Geophysical Sciences

Departmental Counselor: Lawrence Grossman, HGS 389, 702.8153, yosi@uchicago.edu
Departmental Office: HGS 161, 702.8101
Web: 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

The principal distinction between the BA and BS programs is the number of 20000-level courses required for the major and their distribution among subdisciplines. Students are advised, but not required, to complete GEOS courses at the 13000 level in their first or second year.

Program Requirements for the BA in Geophysical Sciences

Candidates for the BA in Geophysical Sciences begin their program of study with GEOS 13100-13200-13300, which is the introductory sequence. Students are strongly encouraged to take these classes before their third year. 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.

Students must also complete one year of chemistry (CHEM 11101-11201-11301/11102-11202-11302 or equivalent), one year of physics (PHYS 12100-12200-12300 or higher), one year of calculus (MATH 13100-13200-13300 or higher), and BIOS 20184-20185.

A minimum of six additional 20000-level science courses are required. At least four must be from the Earth Sciences (List A). Up to two may be chosen from Support Courses for the Earth Sciences (List C). Up to two may be chosen from Mathematics and Statistics Courses (List F). One may be a field course.

Summary of Requirements for the BA in Geophysical Sciences

General Education	CHEM 11101-11201/11102-11202 or equivalent*	
	MATH 13100-13200 or higher*	
	BIOS 20184-20185	
Major	1	CHEM 11301/11302 or equivalent*
	3	PHYS 12100-12200-12300 or higher*
	3	GEOS 13100-13200-13300
	2	MATH 13300 or higher*, plus one Mathematics or Statistics Course (List F)
	6	courses in 20000-level science (at least four courses must be from List A, and up to two courses may be from Lists C and/or F)
	15	

* *Credit may be granted by examination.*

Program Requirements for the BS in Geophysical Sciences

Candidates for the BS in Geophysical Sciences begin their program of study with GEOS 13100-13200-13300, which is the introductory sequence. Students are strongly encouraged to take these classes before their third year. 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.

Students must also complete one year of chemistry (CHEM 11101-11201-11301/11102-11202-11302 or equivalent), one year of physics (PHYS 12100-12200-12300 or higher), one year of calculus (MATH 13100-13200-13300 or higher), and BIOS 20184-20185.

A minimum of eight additional 20000-level science courses are required. At least three must be from the Geophysical Sciences (List A). Up to three may be chosen from Support Courses for the Geophysical Sciences (List C). Up to two may be from Mathematics and Statistics Courses (List F). One may be a field course. One may be a Reading and Research Course (GEOS 29700).

Summary of Requirements for the BS in Geophysical Sciences

General Education		CHEM 11101-11201/11102-11202 or equivalent*
		MATH 13100-13200 or higher*
		BIOS 20184-20185
Major	1	CHEM 11301/11302 or equivalent*
	3	PHYS 12100-12200-12300 or higher*
	3	GEOS 13100-13200-13300
	3	MATH 13300 or higher*, plus two Mathematics or Statistics Courses (List F)
	8	courses in 20000-level science (at least three courses must be from List A, up to three courses may be from List C, and up to two courses may be from List F)
	18	

* *Credit may be granted by examination.*

Program Requirements for the BS in Environmental Science

Candidates for the BS in Environmental Science begin their program of study with GEOS 13300-13400. Students are strongly encouraged to take these classes before their third year. 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.

Students must also complete one year of chemistry (CHEM 11101-11201-11301/11102-11202-11302 or equivalent), one year of physics (PHYS 12100-12200-12300 or higher), one year of calculus (MATH 13100-13200-13300 or higher), and BIOS 20184-20185.

GEOS 23900 (Environmental Chemistry) and BIOS 23351 (Conservation Ecology) are required for the major. NOTE: GEOS 23900 and BIOS 23351 typically are offered every other year.

