Department of the Geophysical Sciences

Chair
- Fred Ciesla

Professors
- David Archer
- Andrew Campbell
- Fred Ciesla
- Nicolas Dauphas
- Andrew M. Davis
- Michael J. Foote
- David Jablonski
- Susan M. Kidwell
- Douglas R. MacAyeal
- Noboru Nakamura
- Michael J. Pellin (part-time)
- David B. Rowley

Associate Professors
- Dorian Abbot
- Philipp Heck (part time)
- Dion L. Heinz
- Elisabeth J. Moyer
- Tiffany Shaw
- Mark Webster

Assistant Professors
- Clara Blättler
- Maureen Coleman
- Malte Jansen
- Edwin Kite
- Graham J. Slater
- Jacob Waldbauer

Emeritus Faculty
- Victor Barcilon
- John E. Frederick
- Lawrence Grossman
- Michael C. LaBarbera, Organismal Biology & Anatomy
- Robert C. Newton
- Frank M. Richter
- Ramesh C. Srivastava
- Alfred M. Ziegler

Program of Graduate Study

Overview and Philosophy

The department serves graduate students who seek the Ph.D. in Earth, planetary, geological and environmental sciences and the paleontological and paleobiological disciplines of biological and historical sciences broadly conceived.

The Ph.D. signifies the graduate's mastery of the problems, techniques and knowledge covering the full spectrum of intellectual pursuit in the many disciplines listed above. The degree additionally acknowledges
the candidate's contribution to specialized knowledge through original research conducted in experimental, observational and theoretical venues. The M.S. is also awarded to graduate students in the program, and is given in recognition of post-undergraduate scholarship. Students considering the program of graduate study should realize, however, that it is conceived primarily for study and research leading to the Ph.D.

The Department of the Geophysical Sciences was created in 1961 when the departments of geology and meteorology of the university were united to better embrace the multidisciplinary nature of research and scholarship applied to Earth, its place in the cosmos and its environmental and biological history. The precursor Department of Geology was founded in the 1890's and reflected the University of Chicago's distinctively modern philosophy toward education and research. What is today lauded as new, namely the approach to physical, chemical, biological and natural science of Earth that values connections and multidisciplinary ways of thinking, was the original organizing principle of the university's activities in Earth science at the time the university was first created. Faithful to its original conception, the department is exemplified today by the diverse, yet interactive, composition of the faculty, students and research activities.

Our program distinguishes itself from those at other institutions through our rigorous adherence to a principle that the path to knowledge in Earth sciences is best traveled when disciplinary ways of thinking are applied interactively. To follow this path, our students and faculty engage each other in a constant exchange of ideas that spans a variety of specialized interests and disciplines. Indeed, the range of specialized interests and disciplines encompassed by our single intimate community is, at typical universities elsewhere, housed in separate departments. The exchange of ideas our community offers is both literal (as when research techniques from one discipline are applied in another) and figurative (as when students of diverse background and interests attend a common seminar), and is marshaled through our philosophical view that intellectual power is drawn from many sources. The tension created by bringing together disparate disciplines with differing traditions leads to constructive discourse in our community.

AREAS OF STUDY

Research, classroom teaching and seminar activity in the program reflect the long tradition of esteem directed toward multidisciplinary knowledge. Graduate study and research today thus ranges from geochemical approaches to nucleosynthesis and planet forming cosmochemistry to geomorphology, from evolutionary paleobiology to microbial ecology, and from climate dynamics of Earth and other planets, biogeochemical cycles to early Earth geochemistry. Graduate students are exposed to the breadth of intellectual activity in the physical and natural science of the Earth through courses they take during their first two years of study and through weekly attendance of seminars where both faculty and visiting scientists present research lectures. Graduate students are expected to develop two skills. First is the ability to conduct scientific discourse across the full range of disciplines. Second is the ability to conduct original research leading to unique contributions in an area of specialization.

Research and teaching within the program is further amplified by associations with other groups within the university. The most notable programs allied with ours are: the committee on evolutionary biology (CEB, research on the evolution of life), the chemistry department (research on atmospheric and environmental chemistry), the department of astronomy and astrophysics (research on exoplanets), the Argonne National Lab (environmental chemistry, advanced computing, the Advanced Photon Source, CARS), the center for robust decision making on climate and energy policy (RDCEP), and the department of statistics.

