Geophysical Sciences

Department Website: http://geosci.uchicago.edu

Program of Study

The Department of the Geophysical Sciences (GEOS) offers unique programs of study in the earth, atmospheric, and planetary sciences. Topics include the physics, chemistry, and dynamics of the atmosphere, oceans, and ice sheets; past and present climate change; the origin and history of the Earth, moon, and meteorites; properties of the deep interior of the Earth and the dynamics of crustal movements; and the evolution and geography of life and the Earth's surface environments through geologic time. These multidisciplinary topics require an integrated approach founded on mathematics, physics, chemistry, and biology.

Both the BA and BS programs prepare students for careers that draw upon the earth, atmospheric, and planetary sciences. However, the BS degree provides a more focused and intensive program of study for students who intend to pursue graduate work in these disciplines. The BA degree also offers thorough study in the geophysical sciences, but it provides a wide opportunity for elective freedom to pursue interdisciplinary interests, such as environmental policy, law, medicine, business, and precollege education.

Program Requirements for the BA in Geophysical Sciences

The requirements for the BA degree in Geophysical Sciences involve completion of:

- six required courses that fulfill general education requirements for the physical sciences, biological sciences, and mathematics
- eight required science or mathematics courses
- seven elective courses pertinent to the major from the electives lists below, which must include:
    - one course in Computational Sciences (List 2)
    - four 20000-level courses designated GEOS in List 1
    - two more 20000-level science courses from any of Lists 1–2

Candidates for the BA in Geophysical Sciences complete a year of chemistry, a year of physics, a year of mathematics (including Calculus I-II), and a year of biology (GEOS 27300 Biological Evolution-Advanced and BIOS 20198 Biodiversity).

The requirement for the third quarter of mathematics may be satisfied by either completing the calculus sequence (recommended for students taking the more introductory MATH 13000s sequence but not specifically required or recommended for the higher tracks such as MATH 15000s, as the first two quarters offer a sufficiently comprehensive calculus training for students to move on to other courses) or taking one of the designated mathematical methods courses instead. In addition, students must complete one elective course from Computational Sciences (List 2).

Students are encouraged to begin discipline-specific courses as early as possible. Required disciplinary courses include GEOS 13100 Physical Geology, GEOS 13200 Earth History, and GEOS 13300 The Atmosphere. With prior consent of the departmental counselor, students with the appropriate background may substitute a 20000-level course, which may be taken during or after the third year.

A minimum of six additional 20000-level science courses are required. At least four must be GEOS courses from List 1. Up to two may be chosen from other science courses in List 1. Up to two may be chosen from Computational Sciences (List 2). One may be a field course.

Summary of Requirements for the BA in Geophysical Sciences

GENERAL EDUCATION

One of the following sequences:		200
CHEM 10100 & CHEM 10200	Introductory General Chemistry I and Introductory General Chemistry II	
CHEM 11100-11200	Comprehensive General Chemistry I-II *	
CHEM 12100 & CHEM 12200	Honors General Chemistry I and Honors General Chemistry II	
One of the following sequences:		200
MATH 13100-13200	Elementary Functions and Calculus I-II *	
MATH 15100-15200	Calculus I-II	
MATH 16100-16200	Honors Calculus I-II	
Both of the following: **		200
BIOS 20198	Biodiversity	

GEOS 27300	Biological Evolution-Advanced %	
Total Units		600

MAJOR

GEOS 13100 & GEOS 13200 & GEOS 13300	Physical Geology and Earth History and The Atmosphere	300
CHEM 11300	Comprehensive General Chemistry III *	100
or CHEM 12300	Honors General Chemistry III	
One of the following sequences:		300
PHYS 12100-12200-12300	General Physics I-II-III *§	
PHYS 13100-13200-13300	Mechanics; Electricity and Magnetism; Waves, Optics, and Heat	
PHYS 14100-14200-14300	Honors Mechanics; Honors Electricity and Magnetism; Honors Waves, Optics, and Heat	
One of the following:		100
MATH 18300	Mathematical Methods in the Physical Sciences I	
MATH 20250	Abstract Linear Algebra	
PHYS 22000	Introduction to Mathematical Methods in Physics	
MATH 13300	Elementary Functions and Calculus III *	
MATH 15300	Calculus III	
MATH 16300	Honors Calculus III	
One Computational Sciences course (List 2)		100
Six electives as follows: †		600
Four courses designated GEOS from List 1: Physical and Biological Sciences		
Two additional courses from List 1: Physical and Biological Sciences and/or from List 2: Computational Sciences		
Total Units		1500

* Credit may be granted by examination.

** Only Environmental Science and Geophysical Sciences majors may use this pairing to satisfy the general education requirement in the biological sciences. Geophysical Sciences majors can take these courses without the Biological Sciences prerequisites (BIOS 20153-20151) unless they pursue a double major in Biological Sciences. They are expected to show competency in mathematical modeling of biological phenomena covered in BIOS 20151.

† Only one of these electives may be a field course (GEOS 29001, GEOS 29002, GEOS 29005) and only one of these electives may be GEOS 29700 Reading and Research in the Geophysical Sciences.

§ PHYS 13100-13200-13300 or PHYS 14100-14200-14300 are the preferred courses. PHYS 12100-12200-12300 is allowable on a case-by-case basis but may not provide adequate preparation to allow for enrollment in higher level PHYS courses. Additionally, PHYS 12100 has a prerequisite of a year of chemistry. Special petition to the department counselor is required for PHYS 12100-12200-12300 approval.

% Biological Evolution-Advanced has several cross-listings. Geophysical Sciences majors *must* register for it under the GEOS 27300 listing.

Program Requirements for the BS in Geophysical Sciences

The requirements for the BS degree in Geophysical Sciences involve completion of:

- six required courses that fulfill general education requirements for the physical sciences, biological sciences, and mathematics
- eight required science or mathematics courses
- ten elective courses pertinent to the major from the electives lists below, which must include:
  - two courses in Computational Sciences (List 2)
  - four 20000-level courses designated GEOS in List 1
  - four more 20000-level science courses from any of Lists 1–2: up to three non-GEOS courses from List 1, up to two from List 2

Candidates for the BS in Geophysical Sciences complete a year of chemistry, a year of physics, a year of mathematics (including Calculus I-II), and a year of biology (GEOS 27300 Biological Evolution-Advanced and BIOS 20198 Biodiversity).

The requirement for the third quarter of mathematics may be satisfied by either completing the calculus sequence (recommended for students taking the more introductory MATH 13000s sequence but not specifically required or recommended for the higher tracks such as MATH 15000s, as the first two quarters offer a sufficiently comprehensive calculus training for students to move on to other courses) or taking one of the designated mathematical methods courses instead. In addition, students must complete two elective courses from Computational Sciences (List 2). The requirements are structured to allow and encourage students to complete sequences that extend through the study of differential equations.

Students are encouraged to begin discipline-specific courses as early as possible. Required disciplinary courses include GEOS 13100 Physical Geology, GEOS 13200 Earth History, and GEOS 13300 The Atmosphere, which is the introductory sequence. With prior consent of the departmental counselor, students with the appropriate background may substitute a 20000-level course, which may be taken during or after the third year.

A minimum of eight additional 20000-level science courses are required. At least four must be GEOS courses from List 1. Up to three may be chosen from other science courses in List 1. Up to two may be chosen from Computational Sciences (List 2). One may be a field course. One may be GEOS 29700 Reading and Research in the Geophysical Sciences.