A minimum of four additional 20000-level science courses are required. One must be a GEOS course and one must be a BIOS course chosen from the Environmental Sciences courses (List B). Others may be chosen from Environmental Sciences Courses (List B), Support Courses for the Environmental Sciences (List D), or Mathematics and Statistics Courses (List F). One may be a field course. One may be a Reading and Research Course (GEOS 29700). Three other courses must be chosen from Support Courses for the Environmental Social Sciences (List E). In addition, two other courses must be chosen from Support Courses for Mathematics and Statistics (List F), one of which must be a statistics course.

Summary of Requirements for the BS in Environmental Science

General Education		CHEM 11101-11201/11102-11202 or equivalent* MATH 13100-13200 or higher* BIOS 20184-20185
Major	1	CHEM 11301/11302 or equivalent*
	3	PHYS 12100-12200-12300 or higher*
	2	GEOS 13300-13400
	1	GEOS 23900 (Environmental Chemistry)
	1	BIOS 23351 (Ecological Applications to Conservation Biology)
	4	courses in 20000-level science, at least one from GEOS in List B, and at least one from BIOS in List B; others may be chosen from Lists B, D, or F
	3	Environmental Social Sciences courses from List E
	3	MATH 13300 or higher*, plus one statistics course and one other course from List F
	18	

* *Credit may be granted by examination.*

List A: Geophysical Sciences Courses

GEOS 21000. Introduction to Mineralogy
GEOS 21100. Introduction to Petrology
GEOS 21200. Physics of the Earth
GEOS 21205. Introduction to Seismology, Earthquakes, and Near-Surface Earth Seismicity
GEOS 21400. Thermodynamics and Phase Change
GEOS 22000. Origin and Evolution of the Solar System
GEOS 22040. Formation of Planetary Systems in our Galaxy: From Dust to Planetesimals
GEOS 22050. Formation of Planetary Systems in our Galaxy: From Planetesimals to Planets
GEOS 22100. Cosmochronology
GEOS 22200. Geochronology
GEOS 23200. Climate Dynamics of the Earth and Other Planets
GEOS 23400. Global Warming
GEOS 23500. Physical Oceanography
GEOS 23600. Chemical Oceanography
GEOS 23700. Proxies and Reconstructions in Paleoceanography
GEOS 23800. Global Biogeochemical Cycles

GEOS 23805. Stable Isotope Biogeochemistry
GEOS 23900. Environmental Chemistry
GEOS 24500. The Atmosphere and Ocean in Motion
GEOS 24600. Laboratory Course on Weather and Climate
GEOS 24705. Energy: Science, Technology, and Human Usage
GEOS 26300. Invertebrate Paleobiology and Evolution
GEOS 26400. Principles of Paleontology
GEOS 27000. Evolutionary History of Terrestrial Ecosystems
GEOS 28000. Introduction to Structural Geology
GEOS 28100. Global Tectonics
GEOS 28300. Principles of Stratigraphy
GEOS 29700. Reading and Research in the Geophysical Sciences

Field Courses in Geophysical Sciences
GEOS 29001. Field Course in Geology and Geophysics
GEOS 29002. Field Course in Modern and Ancient Environments
GEOS 29003. Field Course in Oceanography

List B: Environmental Sciences Courses

Geophysical Sciences
GEOS 21000. Introduction to Mineralogy
GEOS 23200. Climate Dynamics of the Earth and Other Planets
GEOS 23400. Global Warming
GEOS 23600. Chemical Oceanography
GEOS 23800. Global Biogeochemical Cycles
GEOS 23805. Stable Isotope Biogeochemistry
GEOS 23900. Environmental Chemistry
GEOS 24500. Atmosphere and Ocean in Motion
GEOS 24600. Laboratory Course on Weather and Climate
GEOS 24705. Energy: Science, Technology, and Human Usage
GEOS 24711-24712-24714. Feeding the City: The Urban Food Chain
GEOS 28000. Introduction to Structural Geology
GEOS 29700. Reading and Research

