

## EARTH, ATMOSPHERIC, AND PLANETARY SCIENCES (COURSE 12)

### Undergraduate Subjects

#### Core and General Science Subjects

##### 12.00 Frontiers and Careers in Earth, Planets, Climate, and Life

Prereq: None

U (Spring)

2-0-0 units

Provides a broad overview of topics, technologies, and career paths at the forefront of Earth, Atmospheric and Planetary Sciences. Introduces the complex interplay between physics, mathematics, chemistry, biology, and computational methods used to study processes associated with a changing Earth and climate, distant planets, and life. Sessions guided by faculty members discussing current research problems, and by EAPS alumni describing how their careers have evolved. Subject can count toward the 6-unit discovery-focused credit limit for first year students.

*T. Herring*

##### 12.000 Solving Complex Problems

Prereq: None

U (Fall)

1-2-6 units

Provides an opportunity for entering freshmen to gain firsthand experience in integrating the work of small teams to develop effective solutions to complex problems in Earth system science and engineering. Each year's class explores a different problem in detail through the study of complementary case histories and the development of creative solution strategies. Includes exercises in website development, written and oral communication, and team building. Subject required for students in the Terrascope freshman program, but participation in Terrascope is not required of all 12.000 students. Students who pass 12.000 are eligible to participate in the Terrascope field trip the following spring. Limited to freshmen.

*D. McGee, A. Epstein*

##### 12.001 Introduction to Geology

Prereq: None

U (Fall)

3-4-5 units. REST

Major minerals and rock types, rock-forming processes, and time scales. Temperatures, pressures, compositions, structure of the Earth, and measurement techniques. Geologic structures and relationships observable in the field. Sediment movement and landform development by moving water, wind, and ice. Crustal processes and planetary evolution in terms of global plate tectonics with an emphasis on ductile and brittle processes. Includes laboratory exercises on minerals, rocks, mapping, plate tectonics, rheology, glaciers. Two one-day field trips (optional).

*T. Bosak, O. Jagoutz*

##### 12.002 Introduction to Geophysics and Planetary Science

Prereq: Calculus II (GIR) and Physics II (GIR)

U (Spring)

3-1-8 units. REST

Study of the structure, composition, and physical processes governing the terrestrial planets, including their formation and basic orbital properties. Topics include plate tectonics, earthquakes, seismic waves, rheology, impact cratering, gravity and magnetic fields, heat flux, thermal structure, mantle convection, deep interiors, planetary magnetism, and core dynamics. Suitable for majors and non-majors seeking general background in geophysics and planetary structure.

*L. H. Royden, B. Weiss*

##### 12.003 Introduction to Atmosphere, Ocean, and Climate Dynamics

Prereq: Calculus II (GIR) and Physics I (GIR)

U (Fall)

3-0-9 units. REST

Introduces the dynamical processes that govern the atmosphere, oceans, and climate. Topics include Earth's radiation budget, convection and clouds, the circulation of the atmosphere and ocean, and climate change. Illustrates underlying mechanisms through laboratory demonstrations with a rotating table, and through analysis of atmospheric and oceanic data.

*T. Cronin*

**12.006[J] Nonlinear Dynamics: Chaos**

Same subject as 2.050[J], 18.353[J]

Prereq: Physics II (GIR) and (18.03 or 18.032)

U (Fall)

3-0-9 units

Introduction to nonlinear dynamics and chaos in dissipative systems. Forced and parametric oscillators. Phase space. Periodic, quasiperiodic, and aperiodic flows. Sensitivity to initial conditions and strange attractors. Lorenz attractor. Period doubling, intermittency, and quasiperiodicity. Scaling and universality. Analysis of experimental data: Fourier transforms, Poincare sections, fractal dimension, and Lyapunov exponents. Applications to mechanical systems, fluid dynamics, physics, geophysics, and chemistry. See 12.207[J]/18.354[J] for Nonlinear Dynamics: Continuum Systems.

*R. R. Rosales***12.007 Geobiology: History of Life on Earth**

Prereq: None

U (Spring)

3-0-9 units

Surveys the interactive Earth system: biology in geologic, environmental and climate change throughout Earth's history. Introduces the concept of "life as a geological agent" and examines the interaction between biology and the Earth system during the roughly 4 billion years since life first appeared. Topics include the origin of the solar system and the early Earth atmosphere; the origin and evolution of life and its influence on climate up through and including the modern age and the problem of global warming; the global carbon cycle; and astrobiology.

*T. Bosak, G. Fournier***12.009[J] Nonlinear Dynamics: The Natural Environment**

Same subject as 18.352[J]

Prereq: Calculus II (GIR) and Physics I (GIR); *Coreq: 18.03*

Acad Year 2021-2022: U (Spring)

Acad Year 2022-2023: Not offered

3-0-9 units

Analyzes cooperative processes that shape the natural environment, now and in the geologic past. Emphasizes the development of theoretical models that relate the physical and biological worlds, the comparison of theory to observational data, and associated mathematical methods. Topics include carbon cycle dynamics; ecosystem structure, stability and complexity; mass extinctions; biosphere-geosphere coevolution; and climate change. Employs techniques such as stability analysis; scaling; null model construction; time series and network analysis.

*D. H. Rothman***12.010 Computational Methods of Scientific Programming**

Prereq: Calculus II (GIR) and Physics I (GIR)

U (Fall)

4-0-8 units

Introductory subject exposes students to modern programming methods and techniques used in practice by physical scientists today. Emphasis on code design, algorithm development/verification, and comparative advantages/disadvantages of different languages (including Python, Julia and C/C++) and tools (including Jupyter, machine-learning from data or models, cloud and high-performance computing workflows). Students are introduced to and work with common programming tools, types of problems, and techniques for solving a variety of data analytic and equation modeling scenarios from real research: examination visualization techniques; basic numerical analysis; methods of dissemination and verification; practices for reproducible work, version control, documentation, and sharing/publication. No prior programming experience is required.

*T. Herring, C. Hill***12.011[J] Archaeological Science**

Same subject as 3.985[J], 5.24[J]

Prereq: Chemistry (GIR) or Physics I (GIR)

U (Spring)

3-1-5 units. HASS-S

See description under subject 3.985[J].

*D. Hosler, H. N. Lechtman***12.012 MatLab, Statistics, Regression, Signal Processing**

Subject meets with 12.444

Prereq: None. *Coreq: 18.06*

U (Fall)

3-0-9 units

Introduces the basic tools needed for data analysis and interpretation in the Geosciences, as well as other sciences. Composed of four modules, targeted at introducing students to the basic concepts and applications in each module. MatLab: Principles and practice in its uses, script and function modules, basic approaches to solving problems. Statistics: Correlation, means, dispersion, precision, accuracy, distributions, central limit theorem, skewness, probability, Chi-Square, Gaussian and other common distributions used in hypothesis testing. Regression: Random and grid search methods, basic least squares and algorithms applicable to regression, inversion and parameter estimation. Signal Processing: Analog and digital signals, Z-transform, Fourier series, fast Fourier transforms, spectral analysis leakage and bias, digital filtering. Students taking the graduate version complete different assignments.

*F. D. Morgan, T. A. Herring, S. Ravela*

**12.021 Earth Science, Energy, and the Environment**

Prereq: Calculus I (GIR), Chemistry (GIR), and Physics I (GIR)

U (Fall)

3-1-8 units

Provides understanding of the Earth System most relevant to production of our planet's natural energy resources, including the physics, chemistry, and biology of conventional and alternative energy sources. Includes a broad overview of traditional and alternative energy sources: hydrocarbons (conventional and unconventional), nuclear, geothermal, hydroelectric, and wind and tides, along with their potentials and limitations. Develops detailed knowledge of the formation, concentration, and production of fossil and nuclear fuels, as well as the waste products associated with their consumption. An examination of conventional and alternative energy sources includes the environmental issues associated with the exploitation of these resources, both regional and global.

*B. H. Hager***12.031[J] Fundamentals of Ecology**

Same subject as 1.018[J], 7.30[J]

Prereq: None

U (Fall)

4-0-8 units. REST

See description under subject 1.018[J].

*M. Follows, D. Des Marais***12.080 Experiential Learning in EAPS**

Prereq: None

U (Fall, IAP, Spring, Summer)

Units arranged [P/D/F]

Can be repeated for credit.

For Course 12 students participating in off-campus professional experiences related to their course of study. Before registering for this subject, students must have an offer from a company or organization, must identify an EAPS supervisor, and must receive prior approval from their advisor. Upon completion of the experience, student must submit a letter from the company or organization describing what the student accomplished, along with a substantive final report from the student approved by the EAPS supervisor. Consult departmental academic office.

*EAPS Faculty***12.086 Modeling Environmental Complexity**

Subject meets with 12.586

Prereq: 18.03

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: U (Fall)

3-0-9 units

Introduction to mathematical and physical models of environmental processes. Emphasis on the development of macroscopic continuum or statistical descriptions of complex microscopic dynamics. Problems of interest include: random walks and statistical geometry of landscapes; percolation theory and transport in disordered media; fractals, scaling, and universality; ecological dynamics and the structure of ecosystems, food webs, and other natural networks; kinetics of biogeochemical cycles. Appropriate for advanced undergraduates. Beginning graduate students are encouraged to register for 12.586. Students taking the graduate version complete different assignments.

*D. H. Rothman***12.090 Current Topics in Earth, Atmospheric, and Planetary Sciences**

Prereq: Permission of instructor

U (Fall)

Not offered regularly; consult department

Units arranged

Can be repeated for credit.

Laboratory or field work in earth, atmospheric, and planetary sciences. Consult with department Education Office.

*EAPS Faculty***12.091 Current Topics in Earth, Atmospheric, and Planetary Sciences**

Prereq: Permission of instructor

Acad Year 2021-2022: U (Fall, Spring)

Acad Year 2022-2023: Not offered

Units arranged [P/D/F]

Can be repeated for credit.

Laboratory or field work in earth, atmospheric, and planetary sciences. Consult with department Education Office.

*EAPS Faculty*

**12.092 Current Topics in Geology and Geochemistry**

Prereq: None

U (Fall, IAP, Spring)

Not offered regularly; consult department

Units arranged

Can be repeated for credit.

Laboratory or field work in geology and geochemistry. Consult with department Education Office.

*Staff*

**12.093 Current Topics in Geology and Geochemistry**

Prereq: Permission of instructor

U (Spring)

Not offered regularly; consult department

Units arranged [P/D/F]

Can be repeated for credit.

Laboratory or field work in geology and geochemistry. To be arranged with department faculty. Consult with department Education Office.

*EAPS Faculty*

**12.094 Current Topics in Geophysics**

Prereq: Permission of instructor

U (Spring; first half of term)

Units arranged

Can be repeated for credit.

Laboratory or field work in geophysics. Consult with department Education Office.

*EAPS Faculty*

**12.095 Current Topics in Geophysics**

Prereq: Permission of instructor

U (Spring)

Not offered regularly; consult department

Units arranged [P/D/F]

Can be repeated for credit.

Laboratory or field work in geophysics. To be arranged with department faculty. Consult with department Education Office.

*EAPS Faculty*

**12.096 Current Topics in Atmospheric Science and Oceanography**

Prereq: Permission of instructor

U (Fall, IAP, Spring)

Not offered regularly; consult department

Units arranged

Can be repeated for credit.

Laboratory or field work in atmospheric science and oceanography. To be arranged with department faculty. Consult with department Education Office.

*EAPS Faculty*

**12.097 Current Topics in Atmospheric Science and Oceanography**

Prereq: Permission of instructor

U (Spring)

Not offered regularly; consult department

Units arranged [P/D/F]

Can be repeated for credit.

Laboratory or field work in atmospheric science and oceanography. To be arranged with department faculty. Consult with department Education Office.

*EAPS Faculty*

**12.098 Current Topics in Planetary Science**

Prereq: Permission of instructor

U (Fall)

Not offered regularly; consult department

Units arranged

Can be repeated for credit.

Laboratory or field work in planetary science. To be arranged with department faculty. Consult with department Education Office.

*EAPS Staff*

**12.099 Current Topics in Planetary Science**

Prereq: Permission of instructor

U (Fall)

Not offered regularly; consult department

Units arranged [P/D/F]

Can be repeated for credit.

Laboratory or field work in planetary science. To be arranged with department faculty. Consult with department Education Office.

*EAPS Faculty*

**Geology and Geochemistry****12.104 Geochemistry of Natural Waters**

Subject meets with 12.494  
 Prereq: Calculus II (GIR)  
 Acad Year 2021-2022: U (Fall)  
 Acad Year 2022-2023: Not offered  
 3-2-7 units

Equips students with the fundamental skills to identify major controls on the chemistry of waters on the Earth. Students examine key concepts, theories and practical tools (e.g., pH, Eh, alkalinity, surface charge, speciation, and carbonate equilibrium) and apply them as tools to understand and make predictions for the biogeochemical cycles of the Earth systems. Students taking graduate version complete additional assignments.  
*S. Ono*

**12.108 Structure of Earth Materials**

Prereq: Chemistry (GIR)  
 Acad Year 2021-2022: U (Fall)  
 Acad Year 2022-2023: Not offered  
 3-4-5 units

Provides a comprehensive introduction to crystalline structure, crystal chemistry, and bonding in rock-forming minerals. Introduces the theory relating crystal structure and crystal symmetry to physical properties such as refractive index, elastic modulus, and seismic velocity. Surveys the distribution of silicate, oxide, and metallic minerals in the interiors and on the surfaces of planets, and discusses the processes that led to their formation.  
*T. L. Grove*

**12.109 Petrology**

Prereq: 12.108  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: U (Fall)  
 3-6-6 units

Surveys the distribution, chemical composition, and mineral associations in rocks of the Earth's crust and upper mantle, and establishes its relation to tectonic environment. Emphasis is on the use of chemistry and physics to interpret rock forming processes. Topics include dynamics of crust and mantle melting as preserved in the chemical composition of igneous rocks and minerals, the long-term record of global climate change as preserved in the minerals of sedimentary rocks, and the time-temperature-depth record preserved in minerals of metamorphosed crustal rocks.  
*T. L. Grove*

**12.11 Nature's Sandbox: A Record of Great Moments in Earth History**

Prereq: None  
 U (IAP)  
 Not offered regularly; consult department  
 2-0-0 units

Designed for students curious about Earth Systems. Covers how sediments and the sedimentary rock record preserve information about events in Earth History and ancient climates and oceans. Serves as an introduction to the subjects 12.110A Sedimentary Environments and 12.110B Sedimentology in the Field.  
*K. Bergmann*

**12.110A Sedimentary Environments**

Subject meets with 12.465A  
 Prereq: 12.001 or 12.11  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: U (Spring; first half of term)  
 2-1-3 units. Partial Lab

Covers the basic concepts of sedimentation from the properties of individual grains to large-scale basin analysis. Lectures cover sediment textures and composition, fluid flow and sediment transport, and formation of sedimentary structures. Depositional models, for both modern and ancient environments are a major component and are studied in detail with an eye toward interpretation of depositional processes and reconstructing paleoenvironments from the rock record. Satisfies 6 units of Institute Laboratory credit. Students taking graduate version complete additional assignments.  
*K. Bergmann*

### **12.110B Sedimentology in the Field**

Subject meets with 12.465B

Prereq: 12.110A

U (Spring; second half of term)

Not offered regularly; consult department

2-2-5 units. Partial Lab

Can be repeated for credit.