STUDENT ADVISING

A distinctive element in the everyday life of the department is the mentoring relationship the faculty of the department provide for students of the program. In our program, students are regarded as colleagues, not subordinates. Students are guided in their learning and research activities by mentorship engaging both the program faculty and fellow students. This mentorship oversees both the course work activity and the student's research, and is conceived as a means of establishing the student as a full partner in research and scholarship. Formal mentoring activities involve regular academic advisory committee meetings that include a combination of faculty covering the student's field of specialty and faculty covering allied fields where cross disciplinary exchange of ideas or techniques may prove helpful to the student's progress. In addition to formal activities, mentoring also proceeds along informal avenues: the department faculty prides itself in maintaining an open door atmosphere, where students seeking help or advice can readily find it down the hall.

RESEARCH

Dissertation research can address any aspect of physical, chemical, biological and natural sciences of the Earth, its life and environment, and the solar system environment from which the planets were formed. Typically, dissertation research begins in the second year of the student's residence after courses taken in preparation for the preliminary examination have been completed and an oral research prospectus has been defended.

TEACHING, OUTREACH AND PROFESSIONAL SKILLS DEVELOPMENT

Young scientists are faced with an ever increasing demand for breadth in the scope of their professional skills: from teaching to proposal writing, and from website design to mountaineering. To help prepare our students for the varied challenges they will encounter in their post graduate career, we involve them to the maximum extent possible in teaching, research planning, public outreach and field activity. While there are no strict requirements for teaching activities, the majority of our students participate in at least some teaching
as laboratory assistants for the large, undergraduate-level classes taught by our faculty. Typical demands on a
graduate student’s time might involve four to eight hours a week of student contact time, and four to six hours a
week of preparation and grading. To emphasize the value the university places on graduate student participation
in undergraduate teaching, a slightly larger stipend is provided to teaching assistants over research assistants. In
addition to teaching, our graduate students typically become involved in the scientific funding process through
exposure to the efforts undertaken by faculty in the securing of research funds through the writing of proposals.
Public outreach is also an important element of professional skills, and is emphasized through scientific web
site development (required by funding agencies for grants funded in support of scientific research) and other
activities (e.g., local science fairs and lectures at surrounding schools) which emphasize contact with the general
public. Many of our graduate students include field work as part of their research projects—from scuba-based
sampling in Central America to mapping in Tibet—and we offer formal courses and trips to help students
develop their skills for this mode of scientific research. Class trips typically focus on (1) modern and ancient
sedimentary environments, which explicitly integrates across geology and biology (every 2-3 years, usually in a
tropical or subtropical marine setting); (2) sequence stratigraphy of siliciclastics, mostly Meso-Cenozoic; and (3)
integrated structure, tectonics, sedimentation, and paleontology, with an eye to reconstructing paleogeography at
regional scales (early Paleozoics of Great Basin and Death Valley; Cenozoic of southern California). Students also
have opportunities to join faculty in some field campaigns, which include oceanographic cruises.

**Curriculum**

The diversity of intellectual pursuit encompassed by the program places students and faculty into a
challenging position when confronted with the need to design a curriculum capable of preparing students of
the program to become Ph.D. scientists. Our approach to this challenge is to focus on thinking tools that prepare
students for research. Thinking tools embody knowledge of methodologies, awareness of fundamental scientific
problems, understanding of current research areas and creative thought when encountering difficult questions.
These tools are taught, in part, by a curriculum of courses that delve deeply into various subsets of knowledge
covered by the department’s scholarly interests. While a student may enter the program with the ultimate goal
of writing a dissertation in one area of specialization, courses taken in closely allied areas of specialization are
often, by virtue of practicality, all that our curriculum offers. While this may seem detrimental to progress toward
specialized research, in practice, the specific subject material used to build the student’s base of knowledge and
rigorous understanding of thought and methodologies is not strongly correlated with the student’s subsequent
success. Our curriculum of courses thus focuses on teaching notions of understanding and methodologies that
are universal in their application to a wide range of specialized phenomena.