Biological Sciences
BIOS 23280. Genetically Modified Organisms
BIOS 23289. Marine Ecology
BIOS 23351. Ecological Applications to Conservation Biology
BIOS 23406. Biogeography
BIOS 25206. Fundamentals of Bacterial Physiology
BIOS 29291. The History of U.S. Public Health

Field Courses in Environmental Sciences
GEOS 24700. The Planetary Footprint of Farming
GEOS 29005. Field Course in Environmental Sciences

List C: Support Courses for the Geophysical Sciences

*Biological Sciences**
BIOS 20191. Cell and Molecular Biology
BIOS 20194. Developmental Biology
BIOS 20200. Introduction to Biochemistry
BIOS 20260. Chordate Evolutionary Biology
BIOS 21209. Molecular Biology
BIOS 21304. Photosynthesis
BIOS 22243. Biomechanics of Organisms
BIOS 22244. Fundamentals of Invertebrate Biology
BIOS 23240. The Diversity and Evolution of Plants
BIOS 23289. Marine Ecology
BIOS 23351. Ecological Applications to Conservation Biology
BIOS 23403. Systematic Biology
BIOS 25206. Fundamentals of Bacterial Physiology
BIOS 29306. Evolutionary Processes

Chemistry
CHEM 20100, 20200. Inorganic Chemistry I, II
CHEM 22000, 22100, 22200 or 22000, 23100, 23200. Organic Chemistry I, II, III
CHEM 26100, 26200, 26300. Physical Chemistry I, II, III

Physics
PHYS 18500. Intermediate Mechanics
PHYS 19700. Statistical and Thermal Physics
PHYS 22500, 22700. Intermediate Electricity and Magnetism I, II
PHYS 22600. Electronics

* *Excluding courses used to meet general education requirement for the biological sciences.*

List D: Support Courses for the Environmental Sciences

Chemistry
CHEM 20100, 20200. Inorganic Chemistry I, II
CHEM 22000, 22100, 22200 or 22000, 23100, 23200. Organic Chemistry I, II, III
CHEM 26100, 26200, 26300. Physical Chemistry I, II, III

Biological Sciences
BIOS 2018x or 2019x series*
BIOS 20200. Introduction to Biochemistry
BIOS 20242. Physiology

BIOS 21209. Molecular Biology
BIOS 21304. Photosynthesis
BIOS 25206. Fundamentals of Bacterial Physiology
BIOS 26099. Quantitative Topics in Biology I: Ecology

* *Excluding courses used to meet general education requirement for the biological sciences.*

Ecology and Evolution
BIOS 23252. Field Ecology
BIOS 23254. Mammalian Ecology
BIOS 23256. Fundamentals of Molecular Evolution
BIOS 23407. Plant Atmosphere Interactions

List E: Support Courses for the Environmental Social Sciences

Public Policy
PBPL 21800. Economics and Environmental Policy
PBPL 22000. Environmental Policy
PBPL 22600. U.S. Environmental Politics
PBPL 23100. Environmental Law
PBPL 24301. Global Environmental Politics
PBPL 24400. Is Development Sustainable?
PBPL 24701. U.S. Environmental Policy

Economics
ECON 19800. Introduction to Microeconomics
ECON 19900. Introduction to Macroeconomics
ECON 26500. Environmental Economics
ECON 26510. Advanced Topics in Environmental Economics

List F: Support Courses for Mathematics and Statistics

Geophysical Sciences
GEOS 24300. Analysis of Oceanographic Data
GEOS 25200. Data Analysis in the Earth Sciences II: Application to Spatio-Temporal Data
GEOS 25300. Inverse Methods in the Geophysical Sciences