Examines the fundamentals of sedimentary deposits and geological reasoning through first hand fieldwork. Students practice methods of modern geological field study off-campus during a required trip over spring break making field observations, measuring stratigraphic sections and making a sedimentological map. Relevant topics introduced are map and figure making in ArcGIS and Adobe Illustrator and sedimentary petrology. Culminates in an oral and written report built around data gathered in the field. Field sites and intervals of geologic time studied rotate annually and include Precambrian, Phanerozoic and Modern depositional environments. Satisfies 6 units of Institute Laboratory credit. May be taken multiple times for credit. Students taking graduate version complete additional assignments.

*K. Bergmann*

### **12.113 Structural Geology**

Prereq: 12.001

Acad Year 2021-2022: U (Fall)

Acad Year 2022-2023: Not offered

3-3-6 units

Introduces mechanics of rock deformation. Discusses recognition, interpretation, and mechanics of faults, folds, structural features of igneous and metamorphic rocks, and superposed deformations. Introduces regional structural geology and tectonics. Laboratory includes techniques of structural analysis, recognition and interpretation of structures on geologic maps, and construction of interpretive cross sections.

*M. Pec*

### **12.115 Field Geology**

Prereq: 12.113

Acad Year 2021-2022: U (IAP)

Acad Year 2022-2023: Not offered

0-9-0 units. Partial Lab

Introduction to the methods of modern geological field study off-campus during an intensive two-week experience. Exercises include geological and geomorphological mapping on topographic and photographic base maps of a wide variety of bedrock and surficial rocks. Where feasible, geochemical and geophysical field measurements are correlated with geology. Location is usually in the western US. Contact department regarding travel fee and resources for funding opportunities. Meets with 12.482 when offered concurrently. Satisfies 9 units of Institute Laboratory credit.

*O. Jagoutz*

### **12.116 Analysis of Geologic Data**

Prereq: 12.115

Acad Year 2021-2022: U (Spring)

Acad Year 2022-2023: Not offered

0-2-4 units. Partial Lab

Includes in-depth laboratory analysis of samples, interpretation of geological data, and where possible, geophysical and geochemical data. Includes the preparation of reports based on the field studies conducted in 12.115 during January; report generally exceeds 30 pages in length and includes one major revision and rewrite. Instruction in writing techniques provided. Contact department regarding travel fee and resources for funding opportunities. Satisfies 3 units of Institute Laboratory credit.

*O. Jagoutz*

**12.117A Field Geobiology I**

Subject meets with 12.487A

Prereq: None. Coreq: 12.001 or 12.007

U (Spring; first half of term)

Not offered regularly; consult department

2-1-3 units

Examines basic biological processes that operate in sediments. Lectures cover biological, physical and chemical processes that influence the formation and stabilization of sediments, including biomineralization, weathering, erosion, the formation of sedimentary structures and interactions with sediments, flow, and the cycles of nutrients. Lab covers analytical methods used to examine microbial processes, bioinformatic methods used to analyze microbial communities, and techniques used to analyze sediment grain sizes and chemistry. Readings and discussions provide preparation for the 12.117B field trip to a modern sedimentary environment. Enables students to interpret processes in modern sedimentary environments, reconstruct similar processes in the rock record, collect appropriate samples in the field, and analyze microbiological data. Students taking graduate version complete additional assignments.

*T. Bosak*

**12.117B Field Geobiology II**

Subject meets with 12.487B

Prereq: 12.117A

U (Spring; second half of term)

Not offered regularly; consult department

2-2-5 units

Can be repeated for credit.

Teaches fundamentals of field observations and reasoning in geobiology/sedimentology during a required trip to a modern sedimentary environment over spring break, followed by laboratory analyses of collected samples. Students make observations, develop hypotheses, collect samples required to test their hypotheses and interact with lecturers and students investigating the sedimentology of the site. Upon return to MIT, students work on field samples to characterize the sediments, use the preliminary data to develop an understanding of the field site, and write research reports. Students taking graduate version write proposals that present a research question based on the field observations and subsequent analyses. Meets with 12.110B and 12.465B when those subjects examine modern sedimentary environments.

*T. Bosak*

**12.119 Harnessing Power from Environmental Microbes and Chemical Gradients**

Prereq: Biology (GIR), Chemistry (GIR), or 12.007

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: U (Spring)

2-2-5 units

Provides practical instruction on how to make living batteries. Lectures cover the basics of marine and freshwater chemistry and biogeochemistry (pH, redox potential, organic loading, free energy for growth, chemical profiles, sampling and measurement methods). Students explore sediment biogeochemistry by analyzing mineral types and grain sizes, setting up microbial enrichment cultures, and sampling and characterizing microbes and environmental chemistry by microscopy, chemical assays of pore fluids, and bioinformatics tools. Subsequent lab activities teach students to develop and use electrochemical tools to build microbial batteries that can power light sources and instruments. Discussion and reading cover real-world applications of microbial fuel cells.

*T. Bosak, E. Boyle, S. Ono*

**12.12 Nature's Sandbox: The History of Ancient Environments, Climate, and Life**

Prereq: None

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: U (Spring; second half of term)

1-1-1 units

Series of field adventures to survey Earth's history and landscape through a combination of online and in-person instruction, with virtual field trips to Svalbard, Norway, the Death Valley area and Northern Minnesota. In these key sites, students explore the interactions between Earth's surface environments and life, and critical transitions in each. Includes weekly in-class paper discussions and experiential exercises. Three optional one-day field trips provide opportunity to explore the amazing sedimentary record preserved close to MIT. Subject can count toward the 6-unit discovery-focused credit limit for first year students.

*K. Bergmann*

**12.141 Electron Microprobe Analysis**

Prereq: None

U (IAP)

1-1-4 units

Introduction to the theory of x-ray microanalysis through the electron microprobe including ZAF matrix corrections. Techniques to be discussed are wavelength and energy dispersive spectrometry, scanning backscattered electron, secondary electron, cathodoluminescence, and x-ray imaging. Lab sessions involve use of the electron microprobe.

*T. Grove, N. Chatterjee*



**12.158 Molecular Biogeochemistry**

Subject meets with 12.458  
 Prereq: Permission of instructor  
 Acad Year 2021-2022: U (Fall)  
 Acad Year 2022-2023: Not offered  
 3-0-6 units

Covers all aspects of molecular biosignatures, such as their pathways of lipid biosynthesis, the distribution patterns of lipid biosynthetic pathways with regard to phylogeny and physiology, isotopic contents, occurrence in modern organisms and environments, diagenetic pathways, analytical techniques and the occurrence of molecular fossils through the geological record. Students analyze in depth the recent literature on chemical fossils. Lectures provide background on the subject matter. Basic knowledge of organic chemistry required. Students taking graduate version complete additional assignments.

*R. Summons*

**12.163 Geomorphology**

Subject meets with 12.463  
 Prereq: (Calculus I (GIR), Physics I (GIR), and 12.001) or permission of instructor  
 Acad Year 2021-2022: U (Fall)  
 Acad Year 2022-2023: Not offered  
 3-3-6 units

Quantitative examination of processes that shape Earth's surface. Introduction to fluvial, hillslope, and glacial mechanics. Essentials of weathering, soil formation, runoff, erosion, slope stability, sediment transport, and river morphology. Landscape evolution in response to climatic and tectonic forcing. Application of terrestrial theory to planetary surfaces. Additional instruction in geographic information systems (GIS) and remote sensing analysis, field measurement techniques, and numerical modeling of surface processes. Students taking the graduate version complete different assignments.

*T. Perron*

**12.170 Essentials of Geology**

Subject meets with 12.470  
 Prereq: (Calculus II (GIR) and Physics II (GIR)) or permission of instructor  
 U (Fall)  
 Not offered regularly; consult department  
 4-0-8 units

Studies the geology of planetary interiors and surfaces, including plate tectonics, as a unifying theory of terrestrial geology, surface processes, and the Earth's interior. Covers igneous, metamorphic, and sedimentary processes associated with tectonic settings and the typical rock suites created; mineral and rock identification; and causes of compositional differences on many scales (mineral grains, rocks, regions of the Earth, different planets). Also addresses conditions required for melting and melting processes; rock structure and field techniques; and Earth history. Treatment of these topics includes discussions of the geochemical, petrologic, geochronological, experimental, or field techniques used to investigate them; the limitations of current geological techniques and geological controversies; and major geological expeditions, experiments, and studies from the past, along with their premises and results. Students taking graduate version complete additional assignments.

*EAPS Staff*

**12.177 Astrobiology, Origins and Early Evolution of Life**

Subject meets with 12.477  
 Prereq: Biology (GIR), Chemistry (GIR), or permission of instructor  
 Acad Year 2021-2022: U (Fall)  
 Acad Year 2022-2023: Not offered  
 3-0-9 units

Provides an understanding of major areas of research into the problem of the origin of life on the early Earth from an astrobiological perspective. Topics include the timing, setting and conditions for the origin of life on the Hadean Earth; roles of planetary and extra-planetary processes; defining life; prebiotic chemistry; origins of nucleic acids and peptides; evolution of cellularity, replication, metabolism, and translation; establishment of the genetic code; biogenesis vs. ecogenesis; the nature of the last common ancestor of life; conceptualizing the "tree of life;" and the early evolution of the ancestors of bacteria, archaeal, and eukaryal lineages. Students taking graduate version complete an extra project.

*G. Fournier*



**12.178 The Phylogenomic Planetary Record**

Subject meets with 12.478

Prereq: None

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: U (Fall)

3-0-9 units

Introduces the tools of sequence-based phylogenetic analysis and molecular evolution in the context of studying events in Earth's deep past that have been preserved by genomes. Topics include basic concepts of cladistics, phylogeny and sequence evolution, construction of phylogenetic trees of genes and microbial lineages, molecular clocks, dating, and ancestral sequence reconstruction. Special attention to the evolutionary history of microbial metabolisms and their relationship to global biogeochemical cycles across Earth's history. Students taking graduate version complete additional assignments.

*G. Fournier*

**Geophysics****12.201 Essentials of Global Geophysics**

Subject meets with 12.501

Prereq: Physics II (GIR) and 18.03

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: U (Fall)

4-0-8 units

Overview of basic topics in solid-earth geophysics, such as the Earth's rotation, gravity and magnetic field, seismology, and thermal structure. Formulation of physical principles presented in three one-hour lectures per week. Current applications discussed in an additional one-hour tutorial each week. Students taking graduate version complete different assignments.

*R. van der Hilst*

**12.202 Flow, Deformation, and Fracture in Earth and Other Terrestrial Bodies**

Subject meets with 12.502

Prereq: Calculus II (GIR) and Physics I (GIR)

Acad Year 2021-2022: U (Fall)

Acad Year 2022-2023: Not offered

3-2-7 units

Covers fundamentals of deformation and fracture of solids and the flow of viscous fluids. Explores spatial scales from molecular to planetary, and time scales from fractions of a second to millions of years, to understand how and why natural materials on Earth and other terrestrial bodies respond to applied forces. Fundamental concepts include the principles of continuum mechanics, tensor representation of physical properties, forces, tractions, stresses, strain theory, elasticity, contact problems, fracture and friction, and viscous flow and rheological models (plasticity, viscosity, viscoelasticity, elasto-plasticity). Students gather, analyze and interpret data using existing theoretical models. Includes a significant laboratory component that provides practical experience with experimental measurements and tests students' acquired theoretical knowledge. Students taking graduate version complete different assignments.

*B. Minchew, M. Pec*

**12.203 Mechanics of Earth**

Subject meets with 12.503

Prereq: Calculus II (GIR) and Physics I (GIR)

Acad Year 2021-2022: U (Spring)

Acad Year 2022-2023: Not offered

3-2-7 units

Covers topics in the deformation and fracture of solids and the flow of viscous fluids. Explores spatial scales from molecular to planetary, and time scales from fractions of a second to millions of years, to understand how and why natural materials on Earth and other terrestrial bodies respond to applied forces. Introduces anelasticity, granular mechanics, poroelasticity, rate-and-state friction, transport properties of Earth materials (Darcy's law, Fick's law), brittle-ductile transitions, creep of polycrystalline materials, stored energy and dissipation, and convection. Prepares students to gather, analyze and interpret data using existing theoretical models. Through a significant laboratory component, students obtain practical experience with experimental measurements and test their acquired theoretical knowledge. Students taking graduate version complete different assignments.

*B. Minchew, M. Pec*

**12.207[J] Nonlinear Dynamics: Continuum Systems**

Same subject as 1.062[J], 18.354[J]

Subject meets with 18.3541

Prereq: Physics II (GIR) and (18.03 or 18.032)

U (Spring)

3-0-9 units

See description under subject 18.354[J].

*O. Kodio*

**12.213 Alternate Energy Sources**

Prereq: None

U (IAP)

Not offered regularly; consult department

1-4-1 units

Can be repeated for credit.

Explores a number of alternative energy sources such as geothermal energy (heat from the Earth's interior), wind, natural gas, and solar energy. Includes a field trip to visit sites where alternative energy is being harvested or generated. Content and focus of subject varies from year to year.