Summary of Requirements for the BS in Geophysical Sciences

GENERAL EDUCATION

One of the following sequences:		200
CHEM 10100 & CHEM 10200	Introductory General Chemistry I and Introductory General Chemistry II	
CHEM 11100-11200	Comprehensive General Chemistry I-II *	
CHEM 12100 & CHEM 12200	Honors General Chemistry I and Honors General Chemistry II	
One of the following sequences:		200
MATH 13100-13200	Elementary Functions and Calculus I-II *	
MATH 15100-15200	Calculus I-II	
MATH 16100-16200	Honors Calculus I-II	
Both of the following: **		200
BIOS 20198	Biodiversity	
GEOS 27300	Biological Evolution-Advanced %	
Total Units		600

MAJOR

GEOS 13100 & GEOS 13200 & GEOS 13300	Physical Geology and Earth History and The Atmosphere	300
CHEM 11300	Comprehensive General Chemistry III *	100
or CHEM 12300	Honors General Chemistry III	
One of the following sequences:		300
PHYS 12100-12200-12300	General Physics I-II-III *§	
PHYS 13100-13200-13300	Mechanics; Electricity and Magnetism; Waves, Optics, and Heat	
PHYS 14100-14200-14300	Honors Mechanics; Honors Electricity and Magnetism; Honors Waves, Optics, and Heat	
One of the following:		100
MATH 18300	Mathematical Methods in the Physical Sciences I	
MATH 20250	Abstract Linear Algebra	
PHYS 22000	Introduction to Mathematical Methods in Physics	
BIOS 20152	Introduction to Quantitative Modeling in Biology (Advanced)	
MATH 13300	Elementary Functions and Calculus III *	
MATH 15300	Calculus III	
MATH 16300	Honors Calculus III	
Two Computational Sciences courses from List 2		200

Eight electives as follows: ‡	800
Four courses designated GEOS from List 1: Physical and Biological Sciences	
Four additional courses from List 1: Physical and Biological Sciences and/or List 2: Computational Sciences, but only up to three courses may be non-GEOS courses from List 1 and only up to two courses may be from List 2.	
Total Units	1800

* Credit may be granted by examination.

** Only Environmental Science and Geophysical Sciences majors may use this pairing to satisfy the general education requirement in the biological sciences. Geophysical Sciences majors can take these courses without the Biological Sciences prerequisites (BIOS 20153-20151) unless they pursue a double major in Biological Sciences. They are expected to show competency in mathematical modeling of biological phenomena covered in BIOS 20151.

‡ Only one of these electives may be a field course (GEOS 29001, GEOS 29002, GEOS 29005) and only one of these electives may be GEOS 29700 Reading and Research in the Geophysical Sciences.

§ PHYS 13100-13200-13300 or PHYS 14100-14200-14300 are the preferred courses. PHYS 12100-12200-12300 is allowable on a case-by-case basis but may not provide adequate preparation to allow for enrollment in higher level PHYS courses. Additionally, PHYS 12100 has a prerequisite of a year of chemistry. Special petition to the department counselor is required for PHYS 12100-12200-12300 approval.

% Biological Evolution-Advanced has several cross-listings. Geophysical Science majors *must* register for it under the GEOS 27300 listing.

Lists of Elective Courses 1–2

List 1: Physical and Biological Sciences

Geophysical Sciences

GEOS 21000	Mineralogy	100
GEOS 21005	Mineral Science	100
GEOS 21100	Introduction to Petrology	100
GEOS 21200	Physics of the Earth	100
GEOS 21205	Introduction to Seismology, Earthquakes, and Near-Surface Earth Seismicity	100
GEOS 21400	Thermodynamics and Phase Change	100
GEOS 22000	Origin and Evolution of the Solar System	100
GEOS 22040	Planet Formation in the Galaxy I: From Dust to Planetesimals	100
GEOS 22050	Planet Formation in the Galaxy II: From Planetesimals to Planets	100
GEOS 22060	What Makes a Planet Habitable?	100
GEOS 22200	Geochronology	100
GEOS 22600	Topics in Earth Science: The Accretion of Extraterrestrial Matter Throughout Earth's History	100
GEOS 22700	Analytical Techniques in Geochemistry	100
GEOS 23205	Introductory Glaciology	100
GEOS 23600	Chemical Oceanography	100
GEOS 23800	Global Biogeochemical Cycles	100
GEOS 23900	Environmental Chemistry	100
GEOS 24220	Climate Foundations	100
GEOS 24230	Geophysical Fluid Dynamics: Foundations	100
GEOS 24240	Geophysical Fluid Dynamics: Rotation and Stratification	100
GEOS 24250	Geophysical Fluid Dynamics: Understanding the Motions of the Atmosphere and Oceans	100
GEOS 24300	Paleoclimatology	100
GEOS 24705	Energy: Science, Technology, and Human Usage	100
GEOS 24750	Humans in the Earth System	100
GEOS 25400	Intro to Numerical Techniques for Geophysical Sciences	100
GEOS 26100	Phylogenetics and the Fossil Record	100
GEOS 26300	Invertebrate Paleobiology and Evolution	100
GEOS 26600	Geobiology	100
GEOS 26650	Environmental Microbiology	100
GEOS 26905	Topics in Conservation Paleobiology	100

GEOS 28000	Introduction to Structural Geology	100
GEOS 28100	Global Tectonics	100
GEOS 28300	Principles of Stratigraphy	100
GEOS 28600	The Science of Landscapes	100
GEOS 29700	Reading and Research in the Geophysical Sciences	100

Field Courses in Geophysical Sciences

The department sponsors field trips that range in length from one day to several weeks. Shorter field trips typically form part of lecture-based courses and are offered each year. (The trips are open to all students and faculty if space permits.) Longer trips are designed as undergraduate field courses, and one such course may be used as an elective science course for the major. Destinations of field courses have recently included Baja California, Death Valley, Nevada, Salton Trough, Newfoundland, and the Bahamas.

GEOS 29001	Field Course in Geology	100
GEOS 29002	Field Course in Modern and Ancient Environments	100

Astronomy and Astrophysics

ASTR 24100	The Physics of Stars	100

Biological Sciences

BIOS 20188	Fundamentals of Physiology	100
BIOS 20189	Fundamentals of Developmental Biology	100
BIOS 20196	Ecology and Conservation	100
BIOS 20200	Introduction to Biochemistry	100
BIOS 22250	Chordates: Evolution and Comparative Anatomy	100
BIOS 23262	Mammalian Evolutionary Biology	100
BIOS 23266	Evolutionary Adaptation	100
BIOS 23289	Marine Ecology	100
BIOS 23404	Reconstructing the Tree of Life: An Introduction to Phylogenetics	100
BIOS 23406	Biogeography	100
BIOS 25206	Fundamentals of Bacterial Physiology	100

Semester in Environmental Science/MBL

The following courses are the College designations for the Semester in Environmental Science that is taught at the Marine Biological Laboratory (MBL) in Woods Hole, Massachusetts. Registration in ENSC 23820 Biogeochemical Analysis in Terrestrial and Aquatic Ecosystems # Marine Biological Laboratory, ENSC 24100 Ecology - Marine Biological Laboratory, and ENSC 29800 Independent Undergraduate Research in Environmental Sciences Marine Biological Laboratory, plus one of ENSC 24200 Methods in Microbial Ecology - Marine Biological Laboratory, ENSC 24300 Roles of Animals in Ecosystems # Marine Biological Laboratory, or ENSC 28100 Quantitative Environmental Analyses # Marine Biological Laboratory is required. Admission to the Semester in Environmental Science program is by application, which must be received by the MBL generally in March of the year preceding the start of the semester. Admissions decisions will generally be sent in April. Note that these courses start at the beginning of September, typically four weeks prior to the start of the College's Autumn Quarter, and are completed by the end of Autumn Quarter. More information on the course content, the application process, and deadlines can be found at college.uchicago.edu/academics/semester-environmental-science (https://college.uchicago.edu/academics/semester-environmental-science/). Students participating in the Semester in Environmental Science receive credit for four courses in environmental science.