Mathematics
MATH 19620. Linear Algebra
MATH 20000, 20100. Mathematical Methods for Physical Sciences I, II
MATH 20300, 20400, 20500. Analysis in Rn I, II, III
MATH 21100. Basic Numerical Analysis
MATH 22000. Introduction to Mathematical Methods in Physics
MATH 25100. Chaos, Complexity, and Computers (=CMSC 27900)
MATH 27000. Basic Complex Variables

MATH 27300. Basic Theory of Ordinary Differential Equations
MATH 27500. Basic Theory of Partial Differential Equations
MATH 38300. Numerical Solutions to Partial Differential Equations

Physics
PHYS 22100. Mathematical Methods in Physics

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

STAT 22000. Introductory Statistics with Applications
or STAT 23400. Statistical Models and Methods
STAT 22400. Applied Regression Analysis
STAT 24400-24500. Statistical Theory and Methods I, II
STAT 26100. Time Dependent Data

Computing
CMSC 28510. Introduction to Scientific Computing
CMSC 34200. Numerical Hydrodynamics

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. GEOS 29700 (Reading and Research) 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. The research paper must be completed by eighth week of the quarter in which the student will graduate.

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 both program chairs no later than the end of third year. Certain requirements must be met. A consent form, to be signed by the chairs, 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.

Field Trips and Field Courses. The department typically sponsors several trips each year that range in length from one day to five weeks. Destinations of trips have included areas as far afield as Newfoundland; the Canadian Rockies; Baja, California; the Caribbean; Italy; and Iceland. The longer trips are designed as undergraduate field courses (GEOS 29001, 29002, 29003, 29004, 29005). Most of the shorter trips are mostly scheduled in connection with undergraduate and graduate lecture courses. However, the trips are open to all students and faculty if space permits.

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.

BS in Environmental Sciences

Environmental Climatology. BIOS 21304 and 25206; ECON 26500; GEOS 23200 and 24500; MATH 21100 and 25000; and PBPL 22000 and 23100

Environmental Conservation. BIOS 23252, 23289, and 23406; ECON 26500; GEOS 23800; MATH 21100; PBPL 22000 and 23100; and STAT 22400 and 23400

Environmental Geochemistry. BIOS 25206; CHEM 26200; ECON 26500; GEOS 23600 and 23800; MATH 21100; PBPL 22000 and 23100; and STAT 22000

BS in Geophysical Sciences

Chemistry of Atmosphere and Ocean. CHEM 26100, 26200, and 26300; GEOS 23200, 23500, 23600, 23900, and 24500; and MATH 20000 and 20100

Environmental Geochemistry. BIOS 20191; CHEM 26200 and 26300; GEOS 21000, 23600, 23800, 23900, and 28300; MATH 21100; and STAT 23400

Geochemistry. CHEM 26100, 26200, and 26300; GEOS 21000, 21100, 21200, 22000, and 23800; MATH 20000; and STAT 23400

Geophysics. GEOS 21000, 21200, 22000, 25200, and 28100; MATH 20000; PHYS 18500, 22500 and 22700; and STAT 23400

Paleontology. BIOS 22243, 23289, and 23403; GEOS 21000, 26300, 26400, 28000, and 28300; and STAT 22400 and 23400

Physics of Climate. GEOS 23200, 23500, 23800, 24500, and 24600; MATH 20000, 20100, and 21100; and PHYS 18500 and 19700

Structure/Tectonics. GEOS 21000, 21100, 21200, 22000, 22400, and 28000; MATH 20000; PHYS 18500 and 22500; and STAT 23400

Faculty

D. Archer, C. Boyce, F. Ciesla, A. Colman, P. Crane, N. Dauphas, A. Davis, M. Foote, J. Frederick, L. Grossman, D. Heinz, D. Jablonski, S. Kidwell, M. LaBarbera, D. MacAyeal, P. Martin, E. Moyer, N. Nakamura, M. Pellin, R. Pierrehumbert, F. Richter, D. Rowley, R. Srivastava, M. Webster

Courses: Geophysical Sciences (geos)