*F. D. Morgan*

**12.214 Essentials of Applied Geophysics**

Subject meets with 12.507

Prereq: 18.03

U (Fall)

Not offered regularly; consult department

3-3-6 units

Introduces the application of geophysical methods to all aspects of near-surface environmental and engineering geophysics, including the exploration for petroleum, water, and minerals. Topics include seismic, electrical, electromagnetic, ground penetrating radar, magnetics, gravity, rock physics and chemistry, borehole geophysics and the global positioning system (GPS). Uses a quantitative approach to emphasize basic principles and a physical /chemical understanding of each method. Discusses specific illustrative field examples. Lab work is mainly devoted to local field work and equipment preparation for the IAP Field Geophysics class. Students taking graduate version complete additional assignments.

*F. D. Morgan, T. A. Herring, B. H. Hager*

**Atmospheres, Oceans, and Climate**

**12.300[J] Global Change Science**

Same subject as 1.071[J]

Prereq: 18.03

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: U (Fall)

3-0-9 units

See description under subject 1.071[J].

*E. A. B. Eltahir*

**12.301 Climate Science**

Subject meets with 12.842

Prereq: Chemistry (GIR), 18.03, or permission of instructor

U (Fall)

4-0-8 units

Introduction to climate studies, including beginnings of the solar system, time scales, and climate in human history; methods for detecting climate change, including proxies, ice cores, instrumental records, and time series analysis; physical and chemical processes in climate, including primordial atmosphere, ozone chemistry, carbon and oxygen cycles, and heat and water budgets; internal feedback mechanisms, including ice, aerosols, water vapor, clouds, and ocean circulation; climate forcing, including orbital variations, volcanism, plate tectonics, and solar variability; climate models and mechanisms of variability, including energy balance, coupled models, and global ocean and atmosphere models; and outstanding problems. Students taking the graduate version complete different assignments.

*K. Emanuel, E. Boyle*

**12.306 Atmospheric Physics and Chemistry**

Subject meets with 10.571[J], 12.806[J]

Prereq: (18.075 and (5.60 or 5.61)) or permission of instructor

U (Spring)

3-0-9 units

Introduction to the physics and chemistry of the atmosphere including experience with computer codes. Aerosols and theories of their formation, evolution, and removal. Gas and aerosol transport from urban to continental scales. Coupled models of radiation, transport, and chemistry. Solution of inverse problems to deduce emissions and removal rates. Emissions control technology and costs. Applications to air pollution and climate. Students taking the graduate version complete different assignments.

*R. G. Prinn*

**12.307 Weather and Climate Laboratory**

Prereq: Calculus II (GIR) and Physics I (GIR)

U (Spring)

1-4-7 units. Institute LAB

Engages students in projects involving rotating tank laboratory experiments, analysis of data on the sphere, and report writing and presentation. Project themes explore fundamentals of climate science and make contact points with major contemporary environmental challenges facing mankind. Examples include heat and moisture transport in the atmosphere; weather and weather extremes; aerosols, dust, and atmospheric pollution; ocean circulation and transport and plastics in the ocean. Develops skills for how to deal with noisy, imperfect data. Provides instruction and practice in written and oral communication.

*L. Illari, J. Marshall***12.310 An Introduction to Weather Forecasting**

Prereq: Calculus I (GIR) and Physics I (GIR)

U (IAP)

1-1-4 units

Basic principles of synoptic meteorology and weather forecasting. Analysis of hourly weather data and numerical weather prediction models. Regular preparation of weather forecasts.

*L. Illari***12.315 Atmospheric Radiation and Convection**

Subject meets with 12.815

Prereq: 12.390 or permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: U (Spring)

3-0-9 units

Introduction to the physics of atmospheric radiation, remote sensing, and convection, including use of computer codes. Radiative transfer equation including emission and scattering, spectroscopy, Mie theory, and numerical solutions. Physics of dry and moist convection, including moist thermodynamics. Radiative-convective equilibrium. Solution of inverse problems in remote sensing of atmospheric temperature and composition. Students taking graduate version complete different assignments.

*T. Cronin***12.318 Introduction to Atmospheric Data and Large-scale Dynamics**

Subject meets with 12.818

Prereq: None. Coreq: 12.390

U (Fall)

3-3-6 units

Provides a general introduction to meteorological data and analysis techniques, and their use in the MIT Synoptic Laboratory to study the phenomenology and dynamics of large-scale atmospheric flow. Illustrates balance concepts as applied to the dynamics of frontal and synoptic scales, using real-time upper-air and surface station data and gridded analyzed fields. Uses advanced meteorological software packages to access, manipulate, and graphically display the data. Students taking graduate version complete different assignments.

*L. Illari***12.320A[*J*] Introduction to Hydrology and Water Resources**Same subject as 1.070A[*J*]

Prereq: 1.060A; Coreq: 1.061A and 1.106

U (Fall; first half of term)

2-0-4 units

See description under subject 1.070A[*J*].*D. Entekhabi***12.320B[*J*] Introduction to Hydrology Modeling**Same subject as 1.070B[*J*]Prereq: 1.070A[*J*]

U (Fall; second half of term)

2-0-4 units

See description under subject 1.070B[*J*].*D. Entekhabi***12.330[*J*] Fluid Physics**Same subject as 8.292[*J*]

Prereq: 5.60, 8.044, or permission of instructor

U (Spring)

Not offered regularly; consult department

3-0-9 units

See description under subject 8.292[*J*].*Staff*

**12.335 Experimental Atmospheric Chemistry**

Subject meets with 12.835

Prereq: Chemistry (GIR)

U (Fall)

2-4-6 units. Institute LAB

Introduces the atmospheric chemistry involved in climate change, air pollution, and ozone depletion using a combination of interactive laboratory and field studies and simple computer models. Uses instruments for trace gas and aerosol measurements and methods for inferring fundamental information from these measurements. Provides instruction and practice in written and oral communication. Students taking the graduate version complete different assignments.

*R. Prinn, S. Ono*

**12.336[J] Air Pollution and Atmospheric Chemistry**

Same subject as 1.085[J]

Prereq: 18.03

U (Fall)

3-0-9 units

See description under subject 1.085[J].

*C. Heald*

**12.338 Aerosol and Cloud Microphysics and Chemistry**

Subject meets with 1.842[J], 12.814[J]

Prereq: 1.085[J], 12.335, or permission of instructor

U (Spring)

Not offered regularly; consult department

3-0-9 units

Focuses on understanding how aerosol particles form droplets or ice crystals during several atmospheric processes: determining Earth's radiative balance; heterogeneous chemistry and acid rain; understanding where, when and how much precipitation occurs. Provides tools for understanding the physics of aerosol and cloud element motion; the interaction of particles with water vapor, including phase changes and droplet and ice nucleation; the chemical composition of particles and the effect on cloud formation processes; and the effect of cloud processing on aerosol chemistry. Discusses relevant topics of contemporary interest, e.g., geoengineering and weather modification and volcanic effects. Students taking the graduate version complete different assignments.

*D. Cziczo*

**12.346[J] Global Environmental Negotiations**

Same subject as IDS.062[J]

Subject meets with 12.846[J], IDS.525[J]

Prereq: Permission of instructor

U (Fall)

Not offered regularly; consult department

2-0-4 units

See description under subject IDS.062[J].

*N. E. Selin*

**12.348[J] Global Climate Change: Economics, Science, and Policy**

Same subject as 15.026[J]

Prereq: (Calculus II (GIR), 5.60, and 14.01) or permission of instructor

U (Spring)

Not offered regularly; consult department

3-0-6 units

See description under subject 15.026[J].

*Staff*

**12.349 Mechanisms and Models of the Global Carbon Cycle**

Subject meets with 12.849

Prereq: Calculus II (GIR) and Physics I (GIR)

U (Spring)

3-0-9 units

Addresses changes in the ocean, terrestrial biosphere and rocks modulation of atmospheric carbon dioxide on timescales from months to millions of years. Includes feedbacks between carbon cycle and climate. Combines hands-on data analysis with the formulation of simple models rooted in basic physical, chemical and biological principles. Students create individual "toy" global carbon cycle models. Students taking graduate version complete different assignments.

*M. Follows*

**12.372 Elements of Modern Oceanography**

Subject meets with 12.702  
 Prereq: Permission of instructor  
 U (Fall)  
 3-0-9 units

Examines a series of crosscutting topics that exemplify current directions in interdisciplinary oceanography. Focuses on current themes in oceanography, their interdisciplinary nature, and the role of ocean sciences in society. Introduces core concepts across the disciplines of biological, physical, and chemical oceanography as well as marine geology. Emphasizes the interdisciplinary aspects of these core concepts, the kinds of approaches and modes of thinking common to all of the disciplines, and the technological developments underpinning current advances. Students taking graduate version complete different assignments.

*G. Lawson, A. Kirincich (WHOI)*

**12.373 Field Oceanography**

Subject meets with 12.777  
 Prereq: Biology (GIR), Chemistry (GIR), and permission of instructor  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: U (Spring)  
 3-7-5 units. Institute LAB

Provides an introduction to the biogeochemistry of the ocean, and the field techniques and methods used in its study. Emphasizes biogeochemistry and the interrelated nature of elemental cycling, but also examines physical transport and air-sea gas exchange. Covers multiple aspects related to field instrumentation and measurements, including nutrients, oxygen, the carbon system, temperature, and salinity. Presents microbial analyses, such as metagenomics. Includes a mandatory spring break field trip aboard a research vessel; opportunities for funded travel available. Students work in groups to propose a project over the week-long voyage that utilizes the field time to collect samples. During the second half of the term, students analyze and synthesize the data, and present it in a publication-quality manuscript. Students taking graduate version complete additional assignments. Enrollment limited.

*A. R. Babbitt*

**12.377 The History of Earth's Climate**

Subject meets with 12.707  
 Prereq: Permission of instructor  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: U (Spring)  
 3-0-9 units

Studies the climate history of the Earth, from the formation of the early atmosphere and ocean to the present. Evaluates geochemical, sedimentological, and paleontological evidence for changes in ocean circulation, global temperatures, and atmospheric carbon dioxide levels. Covers theories and models of Phanerozoic climate change. Provides a long-term history of the global carbon cycle. Students taking graduate version complete different assignments.

*D. McGee*

**12.385 Science, Politics, and Environmental Policy**

Subject meets with 11.373[[]], 12.885[[]]  
 Prereq: Permission of instructor  
 U (Fall)  
 3-0-6 units

Examines the role of science in US and international environmental policymaking. Surveys the methods by which scientists learn about the natural world; the treatment of science by experts, advocates, the media, and the public and the way science is used in legislative, administrative and judicial decision making. Through lectures, group discussions, and written essays, students develop a critical understanding of the role of science in environmental policy. Potential case studies include fisheries management, ozone depletion, global warming, smog, and endangered species. Students taking the graduate version complete different assignments.

*S. Solomon, J. Knox-Hayes*

**12.386[[]] Environment and History**

Same subject as 21H.185[[]], STS.031[[]]  
 Prereq: None  
 U (Spring)  
 3-0-9 units. HASS-S; CI-H

See description under subject 21H.185[[]]. Enrollment limited.

*K. Brown, S. Solomon*

**12.387[ ] People and the Planet: Environmental Governance and Science**

Same subject as 15.874[ ], IDS.063[ ]

Prereq: None

U (Fall)

3-0-6 units

Introduces governance and science aspects of complex environmental problems and approaches to solutions. Introduces quantitative analyses and methodological tools to analyze environmental issues that have human and natural components. Demonstrates concepts through a series of in-depth case studies of environmental governance and science problems. Students develop writing, quantitative modeling, and analytical skills in assessing environmental systems problems and developing solutions. Through experiential activities, such as modeling and policy exercises, students engage with the challenges and possibilities of governance in complex, interacting systems, including biogeophysical processes and societal and stakeholder interactions.

*N. Selin, S. Solomon, J. Sterman***12.390 Fluid Dynamics of the Atmosphere and Ocean**

Subject meets with 12.800

Prereq: 12.003

U (Fall)

3-0-9 units

Introduction to fluid dynamics. Students acquire an understanding of some of the basic concepts of fluid dynamics that are needed as a foundation for advanced coursework in atmospheric science, physical oceanography, ocean engineering, climate science, etc. Emphasizes fluid fundamentals, with an atmosphere/ocean twist. Students taking graduate version complete additional assignments.

*A. Mahadevan, C. Cenedese****Planetary Science and Astronomy*****12.400 Our Space Odyssey**

Prereq: Physics I (GIR)

U (Spring)

3-0-9 units. REST

Traces historical and scientific advancement of our understanding of Earth's cosmic context. Introduces basic physical principles by which planets form and create their associated features of rings, satellites, diverse landscapes, atmospheres, and climates. Includes the physics of asteroids and comets and their orbital characteristics and links to meteorites. Considers one of the most fundamental questions - whether or not we are alone - by detailing the scientific exploration goals to be achieved at the Moon, Mars, and beyond.

*J. de Wit***12.402[ ] Introduction to Astronomy**

Same subject as 8.282[ ]

Prereq: Physics I (GIR)

U (Spring)

3-0-6 units. REST

See description under subject 8.282[ ].

*M. Tegmark***12.409 Hands-On Astronomy: Observing Stars and Planets**

Prereq: None

U (Spring)

1-3-2 units

Background for, and techniques of, visual observation and electronic imaging of the Moon, planets, satellites, stars, and brighter deep-space objects. Weekly outdoor observing sessions using 8-inch diameter telescopes when weather permits. Indoor sessions introduce skills necessary for observation. Introduction to contemporary observational astronomy including astronomical computing, image and data processing, and how astronomers work. Student must maintain a careful and complete written log which is graded. Consumes an entire evening each week; 100% attendance at observing sessions required to pass. Enrollment limited; priority to first-year students.

*A. Bosh***12.410[ ] Observational Techniques of Optical Astronomy**

Same subject as 8.287[ ]

Prereq: 8.282[ ], 12.409, or other introductory astronomy course

U (Fall)

3-4-8 units. Institute LAB

Fundamental physical and optical principles used for astronomical measurements at visible wavelengths and practical methods of astronomical observations. Topics: astronomical coordinates, time, optics, telescopes, photon counting, signal-to-noise ratios, data analysis (including least-squares model fitting), limitations imposed by the Earth's atmosphere on optical observations, CCD detectors, photometry, spectroscopy, astrometry, and time variability. Project at Wallace Astrophysical Observatory. Written and oral project reports. Limited to 18; preference to Course 8 and Course 12 majors and minors.