ENSC 23820	Biogeochemical Analysis in Terrestrial and Aquatic Ecosystems # Marine Biological Laboratory	100
ENSC 24100	Ecology - Marine Biological Laboratory	100
ENSC 24200	Methods in Microbial Ecology - Marine Biological Laboratory	100
ENSC 24300	Roles of Animals in Ecosystems # Marine Biological Laboratory	100
ENSC 28100	Quantitative Environmental Analyses # Marine Biological Laboratory	100
ENSC 29800	Independent Undergraduate Research in Environmental Sciences Marine Biological Laboratory	100

Chemistry

CHEM 20100-20200	Inorganic Chemistry I-II	200
CHEM 22000-22100-22200	Organic Chemistry I-II-III	300

CHEM 26100-26200-26300	Quantum Mechanics; Thermodynamics; Chemical Kinetics and Dynamics	300
CHEM 26700	Experimental Physical Chemistry †	100

† requires CHEM 26100

Physics

PHYS 18500	Intermediate Mechanics	100
PHYS 22500	Intermediate Electricity and Magnetism I	100
PHYS 22600	Electronics	100
PHYS 22700	Intermediate Electricity and Magnetism II	100

List 2: Computational Sciences

Mathematics

MATH 18300 & MATH 18400	Mathematical Methods in the Physical Sciences I and Mathematical Methods in the Physical Sciences II	200
MATH 15910 or STAT 24300	Introduction to Proofs in Analysis / Numerical Linear Algebra	100
MATH 20250	Abstract Linear Algebra	100
MATH 20300	Analysis in Rn I	100
MATH 20400	Analysis in Rn II	100
MATH 20500	Analysis in Rn III	100
MATH 20310	Analysis in Rn I (accelerated)	100
MATH 20410	Analysis in Rn II (accelerated)	100
MATH 20510	Analysis in Rn III (accelerated)	100
MATH 21100	Basic Numerical Analysis	100
MATH 27000	Basic Complex Variables	100
MATH 27300	Basic Theory of Ordinary Differential Equations	100
MATH 27500	Basic Theory of Partial Differential Equations	100
MATH 38300	Numerical Solutions to Partial Differential Equations	100

Biological Sciences

BIOS 20152	Introduction to Quantitative Modeling in Biology (Advanced)	100

Physics

PHYS 22000	Introduction to Mathematical Methods in Physics §§	100
PHYS 22100	Mathematical Methods in Physics §§§	100

Statistics

Any course in statistics at the 22000 level or higher. Some recommendations follow:

STAT 22000 or STAT 23400	Statistical Methods and Applications * ‡‡ / Statistical Models and Methods	100
STAT 22400	Applied Regression Analysis	100
STAT 22600	Analysis of Categorical Data	100
STAT 24400-24500	Statistical Theory and Methods I-II ‡‡‡	200
STAT 26100	Time Dependent Data	100

Computing

CMSC 12100	Computer Science with Applications I +	100
CMSC 12200	Computer Science with Applications II	100
CMSC 12300	Computer Science with Applications III	100
CMSC 23710	Scientific Visualization	100
CMSC 28510	Introduction to Scientific Computing	100

* AP credit for STAT 22000 does not count toward the major requirements. Students with AP credit for STAT 22000 should plan to take at least one other course from List 2 (BA program) or two other courses from List 2 (BS program).

§ Recommended prerequisite is MATH 19620 or MATH 15300 or MATH 16300

§§ Would generally substitute for MATH 18300-18400

§§§ Recommended in addition to MATH 18300-18400 for advanced students—covers partial differential equations

‡‡ STAT 23400 has a higher programming component than STAT 22000

‡‡‡ Recommended for advanced students. Must be taken as a sequence to be credited. STAT 24400-24500 have no prerequisite but it is possible to take both STAT 23400 and STAT 24400-24500.

+ Students seeking to double major in Computer Science must complete CMSC 12100-1220-12300 as a sequence per the Computer Science rule.

Grading

Students majoring in geophysical sciences must receive quality grades in all courses taken to meet requirements in the major.

Honors

The BA or BS degree with honors is awarded to students who meet the following requirements: (1) a GPA of 3.25 or higher in the major and of 3.0 or higher overall; (2) completion of a paper based on original research, supervised and approved by a faculty member in geophysical sciences; (3) an oral presentation of the thesis research. All theses will be examined by the supervisor and a second reader from the faculty. Manuscript drafts will generally be due in the sixth week of the quarter in which the student will graduate (fifth week in Summer Quarter), and final manuscripts and oral presentations in the eighth week (seventh week in Summer Quarter).

Students are strongly encouraged to reach out to potential faculty supervisors no later than their third year, since theses generally arise out of research projects already begun with faculty members. When a thesis topic is determined, students should notify the undergraduate adviser of their intent to complete a thesis and confirm their eligibility. GEOS 29700 Reading and Research in the Geophysical Sciences can be devoted to the preparation of the required paper; however, students using this course to meet a requirement in the major must take it for a quality grade.

Students who wish to submit a single paper to meet the honors requirement in geophysical sciences and the BA paper requirement in another major should discuss their proposals with the undergraduate advisers from both programs no later than the end of third year. Certain requirements must be met. A consent form, to be signed by the undergraduate advisers, is available from the College adviser. It must be completed and returned to the College adviser by the end of Autumn Quarter of the student's year of graduation.

Sample BS Programs

Each student will design an individual plan of course work, choosing from a wide range of selections that take advantage of rich offerings from a variety of subdisciplines. The sample programs that appear below are merely for the purpose of illustration; many other variations would be possible. NOTE: Courses that meet general education requirements and are required for the major are not listed.

Environmental Geochemistry

CHEM 26200-26300	Thermodynamics; Chemical Kinetics and Dynamics	200
GEOS 21000	Mineralogy	100
GEOS 23600	Chemical Oceanography	100
GEOS 23800	Global Biogeochemical Cycles	100
GEOS 23900	Environmental Chemistry	100
GEOS 26650	Environmental Microbiology	100
GEOS 28300	Principles of Stratigraphy	100
GEOS 25400	Intro to Numerical Techniques for Geophysical Sciences	100
STAT 23400	Statistical Models and Methods	100

Geochemistry

CHEM 26100-26200-26300	Quantum Mechanics; Thermodynamics; Chemical Kinetics and Dynamics	300
GEOS 21000	Mineralogy	100
GEOS 21100	Introduction to Petrology	100
GEOS 22200	Geochronology	100
GEOS 23600	Chemical Oceanography	100
GEOS 23800	Global Biogeochemical Cycles	100
GEOS 23900	Environmental Chemistry	100
MATH 20000-20100	Mathematical Methods for Physical Sciences I-II	200

Geophysics

CMSC 12100-12200-12300	Computer Science with Applications I-II-III	300
GEOS 21000	Mineralogy	100

GEOS 21100	Introduction to Petrology	100
GEOS 21200	Physics of the Earth	100
GEOS 21205	Introduction to Seismology, Earthquakes, and Near-Surface Earth Seismicity	100
GEOS 28100	Global Tectonics	100
PHYS 18500	Intermediate Mechanics	100
PHYS 22100	Mathematical Methods in Physics	100

Paleontology

BIOS 23289	Marine Ecology	100
BIOS 23404	Reconstructing the Tree of Life: An Introduction to Phylogenetics	100
GEOS 21000	Mineralogy	100
GEOS 26300	Invertebrate Paleobiology and Evolution	100
GEOS 26600	Geobiology	100
GEOS 28000	Introduction to Structural Geology	100
GEOS 28300	Principles of Stratigraphy	100
STAT 22400	Applied Regression Analysis	100
STAT 23400	Statistical Models and Methods	100

Physics of Climate

GEOS 22060	What Makes a Planet Habitable?	100
GEOS 23800	Global Biogeochemical Cycles	100
GEOS 24220	Climate Foundations	100
GEOS 24230	Geophysical Fluid Dynamics: Foundations	100
GEOS 24240	Geophysical Fluid Dynamics: Rotation and Stratification	100
GEOS 24250	Geophysical Fluid Dynamics: Understanding the Motions of the Atmosphere and Oceans	100
MATH 20000-20100	Mathematical Methods for Physical Sciences I-II	200
GEOS 25400	Intro to Numerical Techniques for Geophysical Sciences	100
STAT 23400	Statistical Models and Methods	100