**Required Course Activities**

This time period is divided into two parts, the pre-candidacy phase where the student focuses on course
work and general scholarship, and the candidacy phase where the student focuses on specialized research
directed to the completion of the dissertation. While flexibility is a distinct advantage of the department’s small,
intimate setting of graduate study compared to other, larger programs, graduate students are normally expected
to progress through their study as follows. Classes are taken through the first two years of residence at the
university, and a preliminary examination is taken normally in the spring of the second year. Classes are selected
from the department’s graduate courses, appropriate upper-level undergraduate courses and courses offered
elsewhere in the university. Selection of courses is made through consultation with a faculty advisory committee,
which meets regularly through the first two years of the student’s residence.

The preliminary examination taken at the end of the second year of residence serves to promote students
to candidacy for the Ph.D. The purpose of the examination is to ensure the student’s progress in the two
goals of graduate study: breadth of fundamental knowledge, and depth of knowledge in a particular area of
specialization (chosen normally to be consistent with the student’s anticipated dissertation topic).

The preliminary examination has two parts. The written part (taken either in one single sitting or as a series
of written tests taken in conjunction with final exams of courses, depending on the particular situation) covers
the aspects of knowledge addressed in courses and in the weekly seminars which students are expected to
attend. The oral part requires the student to present a research prospectus to a committee of faculty advisors. The
topic of this prospectus is normally expected to be the student’s planned research activity directed toward the
thesis.

**The Dissertation**

The Ph.D. degree is awarded to the candidate who has completed a written dissertation, defended it orally
to a body of scientists which includes members of the department’s faculty (who have the responsibility to vote
in favor or against acceptance of the dissertation), and who have submitted the dissertation to the university
dissertation office in proper form.

**Courses**

Courses are modified from year to year. Students are expected to consult the Schedule of Classes published
by the Office of the University Registrar for information regarding courses offered on an infrequent basis.
A student’s course load is expected to be three to four classes per quarter during the first five quarters (not
including Summer Quarter) of residence. Over this period, the student will take a mixture of high level
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(designated by numbers greater than 30000) and medium level (designated by numbers in the 20000s) classes listed under the department's offerings, and appropriate courses offered by other departments of the university.

**GEOPHYSICAL SCIENCES COURSES**

**GEOS 30200. Introduction to Research in the Geophysical Sciences. 100 Units.**
This course is mandatory for all incoming graduate students in the department. Its purpose is to introduce the faculty's current research themes/areas and to familiarize incoming graduate students with research areas they might contemplate for further specialization. Lectures are presented by individual faculty on either 1) a general survey of a research area, or 2) a specialized topic of interest. Student activity varies from year to year and is based on a combination of oral and written presentations.
Instructor(s): Staff Terms Offered: Autumn

**GEOS 30500. Topics in the Geophysical Sciences. 100 Units.**
This course is offered from time-to-time as a means of covering topics that are generally not covered by regularly offered courses in the curriculum. Students should consult with appropriate faculty regarding opportunities to take this course when the situation arises.
Instructor(s): Staff Terms Offered: Autumn. Not offered 2017-2018

**GEOS 31000. Mineralogy. 100 Units.**
This course covers structure, chemical composition, stability, and occurrence of major rock-forming minerals. Labs concentrate on mineral identification with the optical microscope. (L)
Instructor(s): A. Campbell Terms Offered: Winter. Offered every other year.
Equivalent Course(s): GEOS 21000

**GEOS 31005. 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 21005

**GEOS 31200. 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 21200

**GEOS 31205. 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 21205

**GEOS 31400. 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 21400

**GEOS 31500. Mineral Physics. 100 Units.**
The application of physics at the microscopic level to geologic and geophysical problems. Topics: vibrational, electric and transport properties of minerals.
Instructor(s): D. Heinz
Prerequisite(s): 2 yrs. Math beyond Calculus; 1 year Physical Chemistry or 1 year of both Physics and Chemistry; general Geology, general geophysics and Mineralogy, Petrology or equivalent.
GEOS 32040. 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 22040

GEOS 32050. 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 22050

GEOS 32060. 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. This course is part of the College Course Cluster program: Climate Change, Culture and Society.
Instructor(s): Edwin Kite Terms Offered: Winter
Equivalent Course(s): GEOS 22060, ASTR 45900