13100. Physical Geology. 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. *F. Richter. Autumn. L.*

13200. Earth History. *PQ: GEOS 13100 or consent of instructor.* This course covers the paleogeographic, biotic, and climatic development of the Earth. *C. Boyce. Winter. L.*

13300. The Atmosphere. (=ENST 13300) *PQ: MATH 13200 or consent of instructor.* This course introduces the physics, chemistry, and phenomenology of the Earth's atmosphere, with an emphasis on the role of the atmosphere as a component of the planet's life support system. Topics include (1) atmospheric composition, evolution, and structure; (2) solar and terrestrial radiation; (3) the role of water in atmospheric processes; (4) winds, the global circulation, and weather systems; and (5) atmospheric chemistry and pollution. We focus on the mechanisms by which human activity can influence the atmosphere and on interactions between atmosphere and biosphere. *J. Frederick. Spring.*

13400. Global Warming: Understanding the Forecast. (=ENST 12300, PHSC 13400) *PQ: MATH 10600, or placement into 13100 or higher, or consent of instructor required; some knowledge of chemistry or physics helpful.* 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; and an examination of the records of recent and past climates, such as the glacial world and Eocene and Oligocene warm periods. *D. Archer. Autumn, Spring. L.*

21000. Introduction to Mineralogy. *PQ: CHEM 11100-11200-11300 or equivalent.* This course covers structure, chemical composition, stability, and occurrence of major rock-forming minerals. Labs concentrate on mineral identification with the optical microscope. *L. Grossman. Autumn. L.*

21100. Introduction to Petrology. *PQ: GEOS 21000.* 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. *N. Dauphas. Spring. L.*

21200. Physics of the Earth. *PQ: Prior calculus and college-level physics courses, or consent of instructor.* 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. *F. Richter. Spring. L.*

21205. Introduction to Seismology, Earthquakes, and Near-Surface Earth Seismicity. 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. *D. MacAyeal. Autumn.*

21400. Thermodynamics and Phase Change. *PQ: MATH 20000-20100-20200 and college-level chemistry and calculus, or consent of instructor.* This course develops the mathematical structure of thermodynamics with emphasis on relations between thermodynamic variables and equations of state. These concepts are then applied to homogeneous and heterogeneous phase equilibrium, culminating in the construction of representative binary and ternary phase diagrams of petrological significance. *D. Heinz. Autumn.*

22000. Origin and Evolution of the Solar System. (=ASTR 22000) *PQ: Consent of instructor required; knowledge of physical chemistry recommended.* Representative topics include abundance and origin of the elements; formation, condensation, and age of the solar system; meteorites and the historical record of the solar system they preserve; comets and asteroids; the planets and their satellites; temperatures and atmospheres of the planets; and the origin of the Earth's lithosphere, hydrosphere, atmosphere, and biosphere. *L. Grossman. Winter. L.*

22040. Formation of Planetary Systems in our Galaxy: From Dust to Planetesimals. *PQ: One year of college-level calculus and physics or chemistry, or consent of instructor.* 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. *F. Ciesla. Autumn.*

22050. Formation of Planetary Systems in our Galaxy: From Planetesimals to Planets. *PQ: Consent of instructor.* 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. *F. Ciesla. Winter.*

22100. Cosmochronology. *PQ: Background in college-level geology, physics, and mathematics.* This course covers cosmology and the age of the universe (Big-Bang theory is treated in a Newtonian perspective, and some of the methods used for constraining cosmological parameters are presented); the age of the Milky Way (main sequence lifetimes in globular clusters and U/Th ages of old stars); the duration of nucleosynthesis (galactic chemical evolution and its application to cosmochronology); and the age of the solar system (condensation of refractory inclusions and definition of time zero). *N. Dauphas. Winter.*

22200. Geochronology. *PQ: Background in college-level geology, physics, and mathematics.* 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). *N. Dauphas. Autumn.*