Planetary Science

GEOS 21200	Physics of the Earth	100
GEOS 22000	Origin and Evolution of the Solar System	100
GEOS 22060	What Makes a Planet Habitable?	100
GEOS 22200	Geochronology	100
GEOS 24220	Climate Foundations	100
GEOS 25400	Intro to Numerical Techniques for Geophysical Sciences	100
GEOS 28600	The Science of Landscapes	100
ASTR 24100	The Physics of Stars	100
PHYS 18500	Intermediate Mechanics	100
PHYS 22100	Mathematical Methods in Physics	100

Structure/Tectonics

GEOS 21000	Mineralogy	100
GEOS 21100	Introduction to Petrology	100
GEOS 21200	Physics of the Earth	100
GEOS 21205	Introduction to Seismology, Earthquakes, and Near-Surface Earth Seismicity	100
GEOS 28000	Introduction to Structural Geology	100
GEOS 28100	Global Tectonics	100
MATH 20000	Mathematical Methods for Physical Sciences I	100
PHYS 18500	Intermediate Mechanics	100
PHYS 22500	Intermediate Electricity and Magnetism I	100
STAT 23400	Statistical Models and Methods	100

Geophysical Sciences Courses

GEOS 13100. Physical Geology. 100 Units.
This course introduces plate tectonics; the geologic cycle; and the internal and surface processes that make minerals and rocks, as well as that shape the scenery. Topics include: planetary geophysics; evidence leading to the theory of plate tectonics; natural hazards including earthquakes and volcanoes; economic geology including energy resources, ores, and mineral resources; crustal deformation and mountain building; and surface processes (erosion, groundwater). Laboratory exercises introduce identifying features of rocks and minerals, and interpreting geological maps. Biweekly writing assignments explore topics in geology that are supplemental to the lecture material. (L)
Instructor(s): D. Rowley Terms Offered: Autumn

GEOS 13200. Earth History. 100 Units.
This courses covers principles of historical inference in Earth science; the physical, chemical, and biological data that are used to reconstruct Earth history; and the geographic, biotic, and environmental development of Earth. Weekly labs focus on observation and interpretation of sedimentary rocks and fossil assemblages in hand samples. (L)
Instructor(s): M. Foote Terms Offered: Winter
Prerequisite(s): GEOS 13100

GEOS 13300. The Atmosphere. 100 Units.
This course introduces the physics, chemistry, and phenomenology of the Earth's atmosphere, with an emphasis on the fundamental science that underlies atmospheric behavior and climate. Topics include (1) atmospheric composition, evolution, and structure; (2) solar and terrestrial radiation in the atmospheric energy balance; (3) the role of water in determining atmospheric structure; and (4) wind systems, including the global circulation, and weather systems.
Instructor(s): T. Shaw Terms Offered: Spring
Prerequisite(s): MATH 13100-MATH 13200
Equivalent Course(s): ENST 13300, ENSC 13300

GEOS 13400. Global Warming: Understanding the Forecast. 100 Units.
This course presents the science behind the forecast of global warming to enable the student to evaluate the likelihood and potential severity of anthropogenic climate change in the coming centuries. It includes an overview of the physics of the greenhouse effect, including comparisons with Venus and Mars; an overview of the carbon cycle in its role as a global thermostat; predictions and reliability of climate model forecasts of the greenhouse world. This course is part of the College Course Cluster program, Climate Change, Culture, and Society. (L)
Instructor(s): D. MacAyeal Terms Offered: PHSC 13400 is no longer offered; PHSC 13410 is the replacement
Prerequisite(s): Some knowledge of chemistry or physics helpful.
Equivalent Course(s): ENST 12300, ENSC 13400, PHSC 13400

GEOS 13410. Global Warming: Understanding the Forecast (Flipped Class) 100 Units.
This course presents the science behind the forecast of global warming to enable the student to evaluate the likelihood and potential severity of anthropogenic climate change in the coming centuries. It includes an overview of the physics of the greenhouse effect, including comparisons with Venus and Mars; predictions and reliability of climate model forecasts of the greenhouse world. This course is part of the College Course Cluster program, Climate Change, Culture, and Society. This course covers the same material as PHSC 13400, but is organized using a flipped classroom approach in order to increase student engagement and learning.
Instructor(s): D. Abbot Terms Offered: Autumn Spring
Prerequisite(s): Some knowledge of chemistry or physics helpful.
Equivalent Course(s): ENSC 13410, ENST 13410, PHSC 13410

GEOS 13606. Natural Disasters: Science, Statistics, and Minimizing Risk. 100 Units.
This course investigates the mechanisms behind hurricans, floods, earthquakes, and other natural hazards, and how to minimize the risks they can pose. First, we will apply the fundamental principles of physics, chemistry, and biology to understand the earth's climate, geology, and oceans, and how their conditions can become hazardous. Then we will apply this knowledge through physical experiments in the lab, 2D and 3D plots of data fields, and computer-assisted mathematical analysis. We will also explore how to use statistics to assess risk when we analyze data collected about hazards. By the end of the course, students will understand the nature of natural hazards as well as basic strategies for tackling complex scientific problems. Taught by two leading professors in the field, this will be an ideal course for students considering a STEM career, especially those wanting to apply hard science to real-world problems.

GEOS 13610. The Physics of Climate and Weather. 100 Units.
Rarely a month goes by without hearing some news about natural disasters around the world. Whether it is a hurricane, flooding, or a catastrophic wildfire, many of these disasters are associated with extreme weather events or climatic conditions. Increasingly, the conversation then turns towards global climate change and its potential effect on natural disasters. This course will provide you with the concepts needed to understand the fundamentals of weather and climate, how scientists apply the principles of physics and statistics to the earth's environment to dissect seemingly complex phenomena, and how these insights can be used to forecast not only the weather of tomorrow, but also the climate of the next century. By the end of this course you will learn how the

atmospheric and oceanic environments of our planet operate, what causes impactful events to occur, how and why the climate and associated weather events may change in the future, and-perhaps most importantly-how to think like a scientist by meshing principles of physics and statistics with observed data. You will also be exposed to some of the general tools and concepts of STEM research such as programming, problem solving, laboratory measurements, and technical writing.
Terms Offered: Summer

GEOS 13900. Biological Evolution. 100 Units.
This course is an introduction to evolutionary processes and patterns in present-day organisms and in the fossil record and how they are shaped by biological and physical forces. Topics emphasize evolutionary principles. They include DNA and the genetic code, the genetics of populations, the origins of species, and evolution above the species level. We also discuss major events in the history of life, such as the origin of complex cells, invasion of land, and mass extinction. This course is part of the College Course Cluster program: Climate Change, Culture and Society. (L)
Instructor(s): D. Jablonski Terms Offered: Winter
Prerequisite(s): BIOS 10130 or BIOS 10140; No Biological Sciences majors except by petition to the BSCD Senior Advisers.
Note(s): Due to significant overlap of course content, students may register for only one of PHSC 11000, BIOS 12117, or GEOS 13900/BIOS 13123. Students using this course for credit in the GEOS or ENSC major register for GEOS 27300; additional work, including a term paper, will be required.
Equivalent Course(s): BIOS 13123

GEOS 21000. Mineralogy. 100 Units.
This course covers structure, chemical composition, stability, and occurrence of major rock-forming minerals. Labs concentrate on mineral specimen identification and optical microscopy. (L)
Instructor(s): A. Campbell Terms Offered: Autumn
Prerequisite(s): CHEM 10100 & 10200 or equivalent.
Equivalent Course(s): GEOS 31000

GEOS 21005. Mineral Science. 100 Units.
This course examines the relationship between the structure of minerals, their chemistry, and their physical properties. Topics include crystallography, defect properties, phase transitions, and analytical tools, followed by detailed study of specific mineral groups.
Instructor(s): A. Campbell Terms Offered: Winter. Offered every other year.
Prerequisite(s): GEOS 21000 or consent of instructor.
Equivalent Course(s): GEOS 31005

GEOS 21100. Introduction to Petrology. 100 Units.
Students in this course learn how to interpret observable geological associations, structures, textures, and mineralogical and chemical compositions of rocks so as to develop concepts of how they form and evolve. Our theme is the origin of granitic continental crust on the only planet known to have oceans and life. Igneous, sedimentary, and metamorphic rocks; ores; and waste disposal sites are reviewed. (L)
Instructor(s): N. Dauphas Terms Offered: Spring
Prerequisite(s): GEOS 21000 is strongly recommended.