GEOS 32080. Astrophysics of Exoplanets. 100 Units.
Extrasolar planets, a.k.a. exoplanets, are planets orbiting other stars. First definitively detected in the mid 1990s, the planet count has rapidly expanded and their physical characterization has sharpened with improved observational techniques. Theoretical studies of planetary formation and evolution are now attempting to understand this statistical sample. The field also aspires to address questions about life in the universe. This course emphasizes hands-on activities, like working with real astronomical data to find and characterize exoplanets. Topics are the radial velocity, transit, and other discovery and characterization techniques; statistical distributions of known planets; comparisons among planet structure and planetary system types; formation in a protoplanetary disk and subsequent dynamical evolution; the goal of finding life on an exoplanet; colonization of exoplanets; and the Fermi paradox.
Instructor(s): Jacob Bean and Daniel Fabrycky Terms Offered: Spring
Prerequisite(s): ASTR 24100 and PHYS 23400 or PHYS 23410; or consent of instructor.
Equivalent Course(s): ASTR 35800, ASTR 25800

GEOS 32200. 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
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Note(s): Equivalent Course(s): GEOS 32200
Equivalent Course(s): GEOS 22200

GEOS 32300. Cosmochemistry. 100 Units.
Chemical, mineralogical, and petrographic classifications of meteorites. Topics include: abundances of the elements, origin of the elements and stellar evolution, the interstellar medium and formation of the solar nebula, condensation of the solar system, chemical fractionations in meteorites and planets, age of the solar system, extinct radionuclides in meteorites, isotope anomalies.
Instructor(s): A. Davis Terms Offered: Winter
Note(s): This course is offered in alternate years.

GEOS 32400. Nucleosynthesis and Its Record in the Solar System and Stars. 100 Units.
The course will cover the environments where the chemical elements are made (supernovae, red giant stars, the Big Bang) and the record of nucleosynthesis in meteorites, planets and other stars (both by remote observation and study of stardust in the laboratory). The course is open to graduate students and advanced undergraduates.
GEOS 32500. Topics in Planetary Science. 100 Units.
In this seminar we explore the latest research and results in planetary science. General topics to be discussed include planet formation, planetary evolution, spacecraft exploration, and astrobiology. The specific focus for each class offering will be determined by the interests of the faculty and students. Can be taken multiple times for credit since the specific topic will change each quarter.
Instructor(s): Andrew Davis Terms Offered: Autumn

GEOS 32600. 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: Winter
Prerequisite(s): Background in college-level geology and mineralogy or consent of instructor
Equivalent Course(s): GEOS 22600

GEOS 32700. 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 22700

GEOS 33002. Paleobiological Modeling and Analysis-2. 100 Units.
This course is an introduction to multivariate analysis, with emphasis on morphological data and problems in paleontology and evolutionary biology. Topics include: types of data and scales of measurement; data transformations; bivariate analysis; measurement of similarity and difference; clustering; ordination; singular value decomposition; principal component analysis, factor analysis, principal coordinates, correspondence analysis, and other eigenvector methods; and path analysis. Each student will bring a multivariate dataset (not necessarily original) to the course and will write a series of short papers based on analysis of these data. Code written in the R programming language will be supplied for most analyses. Winter quarter, generally in odd numbered years. GEOS 36501 and GEOS 36502 can be taken in either order.

GEOS 33205. 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 23205

GEOS 33300. Advanced Topics in Climate Dynamics. 100 Units.
The course will go beyond radiative-convective equilibrium and explore spatial and temporal aspects of Earth’s climate with a focus on the atmosphere. The goal is to gain a physical understanding of Earth’s climate and its past and future changes. We will discuss a range of topics from the surface and atmospheric energy balance, hydrological cycle, atmospheric general circulation and energy transport, climate variability, paleoclimate, natural and anthropogenic climate change. The course will combine lectures of the theory and observations underlying our understanding of Earth’s climate with student presentations of peer-reviewed papers. The evaluation will be based on a data-analysis project.
Instructor(s): T. Shaw Terms Offered: Spring
Prerequisite(s): GEOS 24220 or equivalent
GEOS 33600. 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 23600, ENSC 23600

GEOS 33800. 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: Autumn
Prerequisite(s): CHEM 11100-11200 or consent of instructor
Equivalent Course(s): GEOS 23800, ENSC 23800

