformation, polarimetry and target discrimination, topographic mapping surface displacements, velocities of ice fields. Prerequisites: EE261. Recommended: EE254, EE278, EE279.
Same as: EE 355

GEOPHYS 270. Electromagnetic Properties of Geological Materials. 2-3 Units.
Laboratory observations and theoretical modeling of the electromagnetic properties and nuclear magnetic resonance response of geological material. Relationships between these properties and water-saturated materials properties such as composition, water content, surface area, and permeability.

GEOPHYS 274. Journey to the Center of the Earth. 3 Units.
The interconnected set of dynamic systems that make up the Earth. Focus is on fundamental geophysical observations of the Earth and the laboratory experiments to understand and interpret them. What earthquakes, volcanoes, gravity, magnetic fields, and rocks reveal about the Earth's formation and evolution.
Same as: GEOLSCI 107, GEOLSCI 207, GEOPHYS 184

GEOPHYS 275. Near-Surface Geophysics: Imaging Groundwater Systems. 3 Units.
Groundwater systems in important agricultural areas of the U.S. The effects of climate change on water availability and crop production. Introduction to methodologies for describing and modeling the integrated surface and groundwater system. The use of geophysical methods to support sustainable groundwater management: airborne method for regional-scale imaging, ground-based and borehole methods for site-specific assessment. Each week includes two hours of class time, some of which will involve computer modeling/analysis of data. Pre-requisite: CME 100 or Math 51, or co-registration in either.
Same as: GEOPHYS 190

GEOPHYS 280. 3-D Seismic Imaging. 2-3 Units.
The principles of imaging complex structures in the Earth subsurface using 3-D reflection seismology. Emphasis is on processing methodologies and algorithms, with examples of applications to field data. Topics: acquisition geometrics of land and marine 3-D seismic surveys, time vs. depth imaging, migration by Kirchhoff methods and by wave-equation methods, migration velocity analysis, velocity model building, imaging irregularly sampled and aliased data. Computational labs involve some programming. Lab for 3 units. Offered every year, Spring quarter.

GEOPHYS 281. Geophysical Inverse Problems. 3 Units.
Concepts of inverse theory, with application to geophysics. Inverses with discrete and continuous models, generalized matrix inverses, resolving kernels, regularization, use of prior information, singular value decomposition, nonlinear inverse problems, back-projection techniques, and linear programming. Application to seismic tomography, earthquake location, migration, and fault-slip estimation. Prerequisite: MATH 51.

GEOPHYS 284. Hydrogeophysics. 3-4 Units.
The use of geophysical methods for imaging and characterizing the top 500 meters of Earth for hydrogeologic applications. Includes material properties, forward modeling, data acquisition, inversion, and integration with other forms of measurement. Each week includes two hours of lectures; plus one 1.5-hour lab that involves acquisition of field data, or computer modeling/analysis of datanOffered occasionally.

GEOPHYS 287. Earthquake Seismology. 3-5 Units.
Seismic wave propagation (body waves and surface waves, reflection/transmission), Green's functions, seismic moment tensors and equivalent forces, representation theorem, finite-source effects. Prerequisites: GEOPHYS 130 or equivalent. Offered every other year.

GEOPHYS 288A. Crustal Deformation. 3-5 Units.
Earthquake and volcanic deformation, emphasizing analytical models that can be compared to data from GPS, InSAR, and strain meters. Deformation, stress, and conservation laws. Dislocation models of strike slip and dip slip faults, in 2 and 3 dimensions. Crack models, including boundary element methods. Dislocations in layered and elastically heterogeneous earth models. Models of volcano deformation, including sills, dikes, and magma chambers. Offered every other year, autumn quarter.

GEOPHYS 288B. Crustal Deformation. 3-5 Units.
Earthquake and volcanic deformation, emphasizing analytical models that can be compared to data from GPS, InSAR, and strain meters. Viscoelasticity, post-seismic rebound, and viscoelastic magma chambers. Effects of surface topography and earth curvature on surface deformation. Gravity changes induced by deformation and elastogravitational coupling. Poro-elasticity, coupled fluid flow and deformation. Earthquake nucleation and rate-state friction. Models of earthquake cycle at plate boundaries.

GEOPHYS 289. Global Positioning System in Earth Sciences. 3-5 Units.
The basics of GPS, emphasizing monitoring crustal deformation with a precision of millimeters over baselines tens to thousands of kilometers long. Applications: mapping with GIS systems, airborne gravity and magnetic surveys, marine seismic and geophysical studies, mapping atmospheric temperature and water content, measuring contemporary plate motions, and deformation associated with active faulting and volcanism.

GEOPHYS 290. Tectonophysics. 3 Units.
The physics of faulting and plate tectonics. Topics: plate driving forces, lithospheric rheology, crustal faulting, and the state of stress in the lithosphere. Exercises: lithospheric temperature and strength profiles, calculation of seismic strain from summation of earthquake moment tensors, slip on faults in 3D, and stress triggering and inversion of stress from earthquake focal mechanisms. Offered every other year, winter quarter.
Same as: GEOPHYS 186

GEOPHYS 299. Teaching Experience in Geophysics. 1 Unit.
For TAs in Geophysics. Course and lecture design and preparation; lecturing practice in small groups. Classroom teaching practice in a Geophysics course for which the participant is the TA.