GEOS 21200. Physics of the Earth. 100 Units.
This course considers geophysical evidence bearing on the internal makeup and dynamical behavior of the Earth, including seismology (i.e., properties of elastic waves and their interpretation, and internal structure of the Earth); mechanics of rock deformation (i.e., elastic properties, creep and flow of rocks, faulting, earthquakes); gravity (i.e., geoid, isostasy); geomagnetism (i.e., magnetic properties of rocks and history, origin of the magnetic field); heat flow (i.e., temperature within the Earth, sources of heat, thermal history of the Earth); and plate tectonics and the maintenance of plate motions. (L)
Instructor(s): D. Heinz Terms Offered: Spring
Prerequisite(s): Prior calculus and college-level physics courses, or consent of instructor.
Equivalent Course(s): GEOS 31200

GEOS 21205. Introduction to Seismology, Earthquakes, and Near-Surface Earth Seismicity. 100 Units.
This course introduces the mechanics and phenomenology of elastic waves in the Earth and in the fluids near the Earth's surface (e.g., S and P waves in the solid earth, acoustic waves in the ocean and atmosphere). Topics include stress and strain, constitutive equations, elasticity, seismic waves, acoustic waves, theory of refraction/reflection, surface waves, dispersion, and normal modes of the Earth. Phenomenology addressed includes exploration geophysics (refraction/reflection seismology), earthquakes and earthquake source characterization, seismograms as signals, seismometers and seismological networks, and digital seismogram analysis.
Instructor(s): D. Heinz Terms Offered: Winter
Equivalent Course(s): GEOS 31205

GEOS 21400. Thermodynamics and Phase Change. 100 Units.
This course develops the thermodynamics of minerals, with emphasis on relations between thermodynamic variables and equations of state. Geological and geochemical applications include homogeneous and

heterogeneous phase equilibrium, culminating in the construction of representative multicomponent phase diagrams of petrological significance, and fluid-rock interactions.
Instructor(s): A. Campbell Terms Offered: Winter
Prerequisite(s): College-level chemistry and calculus.
Equivalent Course(s): GEOS 31400

GEOS 21900. Intro To Structural Geology. 100 Units.
This course explores the deformation of the Earth materials primarily as observed in the crust. We emphasize stress and strain and their relationship to incremental and finite deformation in crustal rocks, as well as techniques for inferring paleostress and strain in deformed crustal rocks. We also look at mesoscale to macroscale structures and basic techniques of field geology in deformed regions.
Instructor(s): D. Rowley Terms Offered: Autumn
Prerequisite(s): GEOS 13100

GEOS 22040. Planet Formation in the Galaxy I: From Dust to Planetesimals. 100 Units.
This course examines the physical and chemical processes that operate during the earliest stages of planet formation when dust in a protoplanetary disk aggregates into bodies 1 to 10 km in size. Topics include the physical and chemical evolution of protoplanetary disks, radial transport of dust particles, transient heating events, and the formation of planetesimals. We discuss the evidence of these processes found in meteorites and observed in disks around young stars. Chemical and physical models of dust evolution are introduced, including an overview of basic numerical modeling techniques.
Instructor(s): F. Ciesla
Prerequisite(s): One year of college-level calculus and physics or chemistry, or consent of instructor.
Note(s): This course is offered in alternate years.
Equivalent Course(s): GEOS 32040

GEOS 22050. Planet Formation in the Galaxy II: From Planetesimals to Planets. 100 Units.
This course explores the stage of planet formation during which 1 to 10 km planetesimals accrete to form planets. Topics include heating of planetesimals, models of giant planet formation, the delivery of water to terrestrial planets, and the impact that stellar mass and external environment have on planet formation. We also discuss what processes determine the properties (mass, composition, and orbital parameters) of a planet and its potential for habitability. Basic modeling techniques and current research papers in peer-reviewed journals are also discussed.
Instructor(s): F. Ciesla
Prerequisite(s): Consent of instructor
Equivalent Course(s): GEOS 32050

GEOS 22060. What Makes a Planet Habitable? 100 Units.
This course explores the factors that determine how habitable planets form and evolve. We will discuss a range of topics, from the formation of planets around stars and the delivery of water, to the formation of atmospheres, climate dynamics, and the conditions that allow for the development of life and the evolution of complex life. Students will be responsible for periodically preparing presentations based on papers in peer-reviewed journals and leading the discussion.
Instructor(s): Edwin Kite Terms Offered: Winter
Equivalent Course(s): ASTR 32060, GEOS 32060, ASTR 22060

GEOS 22200. Geochronology. 100 Units.
This course covers the duration of planetary differentiation and the age of the Earth (i.e., extinct and extant chronometers); timescales for building a habitable planet (i.e., the late heavy bombardment, the origin of the atmosphere, the emergence of life, and continent extraction); dating mountains (i.e., absolute ages, exposure ages, and thermochronology); the climate record (i.e., dating layers in sediments and ice cores); and dating recent artifacts (e.g., the Shroud of Turin). Prerequisite(s): Background in college-level geology, physics, and mathematics. Equivalent Course(s): GEOS 32200
Instructor(s): N. Dauphas Terms Offered: Autumn
Prerequisite(s): Background in college-level geology, physics, and mathematics.
Note(s): Equivalent Course(s): GEOS 32200
Equivalent Course(s): GEOS 32200

GEOS 22600. Topics in Earth Science: The Accretion of Extraterrestrial Matter Throughout Earth's History. 100 Units.
This course will provide a discussion of the nature and variability of extraterrestrial (ET) matter accreted throughout Earth's history that is preserved in the geological record. This record is a rich archive of ET matter whose study not only provides unique insight into the origin and evolution of different Solar System objects but also enables a better understanding of delivery mechanisms. The course will highlight periods of dramatically increased accretion rates and important impact events. This includes events such as the recent Chelyabinsk and Tunguska air blasts, the "global killer" Chicxulub impact 66 Ma ago, the Ordovician meteorite showers, all the way to cataclysmic events that occurred on early Earth. The course will also provide an introduction to related key techniques such as classification with material from the meteorite collection, the identification of impact craters, and the use of tracers of ET material in the geological record.
Instructor(s): P. Heck Terms Offered: Autumn

Prerequisite(s): Background in college-level geology and mineralogy or consent of instructor
Equivalent Course(s): GEOS 32600

GEOS 22700. Analytical Techniques in Geochemistry. 100 Units.
Modern geochemistry requires the use of many sophisticated laboratory instruments. The idea behind GEOS 32700 is to survey the major types of instrumentation used in geochemistry laboratories, including mass spectrometers, electron microscopes, x-ray microanalysis, DNA sequencing, etc. Students should come away from the course with a better appreciation of the inner workings of these instruments rather than treating them as black boxes. As a laboratory portion of the course, students will be trained and do a project using the TESCAN SEM-FIB in the Department of the Geophysical Sciences. The course is open to graduate students and advanced undergraduates.
Instructor(s): Andrew M. Davis & Michael J. Pellin Terms Offered: Autumn
Equivalent Course(s): GEOS 32700

GEOS 23205. Introductory Glaciology. 100 Units.
The fundamentals of glacier and ice-sheet dynamics and phenomenology will be covered in this introductory course (snow and sea ice will be excluded from this course, however may be taken up in the future). Emphasis will be placed on developing the foundation of continuum mechanics and viscous fluid flow as a means of developing the basic equations of glacier deformation, ice-sheet and -shelf flow, basal processes, glacier hydrology, and unstable modes of flow. This course is intended for advanced undergraduate students in physics, math, geophysical sciences, and related fields as well as graduate students considering research in glaciology and climate dynamics. This course is part of the College Course Cluster program: Climate Change, Culture, and Society.
Instructor(s): D. MacAyeal Terms Offered: Winter
Prerequisite(s): Knowledge of vector calculus, linear algebra, and computer programming.
Equivalent Course(s): GEOS 33205