GEOS 33825. Topics in Microbial Biogeochemistry. 100 Units.
In this seminar we explore the role of microorganisms in biogeochemical cycles. Topics include microbial metabolism, physiology, ecology and evolution in natural habitats, responses to short- and long-term climate change, and coevolution of life and its environment over Earth history. Can be taken multiple times for credit since the specific topic will change each quarter.
Instructor(s): M. Coleman Terms Offered: Autumn,Winter

GEOS 33850. Low Temperature Geochemistry. 100 Units.
This course covers topics related to the geochemistry of Earth's surface, including all its fluid and solid components. Specific emphasis will be placed on stable isotopic tools for understanding modern Earth system processes and the ancient geological record. Seminar format will allow students to choose topics of interest to them and shape the reading and discussion content of the course.
Instructor(s): Clara Blättler Terms Offered: Autumn
Equivalent Course(s): ENSC 33850

GEOS 33900. 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): ENSC 23900, GEOS 23900, ENST 23900

GEOS 34200. Fundamentals of Geophysical Fluid Dynamics. 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): D. Abbot Terms Offered: Winter
Prerequisite(s): Knowledge of vector calculus, linear algebra, or consent of instructor
Equivalent Course(s): GEOS 24200

GEOS 34220. 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
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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 24220

**GEOS 34230. 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 24230

**GEOS 34240. 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 24240

**GEOS 34250. 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 24250

**GEOS 34260. 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 24260

**GEOS 34300. 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.
GEOS 34400. Topics in Geophysical Fluid Dynamics. 100 Units.
This course teaches science and art of numerical modeling at an elementary level. Classroom discussions on mathematical principles will be supplemented by a series of actual coding assignments. (Command of a programming language is assumed; this is not a course on programming.) It is our goal that at the end of the course each student will have coded a working copy of shallow water model on a rotating sphere (and do science with it). Prereq: Calculus, working knowledge of Fourier Transform and of a programming language (C, Fortran, IDL, etc.), access to a computer with a compiler and runtime environment. No previous experience in fluid dynamics is necessary, although this course alone does not fully prepare one to become a fluid dynamicist. Instructor(s): N. Nakamura

GEOS 34530. Turbulence and Transport Processes in the Atmosphere and Oceans. 100 Units.
The atmosphere and oceans exhibit non-linear turbulent motions on a wide range of scales. Yet introductory classes in atmosphere and ocean dynamics focus almost exclusively on linear theories. While there is undoubtedly much to learn from linear theory, statistical descriptions of turbulent flows provide a valuable perspective from a different angle. In this advanced graduate course we will discuss the theory of 3-dimensional, 2-dimensional and quasi-geostrophic turbulence, as well as the role of turbulent motions for the transport of properties in the atmosphere and ocean. We will also discuss the wave-turbulence crossover, and eddy-mean-flow interactions, thus connecting back to linear theories. The format of the course will be a mixture of lectures and student-led paper discussions. Instructor(s): M. Jansen Terms Offered: Autumn
Prerequisite(s): GEOS 24230 and GEOS 24240 or equivalent; Knowledge of mechanics (PHYS 13100 or equivalent), vector calculus and linear algebra (MATH 20000-20100-20200 or equivalent). Knowledge of the basics of statistics/stochastics is also expected.

GEOS 34550. 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): 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 24550

GEOS 34600. 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): 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 24600

GEOS 34705. 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.
Equivalent Course(s): ENSC 21150.

GEOS 34750. 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): ENSC 21150, ENST 24705, GEOS 24705

GEOS 35100. Data Analysis for the Geophysical Sciences. 100 Units.
A graduate-level introduction to probability, modeling, and data analysis. Though some emphasis is given to paleontological problems, the goal is to keep approaches sufficiently general that they should be relevant to students across the geophysical sciences as well as evolutionary biology. Required work includes coding exercises and a term project based on original research.
Instructor(s): M. Webster Terms Offered: Winter

GEOS 35400. 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 25400

GEOS 35500. Mathematical Methods for the Earth Sciences. 100 Units.
This course is intended to be a brief introduction to mathematical methods that may be of use in the Earth Sciences. The focus will be on building physical intuition and practical problem solving. Students may solve problems analytically, or write numerical codes to solve them.
Instructor(s): D. Abbot Terms Offered: Spring

GEOS 35900. Physics of Planetary Interiors. 100 Units.
This course considers the physical processes governing the interior structure and evolution of planets, both those orbiting the Sun and exoplanets. Topics include an introduction to condensed matter physics relevant to planet interiors; properties of planetary materials; observational constraints; planet modeling; thermal histories; differentiation and core formation; connection to planetary atmospheres; and magnetic field generation.
Instructor(s): Leslie Rogers Terms Offered: Winter
Prerequisite(s): Open to third- and fourth-year undergraduate students majoring in Astrophysics, Physics or the Geophysical Sciences, or students who have completed two quarters of Calculus.

