

# Geophysical Sciences

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## 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 B.A. and B.S. programs prepare students for careers that draw upon the earth, atmospheric, and planetary sciences. However, the B.S. degree provides a more focused and intensive program of study for students who intend to pursue graduate work in these disciplines. The B.A. 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 B.A. and B.S. 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 B.A. in Geophysical Sciences

Candidates for the B.A. 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 11101-11201/11102-11202 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 B.A. in Geophysical Sciences

|                  |                                 |
|------------------|---------------------------------|
| <i>General</i>   | CHEM 11101-11201/11102-11202 or |
| <i>Education</i> | equivalent*                     |
|                  | MATH 13100-13200 or higher*     |
|                  | BIOS 20184-20185                |

|              |  |  |
|--------------|--|--|
| <i>Major</i> | 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 from List A, and up to two each from Lists C and F |
|              | <hr style="width: 100%; border: 0.5px solid black; margin-bottom: 5px;"/> 15 |  |

\* *Credit may be granted by examination.*

### **Program Requirements for the B.S. in Geophysical Sciences**

Candidates for the B.S. 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 11101-11201/11102-11202 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. Up to three may be chosen from Support Courses for the Earth Sciences (List C). Up to four may be from Mathematics and Statistics Courses (List F). One may be a field course.

### **Summary of Requirements for the B.S. in Geophysical Sciences**

|                          |          |   |
|--------------------------|----------|---|
| <i>General Education</i> |          | CHEM 11101-11201/11102-11202 or equivalent*                                       |
|                          |          | MATH 13100-13200 or higher*   |
|                          |          | BIOS 20184-20185  |
| <i>Major</i>             | 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, as many as three from List C, and two from List F |
|                          | <hr/> 18 |   |

\* *Credit may be granted by examination.*

### Program Requirements for the B.S. in Environmental Science

Candidates for the B.S. in Environmental Science 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 11101-11201/11102-11202 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 are typically 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. Three must be chosen from Support Courses for the Environmental Social Sciences (List E).

### Summary of Requirements for the B.S. in Environmental Science

|                          |       |   |
|--------------------------|-------|---|
| <b>General Education</b> |       | CHEM 11101-11201/11102-11202 or equivalent*   |
|                          |       | MATH 13100-13200 or higher*   |
|                          |       | BIOS 20184-20185  |
| <b>Major</b>             | 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  |
|                          | <hr/> |   |
|                          | 18    |   |

\* Credit may be granted by examination.

### LIST A. *Geophysical Sciences Courses*

GEOS 21200. Physics of the Earth  
 GEOS 21300. Origin and Evolution of the Solar System  
 GEOS 21700. Introduction to Mineralogy  
 GEOS 21800. Introduction to Petrology  
 GEOS 21900. Introduction to Structural Geology  
 GEOS 22200. Principles of Stratigraphy  
 GEOS 22300. Introduction to Paleontology  
 GEOS 22400. Invertebrate Paleobiology and Evolution  
 GEOS 22500. Global Tectonics  
 GEOS 23200. Comparative Planetary Climates  
 GEOS 23300. Physical Oceanography  
 GEOS 23400. Chemical Oceanography  
 GEOS 23700. Cumulus Physics  
 GEOS 23800. Global Biogeochemical Cycles  
 GEOS 23900. Environmental Chemistry  
 GEOS 24500. Atmosphere and Ocean in Motion  
 GEOS 29700. Reading and Research

*Field Courses in Geophysical Sciences*

- GEOS 28001. Field Trip in Geology and Geophysics  
 GEOS 28002. Field Trip in Modern and Ancient Environments  
 GEOS 28003. Field Trip in Oceanography  
 GEOS 28004. Field Trip in Glaciology