GEOS 23600. Chemical Oceanography. 100 Units.
This course explores the chemistry of the ocean system and its variations in space and time. The oceans play an essential role in most (bio)geochemical cycles, interacting in various ways with the atmosphere, sediments, and crust. These interactions can be understood through studying the geochemical and isotopic properties of the ocean, its inputs and outputs, and its evolution as recorded in marine sediments and sedimentary rocks. Topics include: the marine carbon cycle, nutrient cycling, chemical sediments, and hydrothermal systems.
Instructor(s): Clara Blättler Terms Offered: Spring
Prerequisite(s): Completion of one of the following Chemistry Sequences: CHEM 10100-10200-11300 Introductory General Chemistry I-II; Comprehensive General Chemistry III or CHEM 11100-11200-11300 Comprehensive General Chemistry I-II-III or CHEM 12100-12200-12300 Honors General Chemistry I-II-III AND either GEOS 13100 or GEOS 13200.
Equivalent Course(s): GEOS 33600, ENSC 23600

GEOS 23800. Global Biogeochemical Cycles. 100 Units.
This survey course covers the geochemistry of the surface of the Earth, focusing on biological and geological processes that shape the distributions of chemical species in the atmosphere, oceans, and terrestrial habitats. Budgets and cycles of carbon, nitrogen, oxygen, phosphorous, and sulfur are discussed, as well as chemical fundamentals of metabolism, weathering, acid-base and dissolution equilibria, and isotopic fractionation. The course examines the central role that life plays in maintaining the chemical disequilibria that characterize Earth's surface environments. The course also explores biogeochemical cycles change (or resist change) over time, as well as the relationships between geochemistry, biological (including human) activity, and Earth's climate.
Instructor(s): J. Waldbauer Terms Offered: Spring
Prerequisite(s): CHEM 11100-11200 or consent of instructor
Equivalent Course(s): ENSC 23800, GEOS 33800

GEOS 23900. Environmental Chemistry. 100 Units.
The focus of this course is the fundamental science underlying issues of local and regional scale pollution. In particular, the lifetimes of important pollutants in the air, water, and soils are examined by considering the roles played by photochemistry, surface chemistry, biological processes, and dispersal into the surrounding environment. Specific topics include urban air quality, water quality, long-lived organic toxins, heavy metals, and indoor air pollution. Control measures are also considered. This course is part of the College Course Cluster program: Climate Change, Culture, and Society.
Instructor(s): D. Archer Terms Offered: Autumn
Prerequisite(s): CHEM 11100-11200 or equivalent, and prior calculus course
Equivalent Course(s): GEOS 33900, ENST 23900, ENSC 23900

GEOS 24220. Climate Foundations. 100 Units.
This course introduces the basic physics governing the climate of planets, the Earth in particular but with some consideration of other planets. Topics include atmospheric thermodynamics of wet and dry atmospheres, the hydrological cycle, blackbody radiation, molecular absorption in the atmosphere, the basic principles of radiation balance, and diurnal and seasonal cycles. Students solve problems of increasing complexity, moving from pencil-and-paper problems to programming exercises, to determine surface and atmospheric temperatures and how

they evolve. An introduction to scientific programming is provided, but the fluid dynamics of planetary flows is not covered. This course is part of the College Course Cluster program: Climate Change, Culture and Society. (L)
Instructor(s): Liz Moyer Terms Offered: Autumn
Prerequisite(s): Prior physics course (preferably PHYS 13300 and 14300) and knowledge of calculus required; prior geophysical sciences course not required.
Note(s): Prior programming experience helpful but not required.
Equivalent Course(s): GEOS 34220

GEOS 24230. Geophysical Fluid Dynamics: Foundations. 100 Units.
This course is for incoming graduate students in physical sciences intending to take further courses in geophysical fluid dynamics, fluid dynamics, condensed matter physics, and other areas requiring this fundamental skill set. It sets the stage for follow-on courses that present the detail of the behavior of fluids and continuums in geophysical, physical, chemical, and other settings. The material may be a student's first contact with continuum mechanics or a remedial or review for students who have previously taken similar courses. Topics include description of material properties in a continuum, including displacement, velocity, and strain rate; scalar, vector, and tensor properties of continuums, strain, strain rate, and stress; derivations and understanding of mass, momentum, and energy conservation principles in a continuum; applications of conservation principles to simple rheological idealizations, including ideal fluids and potential flow, viscous fluids and Navier-Stokes flow, elasticity and deformation; introductory asymptotic analysis, Reynolds number; heat transfer by conduction and convection, convective instability, Rayleigh number; fluids in gravitational fields, stratification, buoyancy; elliptic, parabolic, and hyperbolic partial differential equations, typical properties of each. Prerequisite(s): Vector calculus, linear algebra, advanced classical mechanics, basic knowledge of computing. Undergrads who take this course should intend to complete a second fluid-dynamics course in Geophysical Sciences.
Instructor(s): D. MacAyeal Terms Offered: Autumn
Prerequisite(s): Vector calculus, linear algebra, advanced classical mechanics, basic knowledge of computing. Undergrads who take this course should intend to complete a second fluid-dynamics course in Geophysical Sciences.
Equivalent Course(s): GEOS 34230

GEOS 24240. Geophysical Fluid Dynamics: Rotation and Stratification. 100 Units.
This course is an introduction to geophysical fluid dynamics for upper-level undergraduates and starting graduate students. The topics covered will be the equations of motion, the effects of rotation and stratification, shallow water systems and isentropic coordinates, vorticity and potential vorticity, and simplified equations for the ocean and atmosphere.
Instructor(s): T. Shaw Terms Offered: Winter
Prerequisite(s): PQ: GEOS 24230 or equivalent; Knowledge of mechanics (PHYS 13100 or equivalent), thermodynamics (PHYS 19700 or equivalent), vector calculus and linear algebra (MATH 20000-20100-20200 or equivalent)
Equivalent Course(s): GEOS 34240

GEOS 24250. Geophysical Fluid Dynamics: Understanding the Motions of the Atmosphere and Oceans. 100 Units.
This course is part of the atmospheres and oceans sequence (GEOS 24220, 24230, 24240, 24250) and is expected to follow Geophysical Fluid Dynamics: Rotation and Stratification (GEOS 24240). The course demonstrates how the fundamental principles of geophysical fluid dynamics are manifested in the large-scale circulation of the atmosphere and oceans and their laboratory analogs. Topics include: balance of forces and the observed structure of the atmospheric and oceanic circulations, statistical description of the spatially and temporally varying circulation, theory of Hadley circulation, waves in the atmosphere and oceans, baroclinic instability, wind-driven ocean circulation.
Instructor(s): N. Nakamura Terms Offered: Spring
Prerequisite(s): GEOS 24230 and 24240, or consent of the instructor. Knowledge of vector calculus, linear algebra, and ordinary differential equations is assumed.
Equivalent Course(s): GEOS 34250

GEOS 24260. Radiation. 100 Units.
Develops the theory of radiation emission, absorption, and scattering by planetary atmospheres. Emphasis on the derivation and solution of the radiative transfer equation for plane parallel, horizontally homogeneous atmospheres.
Instructor(s): D. Abbot
Prerequisite(s): Advanced undergraduate level knowledge of electromagnetic theory, atomic structure, and differential equations.
Equivalent Course(s): GEOS 34260

GEOS 24300. Paleoclimatology. 100 Units.
This class will cover the theory and reconstruction of the evolution of Earth's climate through geologic time. After reviewing fundamental principles that control Earth's climate, the class will consider aspects of the climate reconstructions that need to be explained theoretically, such as the faint young sun paradox, snowball Earth episodes, Pleistocene glacial / interglacial cycles, and long-term Cenozoic cooling. Then we will switch to a

temporal point of view, the history of Earth's climate as driven by plate tectonics and biological evolution, and punctuated by mass extinctions. This will allow us to place the theoretical ideas from the first part of the class into the context of time and biological progressive evolution.
Terms Offered: Winter
Prerequisite(s): One quarter of chemistry
Note(s): D. Archer
Equivalent Course(s): GEOS 34300