*R. Binzel, A. Bosh*

**12.411 Astronomy Field Camp**

Prereq: 12.410[*J*] or 12.410[*J*]  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: U (IAP)  
 0-6-3 units  
 Can be repeated for credit.

Individual research projects in planetary science and astrophysics, involving supervised work at Lowell Observatory in Flagstaff, AZ. Projects may include observations made using Lowell's telescope facilities. Project topics and objectives vary from year to year. Written and oral reports required. Limited to 6.

*A. Bosh*

**12.420 Essentials of Planetary Science**

Subject meets with 12.601  
 Prereq: 12.002 or permission of instructor  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: U (Fall)  
 3-0-9 units

Advanced applications of physical and chemical principles to the study of the solar system. Topics include terrestrial and giant planets, meteorites, asteroids, comets, Kuiper belt objects, rings, impact craters, interiors, surfaces, atmospheres, geomagnetism, cosmochemistry, remote sensing, formation and evolution of the solar system.

*J. de Wit*

**12.421 Physical Principles of Remote Sensing**

Subject meets with 12.621  
 Prereq: Physics II (GIR) and 6.0001  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: U (Fall)  
 3-0-9 units

Introduction to the physics of remote sensing with applications to the study of the Earth, Moon, planets and other solar system bodies, as well as to emerging fields, such as autonomous navigation. Includes the principles of optical, thermal, radar and lidar remote sensing. Covers fundamental properties of electromagnetic waves; principles of electromagnetic scattering from real and idealized materials, including various types of surfaces and vegetation; interaction of electromagnetic radiation with the atmosphere; and thermal and microwave emission from various media. Discusses past, present, and future remote sensing platforms along with the fundamentals of orbital mechanics and data processing tools and methods. Assignments require students to write simple computer programs and plot mathematical functions. Students taking graduate version complete different assignments.

*B. Minchew*

**12.422 Planetary Atmospheres**

Subject meets with 12.622  
 Prereq: 12.003 or permission of instructor  
 Acad Year 2021-2022: U (Fall)  
 Acad Year 2022-2023: Not offered  
 3-0-9 units

Provides a basic understanding of the physics and chemistry of planetary atmospheres. Explores the formation and evolution of atmospheres, their structure and dynamics, and what is known about their chemical composition. Pays particular attention to their energy balance. Also presents the current state of understanding of exoplanet atmospheres. Students taking graduate version complete an additional research project.

*J. de Wit*

**12.425[*J*] Extrasolar Planets: Physics and Detection Techniques**

Same subject as 8.290[*J*]  
 Subject meets with 12.625  
 Prereq: 8.03 and 18.03  
 U (Fall)  
 3-0-9 units. REST

Presents basic principles of planet atmospheres and interiors applied to the study of extrasolar planets. Focuses on fundamental physical processes related to observable extrasolar planet properties. Provides a quantitative overview of detection techniques. Introduction to the feasibility of the search for Earth-like planets, biosignatures and habitable conditions on extrasolar planets. Students taking graduate version complete additional assignments.

*S. Seager*

**12.43[*J*] Space Systems Engineering**

Same subject as 16.83[*J*]  
 Prereq: Permission of instructor  
 U (Fall)  
 3-3-6 units

See description under subject 16.83[*J*].

*K. Cahoy*

**12.431[*J*] Space Systems Development**

Same subject as 16.831[*J*]  
 Prereq: Permission of instructor  
 Acad Year 2021-2022: U (Spring)  
 Acad Year 2022-2023: Not offered  
 2-10-6 units. Institute LAB

See description under subject 16.831[*J*].

*Staff*



**Independent Research Subjects****12.UR Undergraduate Research**

Prereq: None  
 U (Fall, IAP, Spring, Summer)  
 Units arranged [P/D/F]  
 Can be repeated for credit.

Undergraduate research opportunities in Earth, Atmospheric, and Planetary Sciences.

*Consult Department UROP Coordinator*

**12.URG Undergraduate Research**

Prereq: None  
 U (Fall, IAP, Spring, Summer)  
 Units arranged  
 Can be repeated for credit.

Undergraduate research opportunities in Earth, Atmospheric, and Planetary Sciences.

*Consult Department UROP Coordinator*

**12.IND Independent Study**

Prereq: 12.TIP  
 U (Fall, IAP, Spring, Summer)  
 Not offered regularly; consult department  
 Units arranged  
 Can be repeated for credit.

Independent reading, laboratory, or fieldwork in Earth, Atmospheric, and Planetary Sciences. To be arranged by student and an appropriate EAPS faculty member. A written report may be required at the discretion of the advisor. Units arranged should reflect the project requirements.

*Consult EAPS Education Office*

**12.TIP Thesis Preparation**

Prereq: None  
 U (Fall, Spring)  
 2-0-4 units

Definition of and early-stage work on the thesis project. Students develop a written research proposal and begin writing the supporting text of the thesis concurrent with conducting research for the thesis project. Supervision of the writing continues into the spring term which concludes with an oral presentation of the research results.

*J. Abbott*

**12.THU Undergraduate Thesis**

Prereq: 12.TIP  
 U (Fall, IAP, Spring, Summer)  
 Units arranged  
 Can be repeated for credit.

Program of research leading to the writing of a thesis; to be arranged by the student and an appropriate MIT faculty member.

*EAPS Faculty*

**Graduate Subjects****12.44 Practical Experience**

Prereq: None  
 G (Summer)  
 Units arranged  
 Can be repeated for credit.

For Course 12 students participating in off-campus professional experiences related to their research. Before registering for this subject, students must have an offer from a company or organization, must identify an EAPS supervisor, and must receive prior approval from their advisor. Upon completion of the experience, student must submit a letter from the company or organization describing the what the student accomplished, along with a substantive final report from the student approved by the EAPS supervisor. Consult departmental academic office.

*EAPS Faculty*

**12.444 MatLab, Statistics, Regression, Signal Processing**

Subject meets with 12.012

Prereq: 18.06  
 G (Fall)  
 3-0-9 units

Introduces the basic tools needed for data analysis and interpretation in the Geosciences, as well as other sciences. Composed of four modules, targeted at introducing students to the basic concepts and applications in each module. MatLab: Principles and practice in its uses, script and function modules, basic approaches to solving problems. Statistics: Correlation, means, dispersion, precision, accuracy, distributions, central limit theorem, skewness, probability, Chi-Square, Gaussian and other common distributions used in hypothesis testing. Regression: Random and grid search methods, basic least squares and algorithms applicable to regression, inversion and parameter estimation. Signal Processing: Analog and digital signals, Z-transform, Fourier series, fast Fourier transforms, spectral analysis leakage and bias, digital filtering. Students taking the graduate version complete different assignments.

*F. D. Morgan, T. A. Herring, S. Ravela*

**12.445 Communication in the Earth, Atmospheric, and Planetary Sciences**

Prereq: Permission of instructor  
 Acad Year 2021-2022: G (Spring)  
 Acad Year 2022-2023: Not offered  
 3-0-3 units

Concentrated instruction and practice in professional writing and presentation. Topics include review of various communication styles prevalent in the field; strategies for tailoring reports, technical papers, and presentations for specific audiences; and mechanics of organization and style. Weekly assignments in writing or speaking, with peer and instructor feedback. Limited to 6.

*F. D. Morgan*

**12.446 Teaching Experience in EAPS**

Prereq: None  
 G (Fall, Spring)  
 Units arranged [P/D/F]  
 Can be repeated for credit.

Recognizes the educational value derived from satisfactory performance of assigned duties as a Teaching Assistant. Laboratory, field, recitation, or classroom teaching under supervision of a faculty member. Credit for this subject may not be used for any degree granted by Course 12. Total enrollment limited by availability of suitable teaching assignments.

*EAPS Staff*

**12.THG Graduate Thesis**

Prereq: Permission of instructor  
 G (Fall, IAP, Spring, Summer)  
 Units arranged  
 Can be repeated for credit.

Program of research leading to the writing of an SM, PhD, or ScD thesis; to be arranged by the student and an appropriate MIT faculty member.

*Consult Department Headquarters*

***Geology and Geochemistry*****12.450 Seminar in Geology and Geochemistry**

Prereq: Permission of instructor  
 G (Spring)  
 Not offered regularly; consult department  
 2-0-4 units  
 Can be repeated for credit.

Seminar on topics of current interest in geology and geochemistry. Required background preparation for students taking pre-doctoral general examinations in these subjects.

*Geology and Geochemistry Staff*

**12.451 Seminar in Regional Tectonics**

Prereq: Permission of instructor  
 G (Fall, Spring)  
 Not offered regularly; consult department  
 3-0-6 units  
 Can be repeated for credit.

Applies techniques of tectonic synthesis to study the roles of particular orogenic belts in global plate tectonics. Treats different applications in different terms, so that the subject may be taken repeatedly to learn the range of orogenic responses to temporal and spatial variations of activity at plate boundaries.

*B. C. Burchfiel, L. H. Royden*

**12.456 Seminar in Rock Mechanics**

Prereq: Permission of instructor  
 G (Spring)  
 Not offered regularly; consult department  
 2-0-4 units  
 Can be repeated for credit.

Discussion of current research or advanced topics in continental tectonics, rock mechanics, or experimental structural geology.

*EAPS Staff*

**12.458 Molecular Biogeochemistry**

Subject meets with 12.158  
 Prereq: Permission of instructor  
 Acad Year 2021-2022: G (Fall)  
 Acad Year 2022-2023: Not offered  
 3-0-6 units

Covers all aspects of molecular biosignatures, such as their pathways of lipid biosynthesis, the distribution patterns of lipid biosynthetic pathways with regard to phylogeny and physiology, isotopic contents, occurrence in modern organisms and environments, diagenetic pathways, analytical techniques and the occurrence of molecular fossils through the geological record. Students analyze in depth the recent literature on chemical fossils. Lectures provide background on the subject matter. Basic knowledge of organic chemistry required. Students taking graduate version complete additional assignments.

*R. Summons*

### **12.463 Geomorphology**

Subject meets with 12.163

Prereq: (Calculus I (GIR), Physics I (GIR), and 12.001) or permission of instructor

Acad Year 2021-2022: G (Fall)

Acad Year 2022-2023: Not offered

3-3-6 units

Quantitative examination of processes that shape Earth's surface. Introduction to fluvial, hillslope, and glacial mechanics. Essentials of weathering, soil formation, runoff, erosion, slope stability, sediment transport, and river morphology. Landscape evolution in response to climatic and tectonic forcing. Application of terrestrial theory to planetary surfaces. Additional instruction in geographic information systems (GIS) and remote sensing analysis, field measurement techniques, and numerical modeling of surface processes. Students taking the graduate version complete different assignments.

*T. Perron*

### **12.465A Sedimentary Environments**

Subject meets with 12.110A

Prereq: Permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Spring; first half of term)

2-1-3 units

Covers the basic concepts of sedimentation from the properties of individual grains to large-scale basin analysis. Lectures cover sediment textures and composition, fluid flow and sediment transport, and formation of sedimentary structures. Depositional models, for both modern and ancient environments are a major component and are studied in detail with an eye toward interpretation of depositional processes and reconstructing paleoenvironments from the rock record. Students taking graduate version complete additional assignments.

*K. Bergmann*

### **12.465B Sedimentology in the Field**

Subject meets with 12.110B

Prereq: 12.456 or permission of instructor  
G (Spring; second half of term)

Not offered regularly; consult department

2-2-5 units

Can be repeated for credit.

Examines the fundamentals of sedimentary deposits and geological reasoning through first hand fieldwork. Students practice methods of modern geological field study off-campus during a required trip over spring break making field observations, measuring stratigraphic sections and making a sedimentological map. Relevant topics introduced are map and figure making in ArcGIS and Adobe Illustrator and sedimentary petrology. Culminates in an oral and written report built around data gathered in the field. Field sites and intervals of geologic time studied rotate annually and include Precambrian, Phanerozoic and Modern depositional environments. May be taken multiple times for credit. Students taking graduate version complete additional assignments.

*K. Bergmann*

### **12.467 Seminar in Geomorphology**

Prereq: Permission of instructor

G (Spring)

2-0-1 units

Can be repeated for credit.

Discussion of current research or advanced topics in landscape evolution, surface hydrology, mechanics of sediment transport, basin analysis, or experimental geomorphology. Advanced instruction in process geomorphology.

*Perron, T*

**12.470 Essentials of Geology**

Subject meets with 12.170

Prereq: (Calculus II (GIR) and Physics II (GIR)) or permission of instructor

G (Fall)

Not offered regularly; consult department

4-0-8 units

Geology of planetary interiors and surfaces, including plate tectonics, as a unifying theory of terrestrial geology, surface processes, and the Earth's interior. Igneous, metamorphic, and sedimentary processes associated with tectonic settings and the typical rock suites created. Mineral and rock identification. Causes of compositional differences on many scales: mineral grains, rocks, regions of the Earth, different planets. Conditions required for melting and melting processes. Rock structure and field techniques. Earth history. Treatment of these topics includes discussions of the geochemical, petrologic, geochronological, experimental, or field techniques used to investigate them; the limitations of current geological techniques and geological controversies; and great geological expeditions, experiments, and studies from the past, their premises, and their results. Students taking graduate version complete additional assignments.

*EAPS Staff*

**12.471 Essentials of Geobiology**

Prereq: None

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Fall)

3-4-5 units

Introduces basic concepts of microbial structure, growth, energetics, molecular biology, and biochemistry. Presents examples of microbial interactions with environments throughout Earth's history as well as current topics in astrobiology. Includes lectures, discussions of literature, and a field trip. Lab focuses on student-designed projects that involve cultivation, modeling, or sample analyses. Intended for students whose background is not in biology, but who want to learn more about the contribution of microbes to geochemistry and planetary evolution.

*T. Bosak*

**12.473 Paleomagnetism and Planetary Magnetism**

Prereq: (12.002 and 18.03) or permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Fall)

2-0-4 units

Introduces the study of natural remanent magnetization and the generation of planetary magnetic fields. Topics include paleomagnetism, rock magnetism, geomagnetism, magnetostratigraphy, paleomagnetic measurement techniques, polar wander and continental drift, biomagnetism, dynamo theory, and the history and evolution of magnetic fields on the Earth and planets.