GEOPHYS 302. Seismic Wavefields in Multiscale Media. 1 Unit.
This short course will be combine elements of theoretical, computational, practical concerns centered around wavefield complexity induced by source and/or structure, and how this maps to different, appropriate wave propagation methods and inverse problems. The short course will include a mix of reading material, lecturing, and hands-on interactive exercises.

GEOPHYS 304. Effects of Global Change and Agriculture on Hydrology. 1 Unit.
Effects of global change on crop production and fluxes of water across the surface and through the subsurface. Nexus of food, energy, and water through primary literature, and relevant data analyses. Students will be introduced to concepts ranging from global climate change to climate impact assessments, and to methodologies including remote sensing, climate model downscaling, and process-based landscape hydrologic modeling.

GEOPHYS 306. Topics in Multiphase Instabilities and Extreme Events. 1 Unit.
This Seminar will explore the role of multiphase instabilities in the onset and evolution of extreme events. We will explore the different types of instabilities that arise in different multiphase aggregates and why they might be critical for understanding the nonlinear behavior of natural systems.

GEOPHYS 308. Topics in Disaster Resilience Research. 1 Unit.
This seminar will explore past and current research on disaster risk and resilience, towards the development of new frontiers in resilience engineering science research. Designed for graduate students engaged in the topic of risk and resilience research, the seminar will be organized around weekly readings and discussion groups. May be repeat for credit.
Same as: CEE 308

GEOPHYS 385A. Reflection Seismology. 1-2 Unit.
Research in reflection seismology and petroleum prospecting. May be repeated for credit.

GEOPHYS 385B. Environmental Geophysics. 1-2 Unit.
Research on the use of geophysical methods for near-surface environmental problems. May be repeated for credit.

GEOPHYS 385D. Theoretical Geophysics. 1 Unit.
Research on physics and mechanics of earthquakes, volcanoes, ice sheets, and nglaciers. Emphasis is on developing theoretical understanding of processes governing natural phenomena.

GEOPHYS 385E. Tectonics. 1-2 Unit.
Research on the origin, major structures, and tectonic processes of the Earth's crust. Emphasis is on use of deep seismic reflection and refraction data. May be repeated for credit.

GEOPHYS 385G. Radio Glaciology. 1-2 Unit.
Research on the acquisition, processing, and analysis of radio geophysical signals in observing the subsurface conditions and physical processes of ice sheets, glaciers, and icy moons.

GEOPHYS 385K. Crustal Mechanics. 1-2 Unit.
Research in areas of petrophysics, seismology, in situ stress, and subjects related to characterization of the physical properties of rock in situ. May be repeated for credit.

GEOPHYS 385L. Earthquake Seismology, Deformation, and Stress. 1 Unit.
Research on seismic source processes, crustal stress, and deformation associated with faulting and volcanism. May be repeated for credit.

GEOPHYS 385N. Experimental Rock Physics. 1-2 Unit.
Research on the use of laboratory geophysical methods for the characterization of the physical properties of rocks and their response to earth stresses, temperature, and rock-fluid interactions. May be repeated for credit.

GEOPHYS 385Q. Seismology. 1-2 Unit.
Research on Source and Structural Seismology of the Earth. May be repeated for credit.

GEOPHYS 385R. Physical Volcanology. 1 Unit.
Research on volcanic processes. May be repeat for credit.

GEOPHYS 385S. Wave Physics. 1-2 Unit.
Theory, numerical simulation, and experiments on seismic and electromagnetic waves in complex porous media. Applications from Earth imaging and in situ characterization of Earth properties, including subsurface monitoring. Presentations by faculty, research staff, students, and visitors. May be repeated for credit.

GEOPHYS 385T. Planetary Magnetism. 1-2 Unit.
Research on the application of paleomagnetism to study planetary processes such as dynamo field generation, geodynamical evolution, and impact cratering. May be repeated for credit.

GEOPHYS 385V. Poroelasticity. 1-2 Unit.
Research on the mechanical properties of porous rocks: dynamic problems of seismic velocity, dispersion, and attentuation; and quasi-static problems of faulting, fluid transport, crustal deformation, and loss of porosity. Participants define, investigate, and present an original problem of their own. May be repeated for credit.

GEOPHYS 385W. GEOPHYSICAL MULTI-PHASE FLOWS. 1-2 Unit.
Research on the dynamics of multi-phase systems that are fundamental to many geophysical problems such as ice sheets and volcanoes.

GEOPHYS 385Z. Radio Remote Sensing. 1-2 Unit.
Research applications, especially crustal deformation measurements. Recent instrumentation and system advancements. May be repeated for credit.

GEOPHYS 400. Research in Geophysics. 1-15 Unit.
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GEOPHYS 801. TGR Project. 0 Units.
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GEOPHYS 802. TGR Dissertation. 0 Units.
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