23000. Atmospheric Chemistry. *PQ: Prior chemistry and calculus courses required; some Matlab or other programming experience recommended.* This course covers chemical transformation in the Earth's atmosphere, including kinetics, photochemistry, and chemical cycles. Topics include chemical processes in the stratosphere, free troposphere, and near-surface region (air pollution and photochemical smog). We also discuss sources, sinks, and lifetimes of species of importance to biology and climate. There is a comparison with atmospheres of other planets and an introduction to chemistry/climate models. *E. Moyer. Winter. L.*

23200. Climate Dynamics of the Earth and Other Planets. *PQ: Prior physics course (preferably PHYS 13300 and 14300) and knowledge of calculus required; prior geophysical sciences course not required. Prior programming experience helpful but not required.* 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. *E. Moyer. Autumn. L.*

23400. Global Warming: Understanding the Forecast. *PQ: MATH 10600, or placement in MATH 13100 or higher, or consent of instructor required; some knowledge of chemistry or physics helpful.* 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; and an examination of the records of recent and past climates, such as the glacial world and Eocene and Oligocene warm periods. Lectures are shared with PHSC 13400, but students enrolled in GEOS 23400 are required to write an individual research term paper. *D. Archer. Spring. L.*

23500. Physical Oceanography. *PQ: GEOS 23200 or consent of instructor.* This course provides a conceptual understanding of the dynamics of ocean circulation and a background in physical oceanography for students interested in further study of climate dynamics, chemical oceanography, marine biology, and paleontology. Topics include geometry of map projections, hypsometry of ocean basins and the geoid, temperature and salinity structure, watermasses, geostrophy and geostrophic adjustment, Ekman layers, coastal upwelling, Sverdrup balance, vorticity balance and western intensification, and waves and tides. *D. MacAyeal, P. Martin. Winter. L.*

23600. Chemical Oceanography. *PQ: Consent of instructor.* This course introduces the geochemistry of the oceans with an emphasis on topics relevant to global change, past and future. The role of the ocean in the global carbon cycle is discussed, along with the interplay between ocean circulation, biology, and physical chemistry and its impact on the distributions of nutrients, carbon, and oxygen in the ocean. Also covered are sediment geochemistry and what sediments can tell us about oceans and climates of the past. *P. Martin. Autumn.*

23700. Proxies and Reconstructions in Paleoceanography. *PQ: Third-year standing or higher. Knowledge of physical or chemical oceanography and/or interest in research in paleoceanography or paleoclimate.* This course covers the tools used to reconstruct the environmental history of the oceans, as well as some of the actual reconstructions. Our focus is on tools used for and reconstructions during the Cenozoic. *P. Martin. Spring. L.*

23800. Global Biogeochemical Cycles. *PQ: CHEM 11100-11200 or consent of instructor.* This survey course covers the geochemistry of the surface of the Earth, with emphasis on biological and geological processes, their assembly into self-regulating systems, and their potential sensitivity to anthropogenic or other perturbations. Budgets and cycles of carbon, nitrogen, oxygen, phosphorous, sulfur, and silicon are discussed, as well as fundamentals of the processes of weathering, sediment diagenesis, and isotopic fractionation. What is known about the biogeochemistry of the Earth through geologic time is also presented. *D. Archer. Autumn.*

23805. Stable Isotope Biogeochemistry. *PQ: CHEM 11100-11200-11300 or equivalent; 13100-13200-13300 or consent of instructor*. Stable isotopes of H, C, O, N, and S are valuable tools for understanding the biological and geochemical processes that have shaped the composition of Earth's atmosphere and oceans throughout our planet's history. This course examines basic thermodynamic and kinetic theory to describe the behavior of isotopes in chemical and biological systems. We then examine the stable isotope systematics of localized environmental processes, and see how local processes contribute to global isotopic signals that are preserved in ice, sediment, rock, and fossils. Special emphasis is placed on the global carbon cycle, the history of atmospheric oxygen levels, and paleoclimate. *A. Colman. Winter.*