GEOS 24550. Ocean Circulation. 100 Units.
In this course we discuss the dynamics of the global-scale ocean circulation, which plays an important role in the climate system via the transport and storage of heat and carbon. Topics include the wind-driven ocean gyres, the ocean's thermocline, the turbulent Antarctic Circumpolar Current as a critical connector of the major ocean basins, as well as the meridional overturning circulation. The course aims to promote a fundamental understanding of ocean dynamics, rather than a purely empirical treatment, and hence builds on the fluid dynamical equations that govern the oceanic motions. The structure of the course includes a combination of lectures, in-class exercises, and discussion of material read by the students at home. The course is suitable for graduate students and upper-level undergraduates.
Instructor(s): Malte Jansen Terms Offered: Spring
Prerequisite(s): Prerequisite(s): GEOS 24230/34230 and GEOS 24240/34240, or consent of instructor. Knowledge of vector calculus, linear algebra, and ordinary differential equations is assumed.
Equivalent Course(s): GEOS 34550

GEOS 24600. Introduction to Atmosphere, Ocean, and Climate Modeling. 100 Units.
This hands-on course will discuss how we model atmosphere- ocean- and climate-dynamics using numerical models of varying complexity. We will discuss both the relevant physics as well as numerical techniques, including finite-difference methods for ordinary and partial differential equations, as well as spectral methods. The primary focus of the course will be on relatively simple models, including 1D energy balance models, radiative-convective columns, and quasi-geostrophic models for atmosphere and ocean dynamics, which can be fully understood and applied in the context of a quarter-long course. We will end with an overview of the physics and numerics used in more complex general circulation and coupled climate models. The course will be structured using a combination of lectures, in-class exercises, and discussion of homework exercises. Homework will include programming exercises as well as simulations and analysis using existing model code.
Instructor(s): M. Jansen Terms Offered: Autumn
Prerequisite(s): Prerequisites: GEOS 24220/34220 “Climate foundations”; knowledge of vector calculus, linear algebra, and partial differential equations; basic knowledge of python (could potentially be replaced by significant programming experience in other languages). Recommended: Geophysical fluid dynamics 24220/34220 and 24240/34240.
Equivalent Course(s): GEOS 34600

GEOS 24705. Energy: Science, Technology, and Human Usage. 100 Units.
This course covers the technologies by which humans appropriate energy for industrial and societal use, from steam turbines to internal combustion engines to photovoltaics. We also discuss the physics and economics of the resulting human energy system: fuel sources and relationship to energy flows in the Earth system; and modeling and simulation of energy production and use. Our goal is to provide a technical foundation for students interested in careers in the energy industry or in energy policy. Field trips required to major energy converters (e.g., coal-fired and nuclear power plants, oil refinery, biogas digester) and users (e.g., steel, fertilizer production). This course is part of the College Course Cluster program: Climate Change, Culture and Society.
Instructor(s): E. Moyer
Prerequisite(s): Knowledge of physics or consent of instructor.
Note(s): See GEOS 24750/ENSC 21150.
Equivalent Course(s): ENST 24705, ENSC 21100, GEOS 34705

GEOS 24750. Humans in the Earth System. 100 Units.
Human activities now have global-scale impact on the Earth, affecting many major biogeochemical cycles. One third of the Earth's surface is now used for production of food for humans, and CO2, the waste product of human energy use, now substantially affects the Earth's radiative balance. This course provides a framework for understanding humanity as a component of Earth system science. The course covers the Earth's energy flows and cycles of water, carbon, and nitrogen; their interactions; and the role that humans now play in modifying them. Both agriculture and energy technologies can be seen as appropriation of natural energy flows, and we cover the history over which human appropriations have become globally significant. The course merges geophysical and biological sciences and engineering, and includes lab sessions and field trips to agriculture, water management, and energy facilities to promote intuition. One year of university-level science is recommended.
Terms Offered: Spring
Equivalent Course(s): GEOS 34750, ENSC 21150, ENST 24750

GEOS 25400. Intro to Numerical Techniques for Geophysical Sciences. 100 Units.
This class provides an introduction to different types of numerical techniques used in developing models used in geophysical science research. Topics will include how to interpolate and extrapolate functions, develop functional fits to data, integrate a function, or solve partial differential equations. Students are expected to have

some familiarity with computers and programming-programming methods will not be discussed in detail. While techniques will be the focus of the class, we will also discuss the planning needed in developing a model as well as the limitations inherent in such models.
Instructor(s): Ciesla, F. Terms Offered: Winter
Equivalent Course(s): GEOS 35400

GEOS 26100. Phylogenetics and the Fossil Record. 100 Units.
Phylogenies are branching diagrams that reflect evolutionary relationships. In addition to providing information on the history of life, phylogenies are fundamental to modern methods for studying macroevolutionary and macroecological pattern and process. In the biological sciences, phylogenies are most often inferred from genetic data. In paleobiology, phylogenies can only be inferred from the fossilized remains of morphological structures, and collecting and analyzing morphological data present a different set of challenges. In this course, students will study both traditional and state-of-the-art approaches to inferring phylogenies in the fossil record, from data collection to interpretation. Lectures will explore the statistical underpinnings of phylogenetic methods, as well as their practical implementation in commonly used software. Topics will include: identifying and coding morphological characters, models of morphological evolution, parsimony, maximum likelihood, and bayesian methods, supertree approaches, and integrating time into phylogenetic inference. Fifty percent of the final assessment will come from a research paper due at the end of the quarter.
Instructor(s): G. Slater Terms Offered: Autumn. Course is offered every other year.
Prerequisite(s): BIOS 20197 or equivalent.
Equivalent Course(s): GEOS 36100

GEOS 26300. Invertebrate Paleobiology and Evolution. 100 Units.
This course provides a detailed overview of the morphology, paleobiology, evolutionary history, and practical uses of the invertebrate and microfossil groups commonly found in the fossil record. Emphasis is placed on understanding key anatomical and ecological innovations within each group and interactions among groups responsible for producing the observed changes in diversity, dominance, and ecological community structure through evolutionary time. Labs supplement lecture material with specimen-based and practical application sections. An optional field trip offers experience in the collection of specimens and raw paleontological data. Several "Hot Topics" lectures introduce important, exciting, and often controversial aspects of current paleontological research linked to particular invertebrate groups. (L)
Instructor(s): M. Webster Terms Offered: Autumn
Prerequisite(s): GEOS 13100 and 13200, or equivalent. Students majoring in Biological Sciences only; Completion of the general education requirement in the Biological Sciences, or consent of instructor.
Equivalent Course(s): EVOL 32400, BIOS 23261, GEOS 36300

GEOS 26600. Geobiology. 100 Units.
Geobiology seeks to elucidate the interactions between life and its environments that have shaped the coevolution of the Earth and the biosphere. The course will explore the ways in which biological processes affect the environment and how the evolutionary trajectories of organisms have in turn been influenced by environmental change. In order to reconstruct the history of these processes, we will examine the imprints they leave on both the rock record and on the genomic makeup of living organisms. The metabolism and evolution of microorganisms, and the biogeochemistry they drive, will be a major emphasis.
Instructor(s): M. Coleman, J. Waldbauer
Prerequisite(s): GEOS 13100-13200-13300 or college-level cell & molecular biology
Equivalent Course(s): ENSC 24000, GEOS 36600

GEOS 26650. Environmental Microbiology. 100 Units.
The objective of this course is to understand how microorganisms alter the geochemistry of their environment. The course will cover fundamental principles of microbial growth, metabolism, genetics, diversity, and ecology, as well as methods used to study microbial communities and activities. It will emphasize microbial roles in elemental cycling, bioremediation, climate, and ecosystem health in a variety of environments including aquatic, soil, sediment, and engineered systems.
Instructor(s): M. Coleman Terms Offered: Autumn
Prerequisite(s): CHEM 11100-11200 and BIOS 20186 or BIOS 20197 or BIOS 20198
Equivalent Course(s): GEOS 36650, ENSC 24500