**LIST B. *Environmental Sciences Courses***

- GEOS 21700. Introduction to Mineralogy  
 GEOS 21900. Introduction to Structural Geology  
 GEOS 23200. Comparative Planetary Climates  
 GEOS 23400. Chemical Oceanography  
 GEOS 23800. Global Biogeochemical Cycles  
 GEOS 23900. Environmental Chemistry  
 GEOS 24500. Atmosphere and Ocean in Motion  
 GEOS 29700. Reading and Research  
 BIOS 23280. Genetically Modified Organisms  
 BIOS 23289. Marine Ecology  
 BIOS 23351. Ecological Applications to Conservation Biology  
 BIOS 23406. Biogeography  
 BIOS 25206. Bacterial Physiology  
 BIOS 29291. The History of U.S. Public Health

*Field Courses in Environmental Sciences*

- GEOS 28005. Field Trip in Environmental Sciences

**LIST C. *Support Courses for the Geophysical Sciences***

*Biology*

- BIOS 20184. Biological Diversity\*  
 BIOS 20185. Ecology and Evolution\*  
 BIOS 20191. Cell and Molecular Biology  
 BIOS 20194. Developmental Biology  
 BIOS 20200. Introduction to Biochemistry  
 BIOS 20239. Molecular Biology  
 BIOS 20260. Chordate Evolutionary Biology  
 BIOS 21304. Photosynthesis  
 BIOS 22244. Introduction to Invertebrate Zoology  
 BIOS 22243. Biomechanics of Organisms  
 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. Introduction to Bacterial Physiology  
 BIOS 29306. Evolutionary Processes

*Chemistry*

CHEM 20100, 20200. Inorganic Chemistry I, II  
CHEM 22000, 22100, 22200 or 22000, 23100, 23200.

Organic Chemistry

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

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

CHEM 22000, 22100, 22200 or 22000, 23100, 23200 Organic Chemistry

CHEM 26100, 26200, 26300. Physical Chemistry

*Biology*

BIOS 2018x of 2019x series\*

BIOS 20200. Introduction to Biochemistry

BIOS 20239. Molecular Biology

BIOS 20242. Physiology

BIOS 21304. Photosynthesis

BIOS 25206. Introduction to Bacterial Physiology

BIOS 26106. Quantitative Topics in Ecology

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

*Ecology and Evolution*

BIOS 23252. Field Ecology

BIOS 23254. Mammal Ecology

BIOS 23256. 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. The Environment in U.S. Politics

PBPL 23100. Environmental Law

PBPL 24300. 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***

*Geosciences*

GEOS 23500. Data Analysis in the Earth Sciences I  
 GEOS 23600. Data Analysis in the Earth Sciences II:  
     Application to Spatio-Temporal Data  
 GEOS 21000. Scientific Computing  
 GEOS 35401. Numerical Methods for Fluid Dynamics

*Mathematics*

MATH 20000, 20100. Mathematical Methods for Physical Sciences I, II  
 MATH 20300, 20400, 20500. Analysis in  $R^n$  I, II, III  
 MATH 21100. Basic Numerical Analysis  
 MATH 22000. Introduction to Mathematical Methods in Physics  
 MATH 25000. Elementary Linear Algebra  
 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 (=CMSC 38300)

*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. Introduction to Time Series Analysis

*Computing*

CMSC 28510. Introduction to Scientific Computing



|                    | AUTUMN   | WINTER   | SPRING   | SUMMER  |
|--------------------|--|--|--|---|
| <i>First Year</i>  | GEOS 13100<br>General<br>Chemistry<br><br>Calculus | GEOS 13200<br>General<br>Chemistry<br><br>Calculus | GEOS 13300<br>General<br>Chemistry<br><br>Calculus |   |
| <i>Second Year</i> | PHYS 12100<br><br>MATH 20000                       | PHYS 12200<br><br>MATH 20100                       | PHYS 12300<br><br>MATH 20200                       | GEOS 22800<br>or<br>GEOS 24000                    |
| <i>Third Year</i>  | geophysical<br>sciences<br>elective                | geophysical<br>sciences<br>elective                | geophysical<br>sciences<br>elective                | GEOS 22800<br>(if not taken<br>in second<br>year) |
| <i>Fourth Year</i> | geophysical<br>sciences<br>elective                | geophysical<br>sciences<br>elective                | geophysical<br>sciences<br>elective                |   |

#### 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 B.A. or B.S. degree with honors is awarded to students who meet the following requirements: (1) a GPA in the major of 3.0 or higher; and (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.