*B. P. Weiss*

**12.474 Origin and Evolution of the Earth's Crust**

Prereq: Permission of instructor

G (Spring)

Not offered regularly; consult department

3-0-6 units

Broad overview of the origin and evolution of Earth's crust and mantle with emphasis on the study of the Precambrian rock record. Topics include: processes of crustal growth, stabilization, and reactivation; evaluation of secular change; and use of radiogenic isotopes in geochronology and as tracers of crust forming processes.

*O. Jagoutz*

**12.475 Plate Tectonics and Continental Deformation**

Prereq: Permission of instructor

G (Spring)

Not offered regularly; consult department

3-0-6 units

First half covers basic elements of plate tectonics, including sea floor spreading, magnetic anomalies, and subduction zone. Second half covers implications of plate tectonics for continental processes, including continental rifting, continental collision, and mountain building. Emphasis will be on correlating plate tectonic and continental processes using specific examples from around the world.

*L. H. Royden*

### 12.476 Radiogenic Isotope Geology

Prereq: Permission of instructor

G (Spring)

Not offered regularly; consult department

3-3-6 units

Applications of the variations in the relative abundance of radiogenic isotopes to problems of petrology, geochemistry, and tectonics.

Topics: geochronology; isotopic evolution of Earth's crust and mantle; petrogenesis; and analytical techniques.

*EAPS Staff*

### 12.477 Astrobiology, Origins and Early Evolution of Life

Subject meets with 12.177

Prereq: Permission of instructor

Acad Year 2021-2022: G (Fall)

Acad Year 2022-2023: Not offered

3-0-9 units

Provides an understanding of major areas of research into the problem of the origin of life on the early Earth from an astrobiological perspective. Topics include the timing, setting and conditions for the origin of life on the Hadean Earth; roles of planetary and extra-planetary processes; defining life; prebiotic chemistry; origins of nucleic acids and peptides; evolution of cellularity, replication, metabolism, and translation; establishment of the genetic code; biogenesis vs. ecogenesis; the nature of the last common ancestor of life; conceptualizing the "tree of life;" and the early evolution of the ancestors of bacteria, archaeal, and eukaryal lineages. Students taking graduate version complete an extra project.

*G. Fournier*

### 12.478 The Phylogenomic Planetary Record

Subject meets with 12.178

Prereq: None

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Fall)

3-0-9 units

Introduces the tools of sequence-based phylogenetic analysis and molecular evolution in the context of studying events in Earth's deep past that have been preserved by genomes. Topics include basic concepts of cladistics, phylogeny and sequence evolution, construction of phylogenetic trees of genes and microbial lineages, molecular clocks, dating, and ancestral sequence reconstruction. Special attention to the evolutionary history of microbial metabolisms and their relationship to global biogeochemical cycles across Earth's history. Students taking graduate version complete additional assignments.

*G. Fournier*

### 12.480 Thermodynamics for Geoscientists

Prereq: 3.046 or 5.60

Acad Year 2021-2022: G (Spring)

Acad Year 2022-2023: Not offered

3-0-9 units

Principles of thermodynamics are used to infer the physical conditions of formation and modification of igneous and metamorphic rocks. Includes phase equilibria of homogeneous and heterogeneous systems and thermodynamic modelling of non-ideal crystalline solutions. Surveys the processes that lead to the formation of metamorphic and igneous rocks in the major tectonic environments in the Earth's crust and mantle.

*T. L. Grove*

### 12.481 Advanced Field Geology I

Prereq: 12.113

G (Fall)

Not offered regularly; consult department

2-2-2 units

Can be repeated for credit.

Introduction to the problems to be investigated in 12.482, as well as the regional setting and local geology of the field area. Various special techniques may be introduced and preparatory investigations may be conducted that are specific to the area to be studied in 12.482.

*O. Jagoutz*

### 12.482 Advanced Field Geology II

Prereq: 12.481

Acad Year 2021-2022: G (IAP)

Acad Year 2022-2023: Not offered

Units arranged

Can be repeated for credit.

In January, a geological and geomorphological study of a selected field area is conducted during a two-week excursion. Exercises include geological and geomorphological mapping on topographic and photographic base maps of a wide variety of bedrock and surficial rocks. Where feasible, geochemical and geophysical field measurements are correlated with geology. Meets with 12.115 when offered concurrently.

*O. E. Jagoutz*

**12.486 Advanced Igneous Petrology**

Prereq: Permission of instructor  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: G (Spring)  
 3-2-7 units  
 Can be repeated for credit.

Comprehensive overview of igneous rocks from the Earth, Moon, and meteorite parent bodies. Discusses the compositional diversity of igneous rocks and how it can be used to elucidate rock forming processes in the major tectonic provinces on modern Earth, including mid-ocean ridges, subduction zones, ocean islands, and inter-continental rifting environments. Also covers magma generation processes in the terrestrial planets prior to 2.6 billion years ago. Laboratory exercises on selected suites of igneous rocks reinforce readings and classroom discussions. Uses evidence from related geo-science disciplines to develop an integrative approach to understanding processes that lead to the chemical differentiation of planetary bodies through time. Subject matter may be modified to reflect the interests of the group.

*T. L. Grove*

**12.487A Field Geobiology I**

Subject meets with 12.117A  
 Prereq: Permission of instructor  
 G (Spring; first half of term)  
 Not offered regularly; consult department  
 2-1-3 units

Examines basic biological processes that operate in sediments. Lectures cover biological, physical and chemical processes that influence the formation and stabilization of sediments, including biomineralization, weathering, erosion, the formation of sedimentary structures and interactions with sediments, flow, and the cycles of nutrients. Lab covers analytical methods used to examine microbial processes, bioinformatic methods used to analyze microbial communities, and techniques used to analyze sediment grain sizes and chemistry. Readings and discussions provide preparation for the 12.487B field trip to a modern sedimentary environment. Enables students to interpret processes in modern sedimentary environments, reconstruct similar processes in the rock record, collect appropriate samples in the field, and analyze microbiological data. Students taking graduate version complete additional assignments.

*T. Bosak*

**12.487B Field Geobiology II**

Subject meets with 12.117B  
 Prereq: Permission of instructor  
 G (Spring; second half of term)  
 Not offered regularly; consult department  
 2-2-5 units

Teaches fundamentals of field observations and reasoning in geobiology/sedimentology during a required trip to a modern sedimentary environment over spring break, followed by laboratory analyses of collected samples. Students make observations, develop hypotheses, collect samples required to test their hypotheses and interact with lecturers and students investigating the sedimentology of the site. Upon return to MIT, students work on field samples to characterize the sediments, use the preliminary data to develop an understanding of the field site, and write research reports. Students taking graduate version write proposals that present a research question based on the field observations and subsequent analyses. Meets with 12.110B and 12.465B when those subjects examine modern sedimentary environments.

*T. Bosak*

**12.493[J] Microbial Genetics and Evolution**

Same subject as 1.87[J], 7.493[J], 20.446[J]  
 Prereq: 7.03, 7.05, or permission of instructor  
 G (Fall)  
 4-0-8 units

See description under subject 7.493[J].

*A. D. Grossman, O. Cordero*

**12.494 Geochemistry of Natural Waters**

Subject meets with 12.104  
 Prereq: Calculus II (GIR)  
 Acad Year 2021-2022: G (Fall)  
 Acad Year 2022-2023: Not offered  
 3-2-7 units

Equips students with the fundamental skills to identify major controls on the chemistry of waters on the Earth. Students examine key concepts, theories and practical tools (e.g., pH, Eh, alkalinity, surface charge, speciation, and carbonate equilibrium) and apply them as tools to understand and make predictions for the biogeochemical cycles of the Earth systems. Graduate students complete additional assignments.

*S. Ono*

**Geophysics****12.501 Essentials of Global Geophysics**

Subject meets with 12.201  
 Prereq: Physics II (GIR) and 18.03  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: G (Fall)  
 4-0-8 units

Overview of basic topics in solid-earth geophysics, such as the Earth's rotation, gravity and magnetic field, seismology, and thermal structure. Formulation of physical principles presented in three one-hour lectures per week. Current applications discussed in an additional one-hour tutorial each week. Students taking graduate version complete different assignments.

*R. van der Hilst*

**12.502 Flow, Deformation, and Fracture in Earth and Other Terrestrial Bodies**

Subject meets with 12.202  
 Prereq: Calculus II (GIR) and Physics I (GIR)  
 Acad Year 2021-2022: G (Fall)  
 Acad Year 2022-2023: Not offered  
 3-2-7 units

Covers fundamentals of deformation and fracture of solids and the flow of viscous fluids. Explores spatial scales from molecular to planetary, and time scales from fractions of a second to millions of years, to understand how and why natural materials on Earth and other terrestrial bodies respond to applied forces. Fundamental concepts include the principles of continuum mechanics, tensor representation of physical properties, forces, tractions, stresses, strain theory, elasticity, contact problems, fracture and friction, and viscous flow and rheological models (plasticity, viscosity, viscoelasticity, elasto-plasticity). Students gather, analyze and interpret data using existing theoretical models. Includes a significant laboratory component that provides practical experience with experimental measurements and tests students' acquired theoretical knowledge. Students taking graduate version complete different assignments.

*B. Minchew, M. Pec*

**12.503 Mechanics of Earth**

Subject meets with 12.203  
 Prereq: Calculus II (GIR) and Physics I (GIR)  
 Acad Year 2021-2022: G (Spring)  
 Acad Year 2022-2023: Not offered  
 3-2-7 units

Covers topics in the deformation and fracture of solids and the flow of viscous fluids. Explores spatial scales from molecular to planetary, and time scales from fractions of a second to millions of years, to understand how and why natural materials on Earth and other terrestrial bodies respond to applied forces. Introduces anelasticity, granular mechanics, poroelasticity, rate-and-state friction, transport properties of Earth materials (Darcy's law, Fick's law), brittle-ductile transitions, creep of polycrystalline materials, stored energy and dissipation, and convection. Prepares students to gather, analyze and interpret data using existing theoretical models. Through a significant laboratory component, students obtain practical experience with experimental measurements and test their acquired theoretical knowledge. Students taking graduate version complete different assignments.

*B. Minchew, M. Pec*

**12.507 Essentials of Applied Geophysics**

Subject meets with 12.214  
 Prereq: 18.03  
 G (Fall)  
 Not offered regularly; consult department  
 3-3-6 units

Introduces the application of geophysical methods to all aspects of near-surface environmental and engineering geophysics, including the exploration for petroleum, water, and minerals. Topics include seismic, electrical, electromagnetic, ground penetrating radar, magnetics, gravity, rock physics and chemistry, borehole geophysics and the global positioning system (GPS). Uses a quantitative approach to emphasize basic principles and a physical /chemical understanding of each method. Discusses specific illustrative field examples. Lab work is mainly devoted to local field work and equipment preparation for the IAP Field Geophysics class. Students taking graduate version complete additional assignments.

*F. D. Morgan, T. A. Herring, B. H. Hager*



**12.510 Introduction to Seismology**

Prereq: 18.075 or 18.085

G (Fall)

3-1-8 units

A basic study in seismology and the utilization of seismic waves for the study of Earth's interior. Introduces techniques necessary for understanding of elastic wave propagation in stratified media and for calculation of synthetic seismograms (WKB) and mode summation). Ray theory; interpretation of travel times. (e.g., tomography); surface wave dispersion in layered media; Earth's free oscillations; and seismicity, (earthquake locations, magnitude, moment, and source properties).

*R. van der Hilst, W. Frank***12.511 Field Geophysics**

Prereq: None

Acad Year 2021-2022: G (IAP)

Acad Year 2022-2023: Not offered

1-4-1 units

Covers practical methods of modern geophysics, including the global positioning system (GPS), gravity, and magnetics. Field work is conducted in western US and includes intensive 10-day field exercise. Focuses on measurement techniques and their interpretation. Introduces the science of gravity, magnetics, and the GPS. Measures crustal structure, fault motions, tectonic deformations, and the local gravity and magnetic fields. Students perform high-precision measurements and participate in data analysis. Emphasizes principles of geophysical data collection and the relevance of these data for tectonic faulting, crustal structure, and the dynamics of the earthquake cycle. Students taking graduate version complete additional assignments.

*T. A. Herring, B. H. Hager, F. D. Morgan***12.512 Field Geophysics Analysis**

Prereq: 12.511

Acad Year 2021-2022: G (Spring)

Acad Year 2022-2023: Not offered

2-0-4 units

Focuses on in-depth data analysis and development of skills needed to report results both in writing and orally. Students use data collected in 12.511 to develop written and oral reports of the results, with each student focusing on a different area. For example, students can develop the geophysical modeling or synthesis of the results into other studies in the area. The final written and oral reports are combined into a comprehensive report and presentation of the field camp and its results. Students taking graduate version complete additional assignments.

*T. A. Herring, B. H. Hager, F. D. Morgan***12.515 Data and Models**

Prereq: 18.075 or 18.085

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Spring)

3-0-9 units

Surveys a number of methods of inverting data to obtain model parameter estimates. Topics include review of matrix theory and statistics, random and grid-search methods, linear and non-linear least squares, maximum-likelihood estimation, ridge regression, stochastic inversion, sequential estimation, singular value decomposition, solution of large systems, genetic and simulated annealing inversion, regularization, parameter error estimates, and solution uniqueness and resolution. Computer laboratory and algorithm development.

*F. D. Morgan***12.521 Computational Geophysical Modeling**

Prereq: Permission of instructor

Acad Year 2021-2022: G (Fall)

Acad Year 2022-2023: Not offered

3-0-9 units

Introduces theory, design, and practical methods of computational modeling in geodynamics and geophysical fluid dynamics. Covers the most effective and widely used numerical modeling approaches (e.g., boundary element, finite difference, finite element) and emphasizes problem-solving skills through illustrative examples of heat and mass transfer in the mantle and the ocean. Students acquire experience with various numerical methods through regularly assigned computational exercises and a term-long modeling project of each student's choice.