GEOS 36000. Morphometrics. 100 Units.
This graduate-level course serves as an introduction to the field of morphometrics (the analysis of organismal shape). Quantitative exploratory and confirmatory techniques involving both traditional (length-based) and geometric (landmark-based) summaries of organismal shape are introduced in a series of lectures and practical exercises. Emphasis is placed on the application of morphometric methods to issues such as (but not restricted to) quantification of intraspecific variability; interspecific differences, disparity, ontogenetic growth patterns (allometry), and phylogenetic changes in morphology. Relevant statistical and algebraic operations are explained assuming no prior background. Students are required to bring personal laptop computers, and are expected to acquire and analyze their own data sets during the course.
Instructor(s): M. Webster Terms Offered: Winter
Equivalent Course(s): EVOL 36700

GEOS 36050. Models of Morphological Evolution. 100 Units.
Over the past 30 years the study of morphological evolution, from inference of evolutionary process to understanding correlated trait changes, has increasingly relied on phylogenetic approaches. This is due to the realization that species may exhibit similar traits due to shared evolutionary history as much as due to similar adaptive responses to other factors. The field of phylogenetic comparative methods is rapidly expanding. This graduate course will cover basic and advanced models of morphological character evolution that underlie comparative methods, as well as the statistical models themselves. Topics covered in this class will span: Brownian motion as a model of quantitative trait evolution; Independent contrasts and evolutionary regressions; Measuring phylogenetic signal; Alternative models of quantitative trait evolution - early bursts, Ornstein-
Uhlenbeck processes, and multivariate data; Discrete traits, Markov processes and the threshold model; Phylogenetic analogues of traditional comparative methods (e.g., ANOVA, PCA). Lectures will cover theory behind concepts but students will also be expected to bring laptops to class so as to write code to simulate data and fit statistical models. All coding will be done in the R statistical language.

Instructor(s): G. Slater
Terms Offered: Autumn

GEOS 36100. 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.
Equivalent Course(s): EVOL 46200

GEOS 36200. Evolution and the Fossil Record. 100 Units.
This course serves as an introduction to the practical and theoretical issues involved in obtaining primary systematic data from the fossil record, and demonstrates the criticality of such data to the rigorous documentation and interpretation of evolutionary patterns. Precise topics of the seminar discussions will vary from year to year depending on relevance to student research projects and interest, but are likely to focus on issues such as (but not restricted to) practical techniques in specimen-based paleontology (including fossil preparation and photography), species delimitation (including species concepts, variability, and ecophenotype), stratigraphic/geographic range determination (including biostratigraphic correlation), phylogeny reconstruction (including the relevance of stratigraphic data), and the importance of these topics to broader macroevolutionary issues such as diversity/disparity dynamics and the determination of evolutionary trends, rates and processes.

Equivalent Course(s): EVOL 46200

GEOS 36300. 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 26300

GEOS 36600. 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 26600

GEOS 36650. 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 26650, ENSC 24500
GEOS 36700. Taphonomy. 100 Units.
Lecture and research course on patterns and processes of fossilization, including rates and controls of soft tissue decomposition, post mortem behavior of skeletal hard parts, concentration and burial of remains, scales of time averaging, and the net spatial and compositional fidelity of (paleo)biologic information, including trends across environments and evolutionary time. Offered alternate years.
Instructor(s): S. Kidwell
Equivalent Course(s): EVOL 31800

GEOS 36800. Macroevolution. 100 Units.
Patterns and processes of evolution above the species level, in both recent and fossil organism. A survey of the current literature, along with case studies.
Instructor(s): D. Jablonski
Terms Offered: Spring
Equivalent Course(s): EVOL 31700