Students who wish to submit a single paper to meet the honors requirement in geophysical sciences and the B.A. 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 22800, 22900, 23000, and 24000). 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 B.S. Program.** 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.

*B.S. in Environmental Sciences*

Environmental Climatology. BIOS 20184 and 20185 (Fundamentals sequence), plus 21304, 23351, 23406, and 25206; ECON 26500; GEOS 23200, 23900, and 24500; MATH 21100 and 25000; and PBPL 22000

Environmental Conservation. BIOS 20184 and 20185 (Fundamentals sequence), plus 23351, 23406, and 23289; CHEM 26200; ECEV 23252; ECON 26500; GEOS 23400, 23800, and 23900; MATH 21100; PBPL 22000; and STAT 22400 and 23400

Environmental Geochemistry. BIOS 20184 and 20185 (Fundamentals sequence), plus 23351, 25206, and 23280; CHEM 26200; ECON 26500; GEOS 23400, 23800, and 23900; MATH 21100; PBPL 22000; and STAT 22000

*B.S. in Geophysical Sciences*

Chemistry of Atmosphere and Ocean. BIOS 20184 and 20185 (Fundamentals sequence); CHEM 26100, 26200, and 26300; GEOS 23200, 23300, 23400, 23900, and 24500; and MATH 20000 and 20100

Environmental Geochemistry. BIOS 20184 and 20185 (Fundamentals sequence), plus 20181; CHEM 26200 and 26300; GEOS 21700, 22200, 23400, 23800, and 23900; MATH 21100; and STAT 23400

Geochemistry. BIOS 20184 and 20185 (Fundamentals sequence); CHEM 26100, 26200, and 26300; GEOS 21200, 21300, 21700, 21800, and 23800; MATH 20000; and STAT 23400

Geophysics. BIOS 20184 and 20185 (Fundamentals sequence); GEOS 21200, 21300, 21700, 22500, and 22600; MATH 20000; and STAT 23400

Paleontology. BIOS 20184 and 20185 (Fundamentals sequence), plus 22243, 23289, and 23403; GEOS 21700, 21900, 22200, 22300, and 22400; and STAT 23400 and 23500

Physics of Climate. BIOS 20184 and 20185 (Fundamentals sequence); GEOS 23200, 23300, 23700, 24100, and 24500; MATH 20000 and 20100; and PHYS 18500

Structure/Tectonics. BIOS 20184 and 20185 (Fundamentals sequence); GEOS 21200, 21300, 21700, 21800, 21900, and 22200; MATH 20000; PHYS 18500 and 22500; and STAT 23400

## Faculty

D. Archer, C. Boyce, B. Buffett, P. Crane, N. Dauphas, G. Eshel, M. Foote, J. Frederick, L. Grossman, D. Heinz, D. Jablonski, S. Kidwell, M. LaBarbera, D. MacAyeal, P. Martin, N. Nakamura, S. Peacock, R. Pierrehumbert, F. Richter, D. Rowley, J. Smith, R. Srivastava, M. Wadhwa, M. Webster

## Courses: Geophysical Sciences (GEOS)

**13100. Physical Geology.** This course is an introduction to plate tectonics; the geologic cycle; and the internal and surface processes that make minerals and rocks, and shape the scenery. *D. Rowley. 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, N. Nakamura. 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.* For course description, see Physical Sciences. *D. Archer. Spring. L.*

**21000. Topics in Scientific Computing.** (=CMSC 28501) *PQ: Consent of instructor required; programming experience not required.* For course description, see Computer Science. *R. Pierrehumbert. Autumn, 2007.*

**21200. Physics of the Earth.** *PQ: Prior calculus and college-level physics courses, or consent of instructor.* We consider 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. *D. Heinz. Spring. L.*