*J. Lin, O. Marchal, M. Behn***12.522 Geological Fluid Mechanics**

Prereq: 8.03 and (18.075 or 18.085)

G (Fall)

Not offered regularly; consult department

3-0-9 units

Treats heat transfer and fluid mechanics in the Earth, low Reynolds number flows, convection instability, double diffusion, Non-Newtonian flows, flow in porous media, and the interaction of flows with accreting and deforming boundaries. Applications include: the flow under plates, postglacial rebound, diapirism, magma dynamics, and the mantle convection problem.

*J. A. Whitehead (WHOI)*

**12.525 Mechanisms of Faulting and Earthquakes**

Prereq: Permission of instructor

G (Spring)

Not offered regularly; consult department

3-0-9 units

Explores the fundamental mechanics of faulting and earthquakes from four related perspectives: seismology, geodesy, geodynamics, and rheology. Topics to be covered include (1) the physical processes that control the rheology of faults, including friction and fracture, (2) how these rheological processes are manifest in faulting and earthquakes in the earth from a geodynamics perspective, and (3) how the mechanics of faulting and earthquakes are constrained by seismological and geodetic observations. Both continental and oceanic examples of faulting and earthquakes will be featured.

*J. McGuire, G. Prieto*

**12.533 Rock Physics**

Prereq: Permission of instructor

G (Spring)

Not offered regularly; consult department

3-3-6 units

Fundamentals of experimental and theoretical rock physics taught at an advanced level. Rocks viewed as complex composite media with behavior dependent both on the physical and chemical properties of the constituent phases, and on their geometries. Electrical, fluid transport, and seismic properties covered in detail. Other topics such as magnetic, mechanical, and thermal responses briefly discussed. Weekly laboratory.

*F. D. Morgan*

**12.540 Principles of Global Positioning System**

Prereq: Calculus II (GIR), Physics I (GIR), and 18.06

G (Spring)

3-0-9 units

The principles and applications of the Global Positioning System (US), GLONASS (Russia), Galileo (EU) and Beidou (China), known as Global Navigation Satellite Systems (GNSS), along with other space geodetic systems, including very-long-baseline interferometry (VLBI), satellite laser ranging (SLR), and Interferometric Synthetic Aperture Radar (InSAR). Topics covered include CDMA and FDMA encoding used by these systems to allow measurements of pseudo-range and carrier phase which allow millimeter accuracy positioning, models and analysis methods required for millimeter accuracy positioning. Other topics include: satellite orbit modeling, atmospheric refraction modeling, estimation techniques (including Kalman filtering), statistical and spectral analysis of data.

Application areas include tectonic studies of Earth deformation, meteorology, space weather, and millimeter accuracy tracking of moving objects.

*T. A. Herring*

**12.552 Advanced Seismology: Theory and Applications of Seismic Imaging**

Prereq: 12.510

G (Spring)

Not offered regularly; consult department

3-0-9 units

Introduces fundamental principles of seismic imaging used in both exploration and solid earth applications. Topics include ray theoretical approaches, scattering theory, and seismic waveform modeling. Through lectures, projects and student-led discussions of journal articles, the class covers the whole process of seismic imaging, from data preprocessing to model generation and geological interpretation of the results.

*EAPS Faculty*

**12.560-12.561 Advanced Seminar in Exploration Geophysics**

Prereq: Permission of instructor

G (Fall, IAP, Spring)

Not offered regularly; consult department

2-0-4 units

Can be repeated for credit.

Advanced seminar focusing on areas of current interest in exploration geophysics and seismology. 12.560 is letter-graded.

*Geophysics Staff*

**12.570 Topical Issues in Global Geophysics**

Prereq: Permission of instructor

G (Spring)

Not offered regularly; consult department

Units arranged

Can be repeated for credit.

Series of formal lectures and seminars with the specific content varying by term to reflect current issues in research. Meets jointly with relevant Harvard course.

*R. D. van der Hilst*

**12.571 Seminar in Geophysics**

Prereq: Permission of instructor

G (Fall)

Not offered regularly; consult department

Units arranged [P/D/F]

Can be repeated for credit.

Problems of current interest in geophysics; subject matter varying from term to term.

*Geophysics Staff*

**12.586 Modeling Environmental Complexity**

Subject meets with 12.086

Prereq: 18.03 or permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Fall)

3-0-9 units

Introduction to mathematical and physical models of environmental processes. Emphasis on the development of macroscopic continuum or statistical descriptions of complex microscopic dynamics.

Problems of interest include: random walks and statistical geometry of landscapes; percolation theory and transport in disordered media; fractals, scaling, and universality; ecological dynamics and the structure of ecosystems, food webs, and other natural networks; kinetics of biogeochemical cycles. Appropriate for advanced undergraduates. Beginning graduate students are encouraged to register for 12.586. Students taking the graduate version complete different assignments.

*D. H. Rothman*

**Planetary Science****12.601 Essentials of Planetary Science**

Subject meets with 12.420

Prereq: 8.03 and 18.03

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Fall)

3-0-9 units

Reviews fundamental physical concepts pertaining to the study of the solar system, and highlights recent spacecraft results.

Topics include: meteorites, orbital dynamics, asteroids, impact craters, surfaces, atmospheres, atmospheric dynamics, interiors, magnetospheres, rings, comets, formation of the solar system.

*B. P. Weiss*

**12.603 Solar System Dynamics**

Prereq: Permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Spring)

3-0-9 units

Studies the dynamics of the solar system and its major subsystems, and the dynamics of exoplanets, with a modern emphasis on the qualitative structure of phase space. Topics may include rotational dynamics, spin-orbit coupling, Cassini states, and orbital dynamics, resonances, and Kozai oscillations, tidal evolution and tidal heating.

*J. Wisdom*

**12.611 Advanced Planetary Observations**

Prereq: Permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (IAP)

0-6-3 units

Can be repeated for credit.

Individual research projects in planetary science and astrophysics involving supervised work at Lowell Observatory in Flagstaff, AZ. Projects may include observations made using Lowell's telescope facilities. Project topics and objectives vary from year to year. Written and oral reports required. Enrollment limited.

*A. Bosh*

**12.620[J] Classical Mechanics: A Computational Approach**

Same subject as 6.946[J], 8.351[J]

Prereq: Physics I (GIR), 18.03, and permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Fall)

3-3-6 units

Classical mechanics in a computational framework, Lagrangian formulation, action, variational principles, and Hamilton's principle. Conserved quantities, Hamiltonian formulation, surfaces of section, chaos, and Liouville's theorem. Poincaré integral invariants, Poincaré-Birkhoff and KAM theorems. Invariant curves and cantori. Nonlinear resonances, resonance overlap and transition to chaos. Symplectic integration. Adiabatic invariants. Applications to simple physical systems and solar system dynamics. Extensive use of computation to capture methods, for simulation, and for symbolic analysis. Programming experience required.

*J. Wisdom, G. J. Sussman*

### 12.621 Physical Principles of Remote Sensing

Subject meets with 12.421  
 Prereq: Physics II (GIR) and 6.0001  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: G (Fall)  
 3-0-9 units

Introduction to the physics of remote sensing with applications to the study of the Earth, Moon, planets and other solar system bodies, as well as to emerging fields, such as autonomous navigation. Includes the principles of optical, thermal, radar and lidar remote sensing. Covers fundamental properties of electromagnetic waves; principles of electromagnetic scattering from real and idealized materials, including various types of surfaces and vegetation; interaction of electromagnetic radiation with the atmosphere; and thermal and microwave emission from various media. Discusses past, present, and future remote sensing platforms along with the fundamentals of orbital mechanics and data processing tools and methods. Assignments require students to write simple computer programs and plot mathematical functions. Students taking graduate version complete different assignments.

*B. Minchew*

### 12.622 Planetary Atmospheres

Subject meets with 12.422  
 Prereq: Permission of instructor  
 Acad Year 2021-2022: G (Fall)  
 Acad Year 2022-2023: Not offered  
 3-0-9 units

Provides a basic understanding of the physics and chemistry of planetary atmospheres. Explores the formation and evolution of atmospheres, their structure and dynamics, and what is known about their chemical composition. Pays particular attention to their energy balance. Also presents the current state of understanding of exoplanet atmospheres. Students taking graduate version complete an additional research project.

*J. de Wit*

### 12.625 Extrasolar Planets: Physics and Detection Techniques

Subject meets with 8.290[J], 12.425[J]  
 Prereq: 8.03 and 18.03  
 G (Fall)  
 3-0-9 units

In-depth study of current topics in exoplanets, such as exoplanet transits, radial velocity curves, current survey missions, the mass-radius relation, and super Earths. Class activities consist of reading the current literature, problem sets, and a term project. Students taking graduate version complete additional assignments.

*S. Seager*

### 12.650 Current Topics in Planetary Science

Prereq: Permission of instructor  
 Acad Year 2021-2022: G (Spring)  
 Acad Year 2022-2023: Not offered  
 3-0-9 units  
 Can be repeated for credit.

In-depth discussion of current and classic literature on selected topics in planetary science. Topics vary from year to year.

*J. Wisdom*

### 12.652 Current Topics in Planetary Science

Prereq: Permission of instructor  
 G (Fall, Spring)  
 Not offered regularly; consult department  
 3-0-9 units  
 Can be repeated for credit.

In-depth discussion of current and classic literature on selected topics in the specialty areas of asteroids and the Pluto-Charon system. Topics vary from year to year.

*R. P. Binzel*

### *Geological, Geophysical, and Chemical Oceanography*

#### 12.701 Classic Papers in Physical Oceanography

Prereq: None  
 G (Spring)  
 3-0-3 units

Provides a historical perspective on fundamental topics in oceanography by considering individual works which, when pieced together, contribute to the more cohesive description of how the ocean works. In class discussions, students consider various aspects of the work in question, including motivation, approach, and implications for the broader context. They also synthesize information and make oral presentations. Develops basic analytical and critical skills in paper reading and writing.

*Y. Kwon (WHOI)*

**12.702 Elements of Modern Oceanography**

Subject meets with 12.372

Prereq: None

G (Fall)

3-0-9 units

Examines a series of crosscutting topics that exemplify current directions in interdisciplinary oceanography. Focuses on current themes in oceanography, their interdisciplinary nature, and the role of ocean sciences in society. Introduces core concepts across the disciplines of biological, physical, and chemical oceanography as well as marine geology. Emphasizes the interdisciplinary aspects of these core concepts, the kinds of approaches and modes of thinking common to all of the disciplines, and the technological developments underpinning current advances. Students taking graduate version complete different assignments.

*G. Lawson, A. Kirincich (WHOI)*

**12.703 Presenting Scientific Research**

Prereq: None

G (Fall)

3-0-3 units

Presenting scientific research geared toward a scientific audience. Each student gives one 30-minute talk, one AGU-style 15-minute talk, and one poster presentation. Students present their ongoing research and use the class as a forum to practice for upcoming talks in more formal settings. Abstracts are prepared for each presentation and discussed in class. Students provide comments, questions, encouragement, critiques, etc. on their peers' presentations.

*S. Nielsen, V. Le Roux (WHOI)*

**12.707 The History of Earth's Climate**

Subject meets with 12.377

Prereq: Permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Spring)

3-0-9 units

Studies the climate history of the Earth, from the formation of the early atmosphere and ocean to the present. Evaluates geochemical, sedimentological, and paleontological evidence for changes in ocean circulation, global temperatures, and atmospheric carbon dioxide levels. Covers theories and models of Phanerozoic climate change. Provides a long-term history of the global carbon cycle. Students taking graduate version complete different assignments.

*D. McGee*

**12.708 Topics in Paleoceanography**

Prereq: Permission of instructor

G (Fall)

Units arranged [P/D/F]

Can be repeated for credit.

Seminar focusing on areas of current interest in paleoceanography and paleoclimatology. Includes discussion of current and classic literature. Topics vary from year to year.

*D. Oppo, O. Marchal (WHOI)*

**12.710 Geological Oceanography**

Prereq: Permission of instructor

G (Fall)

3-0-9 units

Provides a high level survey of a broad range of active science topics in Geological Oceanography. Presents background material that graduate students are expected to know in the disciplines of solid-earth geophysics, geochemistry, sedimentology and stratigraphy, coastal processes, and climate, including a representative set of canonical science papers, and builds on this material to give a sense of the current state of the science in these fields. Broad topics include the formation of the earth, petrogenesis, volcanism, plate tectonics, geodynamics, sedimentation in the oceans, coastal morphodynamics, paleo-oceanography, and climate. The interconnectedness of and feedbacks between processes discussed under these various topics is emphasized.

*WHOI Staff*

**12.712 Advanced Marine Seismology**

Prereq: Permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Fall)

3-0-6 units

Can be repeated for credit.

Focuses on synthetic seismograms, ocean bottom refraction seismology, and multi-channel reflection seismology as applied to studies of the ocean sediments, crust, and lithosphere. Topics include: the wave equations for elastic/anelastic, isotropic/anisotropic, homogeneous/heterogeneous and fluid/solid media; ray theory and WKBJ approximations; the Sommerfeld/Weyl integrals, asymptotic analysis, and Lamb's problem for a fluid/solid interface; reflectivity and related methods; finite difference and finite element methods; and special topics of interest to the class. Extensive readings of geophysical and seismological literature.

*R. Stephen (WHOI)*

**12.714 Computational Data Analysis**

Prereq: 18.03

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Spring)

3-0-9 units

An introduction to the theory and practice of analyzing discrete data such as are normally encountered in geophysics and geology. Emphasizes statistical aspects of data interpretation and the nonparametric discrete-time approach to spectral analysis. Topics include: elements of probability and statistics, statistical inference, robust and nonparametric statistics, the method of least squares, univariate and multivariate spectral analysis, digital filters, and aspects of multidimensional data analysis.

*A. D. Chave, T. A. Herring***12.715 Environmental Bioinformatics (New)**

Prereq: None

Acad Year 2021-2022: G (Fall)

Acad Year 2022-2023: Not offered

3-0-9 units

An intensive introduction to computational skills and a survey of modern computational theory and approaches for the manipulation and analysis of genomic data in environmental and non-model systems. Designed to synthesize theory (both biological and computational) and programming to equip students with the ability to understand and carry out hypothesis testing with genomic data. Topics include: introduction to programming and biological algorithms; genomic and transcriptomic data; environmental metagenomics; intraspecific diversity; and best practices in data science and reproducibility.