GEOS 36900. Topics in Paleobiology. 100 Units.
In this seminar we investigate paleobiological or multidisciplinary topics of current interest to students and faculty. Previous subjects include the origin of phyla, historical and macro-ecology, the stratigraphic record and evolutionary patterns, and climate and evolution.
Instructor(s): D. Jablonski, S. Kidwell, T. Price
Terms Offered: Autumn
Equivalent Course(s): ECEV 36900, EVOL 31900

GEOS 36905. Topics in Conservation Paleobiology. 100 Units.
Paleobiological data from very young sedimentary records, including skeletal 'death assemblages' actively accumulating on modern land surfaces and seaboards, 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 Paleontology.
Equivalent Course(s): GEOS 26905, EVOL 36905

GEOS 38000. 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 28000

GEOS 38100. 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 28100

GEOS 38300. 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 28300

GEOS 38400. Topics in Stratigraphy and Biosedimentology. 100 Units.
Seminar course using the primary literature and/or a field problem. Topic selected from the rapidly evolving fields of sequence stratigraphy, basin analysis, and animal sediment relationships.
Equivalent Course(s): EVOL 41500
GEOS 39001. Field Course in Geology. 100 Units.
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.
Prerequisite(s): GEOS 13100-13200 and consent of instructor
Note(s): Interested students should contact the departmental counselor.
Equivalent Course(s): GEOS 29001

GEOS 39002. 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. Destinations vary; past trips have examined tropical carbonate systems of Jamaica and the Bahamas and subtropical coastal Gulf of California. We usually consider biological, as well as physical, processes of sediment production, dispersal, accumulation, and post-depositional modification.
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. This course meets weekly in Winter Quarter prior to Spring Break field work.
Equivalent Course(s): ENSC 29002, GEOS 29002

GEOS 39500. Theory and Practice of Science Education. 000 Units.
In this seminar, students examine their work as teaching assistants through activities that include self-reflection; investigating relevant educational literature; and engaging in in-depth discussions about their own teaching and learning. Readings and discussion topics include questioning techniques, learning theory, cooperative learning, growth mindset, metacognition, developing relationships with students, equity, and differentiation. Students will try out new ideas each week in their learning teams and report their results in class. In many cases, students provide guidance to one another regarding managing issues that typically arise in their learning teams. The seminar is intended for graduate students who are serving as teaching assistants for the first time, and is typically taken in the same quarter in which the student begins teaching.
Instructor(s): Brent Barker Terms Offered: Autumn Spring Winter
Prerequisite(s): Undergraduates serving as course assistants may enroll with instructor consent.
Note(s): Graduate students in Astronomy and Astrophysics and Geophysical Sciences enroll in ASTR 50000 the first quarter in which they will teach.
Equivalent Course(s): ASTR 50000

GEOS 39501. Practicum I: Geophysical Sciences. 100 Units.
A practicum in the Geophysical Sciences. Note that this is the first of a two quarter sequence that must be taken in order.
Instructor(s): Moyer Terms Offered: Autumn

GEOS 39502. Practicum II: Geophysical Sciences. 100 Units.
A practicum in the Geophysical Sciences. Note that this is the second of a two quarter sequence that must be taken in order.
Instructor(s): Moyer Terms Offered: Winter
Prerequisite(s): GEOS 39501

GEOS 39600. 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 29600

GEOS 39650. Environmental Data Science Practicum I. 100 Units.
Research in climate and environmental sciences is increasingly focused on analyses of complex spatio-temporal data, with satellite observations and detailed numerical simulations providing datasets whose size may reach the Tb range. Relevant research questions also increasingly span disciplinary boundaries. This project-based course is intended to provide students with a structured research experience in working with complex environmental data on a project that should lead to publishable science. The course is the first course of a two-course sequence
with GEOS 39660 to be taken in the Spring. Students enroll individually and then form interdisciplinary groups. During the two quarters, groups will work on research projects with guidance from University faculty members and external researchers. Lectures and exercises cover topics in statistics, computer science, data science, and research practices. The course is a requirement for Ph.D. students participating in the University’s NSF Research Traineeship program in Computational Training for Energy and Environmental Sciences but enrollment is open to all graduate students, space permitting. Students enrolled in GEOS 39660 for Spring quarter are encouraged to enroll concurrently in GEOS 39600, Science Writing Practicum, which will guide them through completion of a manuscript for submission.