**21300. Origin and Evolution of the Solar System.** (=ASTR 21300) *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.*

**21700. 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. *Autumn. L.*

**21800. Introduction to Petrology.** *PQ: GEOS 21700.* We 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. *A. Anderson. Spring. L.*

**21900. 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.*

**22200. Principles of Stratigraphy.** *PQ: GEOS 13100-13200 or equivalent required; GEOS 22100 and/or 23300 recommended.* This course introduces principles and methods of stratigraphy. Topics include facies analysis, physical and biostratigraphic correlation, 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.*

**22300. Introductory Paleontology.** (=BIOS 23255, EVOL 32300) *PQ: GEOS 13100-13200, or PHSC 10900-11000, or completion of the general education requirement for 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.*

**22400/32400. Invertebrate Paleobiology and Evolution.** (=BIOS 23261, EVOL 32400) *PQ: GEOS 13100 and 13200, or equivalent.* 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. Field trips offer 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.*

**22500/33200. Global Tectonics.** *PQ: GEOS 13100 or consent of instructor.* We review 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. *D. Rowley. Winter.*

**23200. Climate Dynamics of the Earth and Other Planets.** *PQ: Prior course in physics including classical mechanics (preferably PHYS 13300 or 14300) and thorough knowledge of single variable calculus required; knowledge of geophysical sciences not required.* This course provides an accelerated introduction to the basic physics governing the climate of planets. A self-contained introduction to programming in Python is also included, so that students will be able to gain experience in solving climate physics problems of realistic complexity. The emphasis is on the unifying themes applicable to Venus, Earth, Mars, Titan, the Gas Giants, and as-yet undiscovered extrasolar planets with atmospheres. Topics include thermodynamics of planetary atmospheres, blackbody radiation and basic principles of radiation balance, and thermal inertia and physics of the seasonal cycle. *R. Pierrehumbert. Autumn. L.*

**23300. 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. *S. Peacock. Autumn. L.*

**23400. 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. *D. Archer, S. Peacock, P. Martin. Winter.*

**23600. 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. G. Eshel. Winter. L.*

**23700. Cumulus Physics.** *PQ: CHEM 12100-12200-12300, PHYS 13100-13200-13300, or consent of instructor.* This class introduces atmospheric thermodynamics relevant to cumulus convection. We cover cloud microphysics, including growth of cloud drops by condensation, ice nucleation, and initiation of precipitation. Cumulus dynamics are introduced. *R. Srivastava. Winter.*

**23800. Biogeochemistry and Global Change.** *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, 2007.*

**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. *D. Archer. Autumn. L.*

**24200. 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 class 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. *S. Peacock. Spring.*

**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. *S. Peacock. Spring.*

**24500. 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. Autumn.*

**25300. 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. G. Eshel, P. Martin. Autumn, Winter.*

**28001. Field Course in Geology.** *PQ: GEOS 13100-13200 and consent of instructor.* We visit classic locations to examine a wide variety of geological environments and processes, including active tectonics, ancient and modern sedimentary environments, and geomorphology. For further information on upcoming trips, consult the departmental counselor. *Summer/Autumn.*

**28002. Field Course in Modern and Ancient Environments.** For further information on upcoming trips, consult the departmental counselor. *Spring.*

**28003. Field Course in Oceanography.** *PQ: Consent of instructor.* We 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. For further information on upcoming trips, consult the departmental counselor. *Spring, Summer.*

**28004. Field Course in Glaciology.** *PQ: Consent of instructor.* For further information on upcoming trips, consult the departmental counselor. *Offered 2007-08; not offered 2006-07.*

**28005. Field Course in Environmental Science.** *PQ: Consent of instructor.* For further information on upcoming trips, consult 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. Open by arrangement to selected students, both students in the major and qualified nonmajors. Typically taken on a P/F basis, except by students using this course to meet a requirement in the major who must take it for a quality grade. Summer, Autumn, Winter, Spring.*

*Qualified College students may register for 30000-level courses. For course descriptions, see <http://geosci.uchicago.edu>.*