23900. Environmental Chemistry. (=ENST 23900) *PQ: CHEM 11101-11201 or equivalent, and prior calculus course.* 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 offered in alternate years. D. Archer, A. Colman. Autumn. L.*

24300. Analysis of Oceanographic Data. *PQ: Consent of instructor required; knowledge of Matlab recommended.* This course covers fundamental techniques for the analysis of geophysical and oceanographic time series (e.g., sampling problems, least squares techniques, spectral analysis, interpretation of timeseries, design of experiments). We also cover probability densities, sampling errors, spectral analysis, empirical orthogonal functions, correlation, linear estimation, and objective mapping. We utilize real oceanographic data from diverse environments and on many different spatial and temporal scales with Matlab. *Winter.*

24500. The Atmosphere and Ocean in Motion. *PQ: GEOS 13300 or equivalent, and calculus.* The motion of the atmosphere and ocean not only affects daily weather conditions but is also critical in maintaining the habitable climate of our planet. This course teaches: (1) observed patterns of large-scale circulation of the atmosphere and ocean; (2) physical principles that drive the observed circulation; (3) transport of heat, angular momentum, and other quantities; and (4) climate variability and predictability. The lectures are supplemented by problem sets and a computer lab project. *N. Nakamura. Spring.*

24600. Laboratory Course on Weather and Climate. Working in groups, students gain hands-on experience in designing, implementing, and analyzing experiments concerning the principles of rotating fluids that underlie weather and climate. *N. Nakamura. Spring.*

24700. The Planetary Footprint of Farming. (=ENST 25300) *PQ: Third- or fourth-year standing, or consent of instructor.* This course draws on a ten-day field study of small, organic farms in the Berkshires to explore the environmental impact of modern industrial agriculture and realistic alternatives. Of interest are the roles of natural setting (i.e., geology, climate, meteorology); energy use and material flow; techniques of food production; dietary choices; and development and conservation strategies. A classroom component of lectures, readings, and exercises precedes the field trip. Students are financially responsible for travel in December. *P. Martin. Autumn, Winter.*

24705. Energy: Science, Technology, and Human Usage. (=ENST 24705) *PQ: Knowledge of physics or consent of instructor.* 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). *E. Moyer. Winter.*

24711-24712-24714. Feeding the City: The Urban Food Chain. (=ENST 25701-25702-25703) *PQ: Consent of instructor based on application. Enrollment preference given to second- and third-year students. GEOS 24713 is a zero-unit, noncredit course that must be taken for* P/F *grading. This sequence meets the field study/intern degree requirement for students who are majoring in Environmental Studies.* This is a three-quarter sequence (Winter, Spring, Autumn) combined with an internship (Summer) that focuses on energy use and related greenhouse gas emissions of small-scale, diversified farms serving Chicago. Interns gather data on energy use and greenhouse gas emissions at Chicago-area farms, both rural and urban. Other agriculture or food-related projects are considered on a case-by-case basis. In Winter and Spring Quarters, students participate in an interdisciplinary reading and research course to explore and discuss the environmental impacts, as well as social and economic issues, of local and national food production. Presentations are made by guest lecturers, and students participate in a series of fieldtrips within the Chicago area. Students are then matched with farm sites where they work in Summer Quarter as farm interns and keep detailed records to document energy input/output and other data. In Autumn Quarter, students finish the reading and research component, as well as analyze their collected data. There is also opportunity to develop theses, both science-based and social-science based. *Two-quarters of credit (200 units) are granted in the final quarter after successful completion of all three quarters and the summer internship. To meet requirements for full-time student status, students must carry at least three additional courses while registered for this course. Stipend provided for summer internship. P. Martin. Winter, Spring, Autumn.*