GEOS 26905. Topics in Conservation Paleobiology. 100 Units.
Paleobiological data from very young sedimentary records, including skeletal 'death assemblages' actively accumulating on modern land surfaces and seabeds, provide unique information on the status of present-day populations, communities, and biomes and their responses to natural and anthropogenic stress over the last few decades to millennia. This course on the emerging discipline of 'conservation paleobiology' uses weekly seminars and individual research projects to introduce how paleontologic methods, applied to modern samples, can address critical issues in the conservation and restoration of biodiversity and natural environments, including such basic questions as 'has a system changed, and if so how and when relative to suspected stressors?'. The course will include hands-on experience, either in the field or with already-collected marine benthic samples, to assess societally relevant ecological change in modern systems over time-frames beyond the reach of direct observation. Enrollment limited.
Instructor(s): S. Kidwell Terms Offered: Winter

Prerequisite(s): Additional Notes For undergraduates: completion of GEOS 13100-13200-13300 or equivalent or completion of a 20000 level course in Palentology.
Equivalent Course(s): EVOL 36905, GEOS 36905

GEOS 27300. Biological Evolution-Advanced. 100 Units.
This course is an overview of evolutionary processes and patterns in present-day organisms and in the fossil record and how they are shaped by biological and physical forces. Topics emphasize evolutionary principles. They include DNA and the genetic code, the genetics of populations, the origins of species, and evolution above the species level. We also discuss major events in the history of life, such as the origin of complex cells, invasion of land, and mass extinctions. Aimed at GEOS and ENSC majors, this course differs from GEOS 13900 in requiring a term paper, topic chosen from a list provided by the instructor (L).
Instructor(s): D. Jablonski Terms Offered: Winter
Prerequisite(s): Prerequisite(s): BIOS 10130; No Biological Sciences majors except by petition to the BSCD Senior Advisers.
Note(s): Terms Offered: Winter

GEOS 28000. Introduction to Structural Geology. 100 Units.
This course explores the deformation of the Earth materials primarily as observed in the crust. We emphasize stress and strain and their relationship to incremental and finite deformation in crustal rocks, as well as techniques for inferring paleostress and strain in deformed crustal rocks. We also look at mesoscale to macroscale structures and basic techniques of field geology in deformed regions.
Instructor(s): D. Rowley Terms Offered: Winter
Prerequisite(s): GEOS 13100
Note(s): This course is offered in alternate years.
Equivalent Course(s): GEOS 38000

GEOS 28100. Global Tectonics. 100 Units.
This course reviews the spatial and temporal development of tectonic and plate tectonic activity of the globe. We focus on the style of activity at compressive, extensional, and shear margins, as well as on the types of basin evolution associated with each. (L)
Instructor(s): D. Rowley Terms Offered: Autumn
Prerequisite(s): GEOS 13100 or consent of instructor
Note(s): This course is offered in alternate years.
Equivalent Course(s): GEOS 38100

GEOS 28300. Principles of Stratigraphy. 100 Units.
This course introduces principles and methods of stratigraphy. Topics include facies analysis, physical and biostratigraphic correlation, and development and calibration of the geologic time scale. We also discuss controversies concerning the completeness of the stratigraphic record; origin of sedimentary cycles; and interactions between global sea level, tectonics, and sediment supply. (L)
Instructor(s): S. Kidwell Terms Offered: Autumn
Prerequisite(s): GEOS 13100-13200 or equivalent required; GEOS 23500 and/or 28200 recommended
Note(s): This course is offered in alternate years.
Equivalent Course(s): GEOS 38300

GEOS 28600. The Science of Landscapes. 100 Units.
The focus of this course is geomorphology, both of the Earth and other planets. Moving from the controls on planetary-scale topography down to the scale of individual streams and hillslopes, the course will emphasize fluvial and aeolian sediment transport, and landscape evolution.
Instructor(s): E. Kite Terms Offered: Spring

GEOS 29001. Field Course in Geology. 100 Units.
Students visit classic locations to examine a wide variety of geological environments and processes and to learn basic field skills; themes include tectonics and sedimentation, basin-scale paleogeography, and geomorphology. Course meets weekly in Winter Quarter prior to a Spring Break field trip; interested students should contact an instructor in advance.
Instructor(s): S. Kidwell Terms Offered: Winter
Prerequisite(s): GEOS 13100-13200 and consent of instructor
Note(s): Interested students should contact the departmental counselor.
Equivalent Course(s): GEOS 39001

GEOS 29002. Field Course in Modern and Ancient Environments. 100 Units.
This course uses weekly seminars during Winter Quarter to prepare for a one-week field trip over spring break, where students acquire experience with sedimentary rocks and the modern processes responsible for them, learn field methods, and complete an original research project. We consider biological as well as physical processes of sediment production, dispersal, accumulation, and post-depositional modification. Destinations vary; past trips have examined tropical carbonate systems of Jamaica and the Bahamas and subtropical coastal Gulf of California.
Instructor(s): S. Kidwell, M. LaBarbera Terms Offered: Winter
Note(s): Organizational meeting and deposit usually required in Autumn Quarter; interested students should contact an instructor in advance. Enrollment allowed by permission of instructor.

Equivalent Course(s): ENSC 29002, GEOS 39002

GEOS 29003. Field Course in Oceanography. 100 Units.
Students in this course spend roughly a week sailing a tall ship from the SEA education program, learning oceanographic sampling techniques and data interpretation as well as principles of navigation and seamanship.
Prerequisite(s): Consent of instructor
Note(s): Interested students should contact the departmental counselor.

GEOS 29600. Science Writing Practicum. 100 Units.
Writing is fundamental to science and to the careers of scientists -- even a brilliant scientific idea has no impact if no one understands the paper describing it. In this practicum, students will learn to write papers that communicate their work clearly to the scientific community, that attract citations, and that are compelling even for experts from other fields and members of the general public. The course is intended for students engaged in research and at the stage of working on a paper intended for publication in a peer-reviewed journal, and students are expected to bring their work in progress. Students will learn to evaluate their writing to anticipate its effectiveness with different audiences, and to organize and revise it for maximal impact, using techniques from academic writing and science journalism and insights from cognitive theories of reading. Students from diverse backgrounds will read and critique one another's work weekly, learning to overcome barriers to communication between different communities of scholars and the public. We will also discuss techniques for effective science graphics and oral presentations. The course culminates in a practicum research presentation and production by each student of a final or near-final draft of a manuscript for submission.
Instructor(s): Jeff McMahon Terms Offered: Spring
Prerequisite(s): Consent only. Priority enrollment is given to students in UChicago's NRT research traineeship program on computational environmental sciences (nrt.geosci.uchicago.edu), PI Elisabeth Moyer. Write to jmcmahon@uchicago.edu to request consent to enroll.
Equivalent Course(s): GEOS 39600

GEOS 29700. Reading and Research in the Geophysical Sciences. 100 Units.
Independent study; regular meetings with Geophysical Sciences faculty member required. Topics available include, but are not limited to: Mineralogy, Petrology, Geophysics, High Pressure Geophysics, Geodynamics, Volcanology, Cosmochemistry, Geochemistry, Atmospheric Dynamics, Paleoclimatology, Physical Oceanography, Chemical Oceanography, Paleoceanography, Atmospheric Chemistry, Fluid Dynamics, Glaciology, Climatology, Radiative Transfer, Cloud Physics, Morphometrics, Phylogeny, Analytical Paleontology, Evolution, Taphonomy, Macroevolution, Paleobiology, Paleobotany, Biomechanics, Paleoecology, Tectonics, Stratigraphy.
Instructor(s): Staff Terms Offered: Autumn,Spring,Summer,Winter
Prerequisite(s): Consent of instructor and departmental counselor
Note(s): Students are required to submit the College Reading and Research Course Form. Available to nonmajors for P/F grading. Must be taken for a quality grade when used to meet a requirement in the major.