*WHOI Staff***12.716 Essentials of Oceanic Petrology**

Prereq: 12.710 or permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Spring)

3-2-4 units

Can be repeated for credit.

Qualitative interpretation and quantitative analysis of melting, melt transport, melt-rock reactions, igneous crustal accretion, metamorphism and hydrothermalism at oceanic spreading centers and subduction-related arcs applied to understanding the variations in the composition of the Earth's (oceanic) mantle and crust and accretionary processes at mid-ocean ridges. Combines theoretical methods with field, petrographic, geochemical, and computational techniques. Topics vary from year to year.

*H. Dick, F. Klein (WHOI)***12.717 Coastal Geomorphology**

Prereq: Permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Spring)

3-0-9 units

Explores mechanisms behind the formation and reshaping of coastal environments. Focuses on a process-based understanding of both the fluid dynamic and sediment transport aspects of coastal landforms, and, especially, the importance of feedbacks between the two. Investigates coastal evolution at various scales - from ripples to coastline formation - with an emphasis on the behavior of coastal environments over integrated timescales of days and years to centuries and millennia. Students investigate the effect of storms, sea-level rise, and interactions with biological and anthropogenic influences. Covers a broad array of coastal environments, including beaches, barrier islands, spits, inlets, tidal flats, deltas, rocky coasts, arctic shores, and carbonate atolls.

*A. Ashton***12.718 Kinetics and Mass Transport**

Prereq: Permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Fall)

3-0-6 units

Offers a broad overview of various kinetic and transport processes in geology, including volume and grain boundary solid-state diffusion, defects in minerals, rates of mineral reaction and transformation, crystal nucleation and growth, advective transport in porous media and partially molten aggregates, and percolation theory. Emphasis on processes in crystalline rocks. Covers theoretical, phenomenological, and experimental constraints, with a consistent application to "real-world" settings and actual case histories.

*M. Behn and G. Gaetani (WHOI)***12.739 Marine Microbiology and Biogeochemistry**

Prereq: None

Acad Year 2021-2022: G (Spring)

Acad Year 2022-2023: Not offered

3-0-9 units

Integrates the fields of microbiology and biogeochemistry, and is centered on elucidating the linkages between microorganisms and geochemical processes in the oceans. Divided into modules that first lay the theoretical framework to familiarize students of diverse backgrounds (biologists, chemists, physical oceanographers). Next, introduces specific and general linkages between the topics and the major tools and techniques that have advanced their integrated study. Concludes with a synthesis module examining the role of microorganisms in the biogeochemical cycles of diverse ocean biomes

*A. Apprill, S. Sievert (WHOI)*



**12.740 Paleocceanography**

Prereq: Permission of instructor  
 Acad Year 2021-2022: G (Spring)  
 Acad Year 2022-2023: Not offered  
 3-0-9 units

Studies the basic principles of techniques for reconstructing the history of ocean climate from marine sediment cores, corals, ice cores, and other paleoclimate archives. Examines this data in the light of proposed climate change mechanisms. Micropaleontological, isotopic, geochemical, and mineralogical changes are used to infer changes in seawater composition, atmospheric chemistry, and climate. Observations are interpreted as consequences of changes in ocean temperature, circulation, and chemistry, and are used to evaluate theories proposed to account for glacial/interglacial cycles. Focuses on the past two million years, but major processes and events from the past 100 million years are also included.

*E. A. Boyle*

**12.741 Marine Bioinorganic Chemistry**

Prereq: Permission of instructor  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: G (Fall)  
 2-0-7 units

Provides an overview of trace element biogeochemistry and marine bioinorganic chemistry. Topics include controls on oceanic trace metal distributions; co-evolution of biological metal requirements and metal availability during early Earth history; chemical speciation and its influence on microbial bioavailability; applications of metal isotopes; roles of metalloenzymes and metal proteins in biogeochemical cycles; and biogeochemical applications of metagenomics, metaproteomics, and bioinformatics.

*M. Saito*

**12.742 Marine Chemistry**

Prereq: Permission of instructor  
 G (Fall)  
 3-0-9 units

An introduction to chemical oceanography. Reservoir models and residence time. Major ion composition of seawater. Inputs to and outputs from the ocean via rivers, the atmosphere, and the sea floor. Biogeochemical cycling within the oceanic water column and sediments, emphasizing the roles played by the formation, transport, and alteration of oceanic particles and the effects that these processes have on seawater composition. Cycles of carbon, nitrogen, phosphorus, oxygen, and sulfur. Uptake of anthropogenic carbon dioxide by the ocean. Material presented through lectures and student-led presentation and discussion of recent papers.

*B. Van Mooy, E. Kojawinski (WHOI)*

**12.743 Geochemistry of Marine Sediments**

Prereq: Chemistry (GIR) and 5.60  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: G (Spring)  
 3-0-9 units

Focuses on processes that control the composition of sediments in coastal, shelf, and deep-sea environments and processes that define their roles in biogeochemical cycles. Topics include calculating chemical fluxes across the sediment-water interface; evaluating the sources and reactivity of carbonate, silicic, and detrital sediments; using pore water gradients to calculate diffusion, reaction, and flux rates; sediment dating; estimating accumulation rates; and using stable isotopes and natural-series radioisotopes. Covers evaluation of the links between sedimentary and water column processes; the effects of anthropogenic disturbances (e.g., eutrophication, acidification, warming) on sedimentary processes; and the role of sediments in global biogeochemical cycles. Introduces sampling techniques and mathematical modeling of sedimentary processes.

*D. McCorkle, W. Martin, A. Wang, M. Long (WHOI)*

**12.744 Marine Isotope Chemistry**

Prereq: Permission of instructor  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: G (Spring)  
 3-0-9 units

Fundamentals of using isotopes to study processes and timescales for marine chemistry and geochemistry. Provides basic introduction to the nature, origins, and reasons for the distributions of isotopes in nature, then develops theory and approaches for radioactive dating methods. These are used to constrain the timing and nature of the geochemical evolution of the elements, solar system, earth, ocean, and atmosphere. Covers cosmogenic isotopes and their applications. Briefly discusses basics of mass spectrometry, followed by a closer inspection of the principles and applications of isotope fractionation. Introduces mass independent fractionation and clumped isotope methods. Explores applications of isotope methods to a number of water column processes, including particle scavenging, sedimentation, long term element budgets, redox processes, and air-sea exchange. Emphasizes quantitative methods and problem-solving. Includes problem sessions with development of problem solutions.

*WHOI Staff*



**12.746 Marine Organic Geochemistry**

Prereq: Permission of instructor  
 Acad Year 2021-2022: G (Spring)  
 Acad Year 2022-2023: Not offered  
 3-0-6 units

Provides an understanding of the distribution of organic carbon (OC) in marine sediments from a global and molecular-level perspective. Surveys the mineralization and preservation of OC in the water column and within anoxic and oxic marine sediments. Topics include: OC composition, reactivity and budgets within, and fluxes through, major reservoirs; microbial recycling pathways for OC; models for OC degradation and preservation; role of anoxia in OC burial; relationships between dissolved and particulate (sinking and suspended) OC; methods for characterization of sedimentary organic matter; application of biological markers as tools in oceanography. Both structural and isotopic aspects are covered.

*D. Repeta (WHOI)*

**12.747 Modeling, Data Analysis, and Numerical Techniques for Geochemistry**

Prereq: Permission of instructor  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: G (Fall)  
 3-0-9 units

Emphasizes the basic skills needed for handling and assimilating data as well as the basic tool-set for numerical modeling. Uses MATLAB as its computation engine; begins with an introduction to MATLAB to ensure familiarity with software. Topics include: probability distributions, error propagation, least squares and regression techniques, principle component and factor analysis, objective mapping, Fourier and spectral analysis, numerical solutions to ODEs and PDEs, finite difference techniques, inverse models, and scientific visualization.

*D. Nicholson (WHOI)*

**12.749 Solid Earth Geochemistry**

Prereq: Permission of instructor  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: G (Spring)  
 3-0-9 units

Integrates methods in mineralogy, petrology (both igneous and metamorphic), and trace element and isotope geochemistry to address scientific issues of the solid earth. Covers processes in the solar nebula, accretion, and early differentiation of the earth. Discusses topics in three representative geodynamic environments - mid-ocean ridges, subduction zones, and mantle plumes - with respect to physical framework and petrological/geochemical aspects.

*N. Shimizu, S. Nielsen, G. Gaetani (WHOI)*

**12.751-12.759 Seminar in Oceanography at Woods Hole**

Prereq: Permission of instructor  
 G (Spring)  
 Units arranged [P/D/F]  
 Can be repeated for credit.

Topics in marine geology and geophysics, physical, dynamical, and chemical oceanography. Content varies from term to term. 12.754, 12.755, and 12.756 are letter-graded.

*WHOI Staff*

**12.760-12.761 Seminar in Marine Geology and Geophysics at MIT**

Prereq: Permission of instructor  
 G (Fall, Spring)  
 Not offered regularly; consult department  
 Units arranged [P/D/F]  
 Can be repeated for credit.

Topics in marine geology and geophysics taught at MIT. Content varies from term to term. 12.760 is letter-graded.

*Marine Geology and Geophysics Staff*

**12.770-12.771 Seminar in Chemical Oceanography at MIT**

Prereq: Permission of instructor  
 G (Fall, Spring)  
 Not offered regularly; consult department  
 Units arranged [P/D/F]  
 Can be repeated for credit.

Topics in chemical oceanography taught at MIT. Content varies from term to term. 12.770 is letter-graded.

*Chemical Oceanography Staff*

**12.777 Field Oceanography**

Subject meets with 12.373  
 Prereq: Permission of instructor  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: G (Spring)  
 3-7-5 units

Provides an introduction to the biogeochemistry of the ocean, and the field techniques and methods used in its study. Emphasizes biogeochemistry and the interrelated nature of elemental cycling, but also examines physical transport and air-sea gas exchange. Covers multiple aspects related to field instrumentation and measurements, including nutrients, oxygen, the carbon system, temperature, and salinity. Presents microbial analyses, such as metagenomics. Includes a mandatory spring break field trip aboard a research vessel; opportunities for funded travel available. Students work in groups to propose a project over the week-long voyage that utilizes the field time to collect samples. During the second half of the term, students analyze and synthesize the data, and present it in a publication-quality manuscript. Students taking graduate version complete additional assignments. Enrollment limited.

*A. R. Babbín*

***Atmospheres, Oceans, and Climate*****12.800 Fluid Dynamics of the Atmosphere and Ocean**

Subject meets with 12.390  
 Prereq: 8.03 and 18.04  
 G (Fall)  
 3-0-9 units

Introduction to fluid dynamics. Students acquire an understanding of some of the basic concepts of fluid dynamics that are needed as a foundation for advanced coursework in atmospheric science, physical oceanography, ocean engineering, climate science, etc. Emphasizes fluid fundamentals, with an atmosphere/ocean twist. Students taking graduate version complete additional assignments.

*A. Mahadevan, C. Cenedese*

**12.801 Large-scale Ocean Dynamics**

Prereq: 12.800  
 G (Spring)  
 3-0-9 units

Applies fundamental principles of geophysical fluid dynamics to understand the general patterns of the ocean circulation and stratification. Includes the mid-latitude wind-driven circulation, the Southern Ocean circulation, and the global overturning circulation. Uses a combination of theory, numerical simulations, and observations to illustrate the concepts.

*J. Yang (WHOI)*

**12.802 Waves, Instability and Turbulence at Small Scales**

Prereq: 12.800 or permission of instructor  
 G (Spring)  
 3-0-9 units

Covers basic concepts of wave motion, flow instability, and turbulence in rotating and stratified fluids with emphasis on small scales. Presents wave properties, including the dispersion relation, phase and group velocities, and wave kinematics, and uses these concepts to study the dynamics of surface and internal gravity waves, Poincaré waves, Kelvin waves, and topographic waves. Includes flow instability. Explores general concepts of linear instability in small-scale stratified shear flows (Rayleigh and Kelvin-Helmholtz instabilities); examines non-rotating stratified turbulence resulting from these instabilities. Also discusses wave-mean flow interaction, hydraulic control, the entrainment assumption, and the interpretation of microstructure observations.

*G. Flierl, R. Ferrari*

**12.803 Advanced Geophysical Fluid Dynamics**

Prereq: 12.843  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: G (Spring)  
 2-0-7 units

Further development of topics covered in 12.843, with a more mathematical treatment. Covers current topics of interest in rotating stratified flows of oceans and atmospheres.

*G. Flierl, R. Ferrari*

**12.805 Data Analysis in Physical Oceanography**

Prereq: Permission of instructor  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: G (Fall)  
 3-0-9 units

Directed at making scientifically-sensible inferences from physical oceanography data (both observations and models). Introduces linear inverse methods, including regression, singular value decomposition, objective mapping, and data assimilation. Connects these methods to time series analysis, including Fourier methods, spectra, coherence, and filtering. Focuses on working with data in a computer laboratory setting. Emphasizes how statistical information can be used to improve experimental design. Gives some attention to the instruments and algorithms used to acquire the data.

*G. Gebbie, T. Farrar (WHOI)*

**12.806[J] Atmospheric Physics and Chemistry**

Same subject as 10.571[J]

Subject meets with 12.306

Prereq: (18.075 and (5.60 or 5.61)) or permission of instructor

G (Spring)

3-0-9 units

Introduction to the physics and chemistry of the atmosphere including experience with computer codes. Aerosols and theories of their formation, evolution, and removal. Gas and aerosol transport from urban to continental scales. Coupled models of radiation, transport, and chemistry. Solution of inverse problems to deduce emissions and removal rates. Emissions control technology and costs. Applications to air pollution and climate.

*R. G. Prinn***12.807[J] Atmospheric Chemistry**

Same subject as 1.84[J], 10.817[J]

Prereq: 5.60

G (Fall)

3-0-9 units

See description under subject 1.84[J].

*J. H. Kroll***12.808 Introduction to Observational Physical Oceanography**

Prereq: Permission of instructor

G (Fall)

3-0-9 units

Results and techniques of observations of the ocean in the context of its physical properties and dynamical constraints. Emphasis on large-scale steady circulation and the time-dependent processes that contribute to it. Includes the physical setting of the ocean, atmospheric forcing, application of conservation laws, description of wind-driven and thermohaline circulation, eddy processes, and interpretive techniques.