25200. Data Analysis in the Earth Sciences II: Application to Spatio-Temporal Data. This course covers probability, distributions, sampling, time-series analysis, and spatio-temporal data analysis. While we focus on geophysical applications (e.g., oceanography, atmospheric and climate dynamics, geochemistry, solid-earth geophysics), students from all relevant disciplines are welcome (in past years, topics in such fields as psychology and botany were used as case studies). Work in departmental computing lab required. *Winter. L.*

25300. Inverse Methods in the Geophysical Sciences. *PQ: Consent of instructor.* Inverse theory is a set of mathematical techniques used to obtain inferences about the Earth from physical measurements. The focus of this course is on formulating and solving inverse problems and understanding the nonuniqueness and resolution associated with inversions. We cover solutions of linear and nonlinear inverse problems in geophysics by optimization techniques such as norm minimization and linear programming. Both theory and applications are covered. *Spring.*

26300. Invertebrate Paleobiology and Evolution. (=BIOS 23261, EVOL 32400) *PQ: GEOS 13100 and 13200, or equivalent. Completion of the general education requirement in the biological sciences or consent of instructor.* 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. Labs and field trips required. *M. Webster. Autumn. L.*

26400. Principles of Paleontology. (=BIOS 23255, EVOL 32300) *PQ: GEOS 13100-13200, or completion of the general education requirement in the biological sciences, or consent of instructor.* Our focus is on the nature of the fossil record, the information it provides on patterns and processes of evolution through geologic time, and how it can be used to solve geological and biological problems. Lectures cover the principles of paleontology (e.g., fossilization, classification, morphologic analysis and interpretation, biostratigraphy, paleoecology, macroevolution); labs are systematic, introducing major groups of fossil invertebrates. *M. Foote. Spring. L.*

27000. Evolutionary History of Terrestrial Ecosystems. This seminar course covers the evolution of terrestrial ecosystems from their Paleozoic assembly through to the modern world. The fossil history of plant, vertebrate, invertebrate, and fungal lineages are covered, as well as the diversification of their ecological interactions. The influence of extinction events and important extrinsic factors (e.g., geography, climate, atmospheric composition) also are considered. *C. K. Boyce. Spring. L.*

28000. Introduction to Structural Geology. *PQ: GEOS 13100.* 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. *D. Rowley. Winter.*

28100. Global Tectonics. *PQ: GEOS 13100 or consent of instructor.* 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. *This course is offered in alternate years. D. Rowley. Winter. L.*

28300. Principles of Stratigraphy. *PQ: GEOS 13100-13200 or equivalent required; GEOS 23500 and/or 28200 recommended.* 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. *S. Kidwell. Autumn. L.*

29001. Field Course in Geology. *PQ: GEOS 13100-13200 and consent of instructor.* Students in this course visit classic locations to examine a wide variety of geological environments and processes, including active tectonics, ancient and modern sedimentary environments, and geomorphology. Interested students should contact the departmental counselor. *Summer/Autumn.*

29002. Field Course in Modern and Ancient Environments. This course uses weekly seminars during Winter Quarter to prepare for a one-week fieldtrip over spring break, where students acquire experience with sedimentary rocks and the modern processes responsible for them. The focus for Winter 2010 is the geology and biology of tropical carbonate settings, including the formation of reefs, working out of the Gerace Research Station on San Salvador, Bahamas. Interested students should contact the instructor in Autumn Quarter 2009. *S. Kidwell. Winter.*

29003. Field Course in Oceanography. *PQ: Consent of instructor.* 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. Interested students should contact the departmental counselor. *Spring, Summer.*

29005. Field Course in Environmental Science. *PQ: Consent of instructor.* Interested students should contact the departmental counselor. *Autumn, Winter.*

29700. Reading and Research in the Geophysical Sciences. *PQ: Consent of instructor and departmental counselor. 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. Summer, Autumn, Winter, Spring.*