Instructor(s): Elisabeth Moyer/Staff Terms Offered: Winter
Prerequisite(s): Experience in data analysis and programming typical of 2nd-year or advanced 1st-year Ph.D. students in physical, biological, and social sciences.

GEOS 39660. Environmental Data Science Practicum II. 100 Units.
This project-based course is a continuation of GEOS 39650, Environmental Data Science Practicum I. The two-course sequence is intended to provide students with a structured research experience in working with complex environmental data on a project that should lead to publishable science. Students enroll individually and then work in interdisciplinary groups on research projects with guidance from University faculty members and external researchers. Lectures and exercises cover topics in statistics, computer science, data science, and research practices. The course is a requirement for Ph.D. students participating in the University’s NSF Research Traineeship program in Computational Training for Energy and Environmental Sciences but enrollment is open to all graduate students, space permitting. Students enrolled in GEOS 39660 are encouraged to enroll concurrently in GEOS 39600, Science Writing Practicum, which will guide them through completion of a manuscript for submission.

Instructor(s): Elisabeth Moyer/Staff Terms Offered: Spring
Prerequisite(s): Pre-requisite is GEOS 39650.

GEOS 39800. Reading and Research in the Geophysical Sciences for the Maste. 300.00 Units.
An essay or formal thesis will be required.
Instructor(s): Staff Terms Offered: Autumn Spring Summer Winter
Prerequisite(s): admission to grad status

GEOS 49700. Rdg/Rsch: Geophysical Sciences. 300.00 Units.
GEOS 49700-49799. Topics available include, but are not limited to: Mineralogy, Petrology, Geophysics, High Pressure Geophysics, Geodynamics, Volcanology, Cosmochemistry, Geochemistry, Atmospheric Dynamics, Paleoecology, Physical Oceanography, Chemical Oceanography, Paleoceanography, Atmospheric Chemistry, Fluid Dynamics, Glaciology, Climatology, Radiative Transfer, Cloud Physics, Morphometrics, Phylogeny, Analytical Paleontology, Evolution, Taphonomy, Macroevolution, Paleobiology, Aktuopaleontology, Paleobotany, Biomechanics, Paleocology, Tectonics, Stratigraphy.
Instructor(s): Staff Terms Offered: Summer,Autumn,Winter,Spring
Prerequisite(s): admission to Ph.D. candidacy

GEOS 49710. Advanced Research: Mineralogy. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49711. Advanced Research: Petrology. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49712. Advanced Research: Geophysics. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49713. Advanced Research: High Pressure Geophysics. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49714. Advanced Research: Geodynamics. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49716. Advanced Research: Geochemistry. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49718. Advanced Research: Volcanology. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49723. Advanced Research: Cosmochemistry. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49732. Advanced Research: Atmospheric Dynamics. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49733. Advanced Research: Paleoceanography. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49735. Advanced Research: Physical Oceanography. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences
GEOS 49736. Advanced Research: Chemical Oceanography. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49737. Advanced Research: Cloud Physics. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences.

GEOS 49740. Advanced Research: Atmospheric Chemistry. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49742. Advanced Research: Fluid Dynamics. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49743. Advanced Research: Glaciology. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49746. Advanced Research: Climatology. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49748. Advanced Research: Radiative Transfer. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49749. Advanced Research: Paleoclimatology. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49760. Advanced Research: Morphometrics. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49761. Advanced Research: Phylogeny. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49765. Advanced Research: Analytical Paleontology. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49766. Advanced Research: Evolution. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49767. Advanced Research: Taphonomy. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49768. Advanced Research: Macroevolution. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49769. Advanced Research: Paleobiology. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49770. Advanced Research: Aktuopaleontology. 300.00 Units.

GEOS 49771. Advanced Research: Paleobotany. 300.00 Units.

GEOS 49772. Advanced Research: Biomechanics. 300.00 Units.

GEOS 49773. Advanced Research: Paleoecology. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49781. Advanced Research: Tectonics. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49783. Advanced Research: Stratigraphy. 300.00 Units.
Individualized study focused on Ph.D. research in the geophysical sciences

GEOS 49900. Post Ph. D. Research: Geosci. 300.00 Units.
Instructor(s): Staff Terms Offered: Summer,Autumn,Winter,Spring

GEOS 70000. Advanced Study: Geophysical Sciences. 300.00 Units.
Advanced Study: Geophysical Sciences