*H. Seo, J. Toole (WHOI)***12.809 Hydraulic Phenomena in Geophysical Fluid Flows**

Prereq: Permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Fall)

3-0-6 units

Examination of the hydraulics of nonrotating flows (Long's experiments, hydraulic control, upstream influence, nonlinear wave steepening, hydraulic jump and bores, application to severe downslope winds). Other topics may include: nonrotating stratified flows (two-layer hydraulics, virtual and approach controls, maximal and submaximal flow, application to the Strait of Gibraltar and the Bab al Mandab); and deep ocean straits and sills (steady theories for rotating channel flow, nonlinear Kelvin and frontal waves, rotating hydraulic jumps, geostrophic adjustment in a rotating channel, and applications to the Denmark Strait and other deep passages).

*L. Pratt, K. Helfrich (WHOI)***12.810 Dynamics of the Atmosphere**

Prereq: 12.800

G (Spring)

3-0-9 units

Discusses the dynamics of the atmosphere, with emphasis on the large scale. Topics include internal gravity waves in the atmosphere; potential vorticity conservation and Rossby waves; baroclinic instability and extratropical storms; the tropical Hadley and Walker circulations and equatorial waves; and the general circulation, annular modes, and the response to climate change.

*P. O'Gorman***12.811 Tropical Meteorology**

Prereq: 12.810; or Coreq: 12.843

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Spring)

3-0-9 units

A description of the large-scale circulation systems of the tropical atmosphere and analysis of the dynamics of such systems. Topics include: Radiative-convective equilibrium; the Hadley and Walker circulation; monsoons; tropical boundary layers; theory of the response of the tropical atmosphere to localized sea-surface temperature anomalies; intraseasonal oscillations; equatorial waves; El Niño/Southern Oscillation; easterly waves; and tropical cyclones.

*K. A. Emanuel*

**12.812 The General Circulation of the Atmosphere and Climate Change**

Prereq: 12.810 or permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Fall)

2-0-7 units

Describes the general circulation of Earth's atmosphere and its maintenance. Second half of the course explores the response of the general circulation to climate change.

*P. O'Gorman***12.814[[]] Aerosol and Cloud Microphysics and Chemistry**

Same subject as 1.842[[]]

Subject meets with 12.338

Prereq: Permission of instructor

G (Spring)

Not offered regularly; consult department

3-0-9 units

Focuses on understanding how aerosol particles form droplets or ice crystals during several atmospheric processes: determining Earth's radiative balance; heterogeneous chemistry and acid rain; understanding where, when and how much precipitation occurs. Provides tools for understanding the physics of aerosol and cloud element motion; the interaction of particles with water vapor, including phase changes and droplet and ice nucleation; the chemical composition of particles and the effect on cloud formation processes; and the effect of cloud processing on aerosol chemistry. Discusses relevant topics of contemporary interest, e.g., geoengineering and weather modification and volcanic effects. Students taking the graduate version complete different assignments.

*D. Cziczo***12.815 Atmospheric Radiation and Convection**

Subject meets with 12.315

Prereq: 12.800 or permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Spring)

3-0-9 units

Introduction to the physics of atmospheric radiation, remote sensing, and convection, including use of computer codes. Radiative transfer equation including emission and scattering, spectroscopy, Mie theory, and numerical solutions. Physics of dry and moist convection, including moist thermodynamics. Radiative-convective equilibrium. Solution of inverse problems in remote sensing of atmospheric temperature and composition. Students taking graduate version complete additional assignments.

*T. Cronin***12.817[[]] Atmospheric Composition and Global Change**

Same subject as 1.841[[]]

Prereq: 1.84[[]]

Acad Year 2021-2022: G (Spring)

Acad Year 2022-2023: Not offered

3-0-9 units

See description under subject 1.841[[]].

*C. Heald***12.818 Introduction to Atmospheric Data and Large-scale Dynamics**

Subject meets with 12.318

Prereq: None. Coreq: 12.800

G (Fall)

3-3-6 units

Provides a general introduction to meteorological data and analysis techniques, and their use in the MIT Synoptic Laboratory to study the phenomenology and dynamics of large-scale atmospheric flow. Illustrates balance concepts as applied to the dynamics of frontal and synoptic scales, using real-time upper-air and surface station data and gridded analyzed fields. Uses advanced meteorological software packages to access, manipulate, and graphically display the data. Students taking graduate version complete different assignments.

*L. Illari***12.820 Turbulence in the Ocean and Atmosphere**

Prereq: 12.843

Acad Year 2021-2022: G (Spring)

Acad Year 2022-2023: Not offered

3-0-9 units

Covers phenomena, theory and modeling of turbulence in the Earth's oceans and atmosphere. The scope will range from centimeter- to planetary-scale motions. Includes homogeneous isotropic three- and two-dimensional turbulence, convection, stratified turbulence, quasi-geostrophic turbulence, baroclinic turbulence, and macroturbulence in the ocean and atmosphere.

*R. Ferrari, G. Flierl*

**12.823 Modeling the Biology and Physics of the Ocean**

Prereq: 18.075 or 18.085  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: G (Spring)  
 3-0-6 units

Principles and examples of the construction of physical/ biological models for oceanic systems. Individual-based and continuum representations. Food webs and structured population models. Fluid transport, stirring, and mixing. Effects of rotation and stratification. Advection, diffusion, reaction dynamics. Oceanic examples of physical-biological dynamics: surface mixed layer, upwelling regimes, mesoscale eddies, and oceanic gyres.

*G. Flierl, D. McGillicuddy*

**12.824 Stability Theory for Oceanic & Atmospheric Flows**

Prereq: 12.802 or permission of instructor  
 Acad Year 2021-2022: G (Fall)  
 Acad Year 2022-2023: Not offered  
 3-0-9 units

Basic theory of hydrodynamic instability with special application to flows of interest in oceanography and meteorology. Topics covered include general formulation of stability theory; concept of normal modes and linearization; fundamental stability theorems; baroclinic instability: Charney model, Eady model and the Phillips two-layer model; energy transformations; initial value theory and non-modal instability; barotropic instability for jets and shear layers; radiating instabilities; initial value problems applied to the concepts of convective, absolute and spatial instabilities; finite amplitude theory; stability of non-parallel flows.

*G. Flierl*

**12.830 Topics in Waves and Instability**

Prereq: 12.843  
 G (Fall)  
 Not offered regularly; consult department  
 3-0-9 units

A detailed presentation of selected advanced topics in waves and instability in the atmosphere. The precise selection varies from year to year. Topics have included wave-mean flow interaction, the quasi-biennial oscillation, sudden warmings, critical-level behavior, wave overreflection, nonlinear equilibration, wave breaking, tropical waves, and stationary waves.

*EAPS Staff*

**12.834[[]] Land-Atmosphere Interactions**

Same subject as 1.713[[]]  
 Prereq: Permission of instructor  
 Acad Year 2021-2022: G (Spring)  
 Acad Year 2022-2023: Not offered  
 2-0-4 units

See description under subject 1.713[[]].

*D. Entekhabi*

**12.835 Experimental Atmospheric Chemistry**

Subject meets with 12.335  
 Prereq: Permission of instructor  
 G (Fall)  
 2-4-6 units

Introduces the atmospheric chemistry involved in climate change, air pollution, and ozone depletion using a combination of interactive laboratory and field studies and simple computer models. Uses instruments for trace gas and aerosol measurements and methods for inferring fundamental information from these measurements. Students taking the graduate version complete different assignments.

*R. Prinn, S. Ono, D. Cziczo*

**12.842 Climate Science**

Subject meets with 12.301  
 Prereq: Chemistry (GIR), 18.03, or permission of instructor  
 G (Fall)  
 4-0-8 units

Introduction to climate studies, including beginnings of the solar system, time scales, and climate in human history; methods for detecting climate change, including proxies, ice cores, instrumental records, and time series analysis; physical and chemical processes in climate, including primordial atmosphere, ozone chemistry, carbon and oxygen cycles, and heat and water budgets; internal feedback mechanisms, including ice, aerosols, water vapor, clouds, and ocean circulation; climate forcing, including orbital variations, volcanism, plate tectonics, and solar variability; climate models and mechanisms of variability, including energy balance, coupled models, and global ocean and atmosphere models; and outstanding problems. Students taking the graduate version complete different assignments.

*K. Emanuel, E. Boyle*

**12.843 Large-scale Atmosphere and Ocean Dynamics**

Prereq: 12.801, 12.810, or permission of instructor

G (Fall)

2-4-9 units

Project-based with lectures covering the relevant theory. Students work in groups on four projects. Each of these comprises a numerical part, to illuminate and illustrate the theory, and a data part (drawn from laboratory tank experiments, atmospheric, or ocean observations), to illustrate the phenomena. Topics include: barotropic vorticity dynamics including inversion and evolution, geostrophic and higher order balance, baroclinic dynamics and the evolution of balanced flows, and stability with emphasis on the mutual interaction of disturbances. Projects include a verbal presentation and writeup covering both the numerical and geophysical parts plus additional derivations as needed.

*G. Flierl, L. Illari***12.845[J] Sustainability Science and Engineering**

Same subject as IDS.526[J]

Prereq: None

G (Fall)

Not offered regularly; consult department

3-0-6 units

See description under subject IDS.526[J].

*N. E. Selin***12.846[J] Global Environmental Negotiations**

Same subject as IDS.525[J]

Subject meets with 12.346[J], IDS.062[J]

Prereq: None

G (Fall)

Not offered regularly; consult department

2-0-4 units

See description under subject IDS.525[J].

*N. Selin***12.849 Mechanisms and Models of the Global Carbon Cycle**

Subject meets with 12.349

Prereq: Permission of instructor

G (Spring)

3-0-9 units

Addresses changes in the ocean, terrestrial biosphere and rocks modulation of atmospheric carbon dioxide on timescales from months to millions of years. Includes feedbacks between carbon cycle and climate. Combines hands-on data analysis with the formulation of simple models rooted in basic physical, chemical and biological principles. Students create individual "toy" global carbon cycle models. Students taking graduate version complete different assignments.

*M. Follows***12.850 Computational Ocean Modeling**

Prereq: None

Acad Year 2021-2022: G (Spring)

Acad Year 2022-2023: Not offered

3-0-9 units

Numerical modeling in oceanography and environmental fluid mechanics. Focuses on the building of computational models that describe processes such as transport (advection, diffusion), reaction (ecosystems), and boundary forcing, of relevance in the ocean. Models are developed in a hierarchical manner, starting from the simple (zero-dimensional in space), and incrementally advancing toward more complex, time-evolving systems in one-, two- (shallow water) and three-dimensions (Primitive equations). Students build their own models using the finite volume approach with an appreciation and understanding of the working of general circulation models

*A. Mahadevan (WHOI), W. Zhang (WHOI)***12.853 Advanced geophysical fluid dynamics**

Prereq: 12.843 or permission of instructor

G (Fall)

Not offered regularly; consult department

2-0-7 units

Follow-on to 12.843, with a more mathematical treatment and extension of material to current topics of interest involving rotating, stratified flows of oceans and atmospheres.

*G. Flierl*

**12.860 Climate Variability and Diagnostics**

Prereq: Permission of instructor

G (Fall)

3-0-9 units

Explores climate variability and change, focusing on the atmosphere and ocean, while building experience applying diagnostic analyses to a range of modern observations and models. Provides practical insight, from regional to global scale, with applications to past and future climates. Emphasizes salient features of the mean climate system and modes of natural variability, as well as observed and projected manifestations of anthropogenic climate change. Students gain experience accessing, analyzing, and visualizing a wide range of gridded observational-based datasets, as well as output from global climate model simulations. Develops the tools necessary to apply climate diagnostic analysis to one's own research, as well as the interdisciplinary edge to critically assess and interpret the observational and model results underpinning the Fifth Assessment Reports of the Intergovernmental Panel on Climate Change.

*C. Uhmmerhofer***12.862 Coastal Physical Oceanography**

Prereq: 12.800

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Fall)

3-0-9 units

Introduction to the dynamics of flow over the continental shelf, nearshore, and estuaries, emphasizing both theory and observations. Content varies somewhat according to student and staff interests. Possible topics include fronts, buoyant plumes, surface and bottom boundary layers, wind-driven upwelling, coastal-trapped waves, internal waves, quasi-steady flows, high-latitude shelf processes, tides, and shelf-open ocean interactions.

*R. Todd, D. Ralston (WHOI)***12.863 Advanced Topics in Coastal Physical Oceanography**

Prereq: 12.862 or permission of instructor

G (Spring)

Not offered regularly; consult department

3-0-6 units

More specialized topics in the dynamics of flow over the continental shelf, including coastal-trapped waves, wind-driving, and mean flows. Emphasis on the relationship between theory and observations. Instrumentation and the application of statistical techniques also covered.

*Woods Hole Staff***12.866 Theory of the General Circulation of the Ocean**

Prereq: 12.800, 12.801, and 12.802

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Spring)

3-0-9 units

A review of wind-driven circulation, and the development of the baroclinic theory of the wind-driven circulation. Potential vorticity homogenization and the ventilated thermocline. Wind-driven circulation with continuous stratification, subduction/obduction. Equatorial thermocline and its relation to ENSO. Decadal climate variability. Thermohaline circulation and variability. Abyssal circulation. Mixing and energetics of the oceanic general circulation.

*R. X. Huang (WHOI)***12.870 Air-Sea Interaction: Boundary Layers**

Prereq: Graduate-level fluid mechanics and a subject on waves or permission of instructor

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Spring)

3-0-9 units

Addresses the interaction of the atmosphere and ocean on temporal scales from seconds to days and spatial scales from centimeters to kilometers. Topics include the generation, propagation, and decay of surface waves; the processes by which mass, heat, momentum, and energy are transported vertically within the coupled atmospheric and oceanic boundary layers and across the air-sea interface; and the statistical tools, mathematical models, and observational methods that are used to quantify these processes.

*R. Todd, D. Ralston (WHOI)***12.884[[]] Dimensions of Geoenineering**

Same subject as 1.850[[]], 5.000[[]], 10.600[[]], 11.388[[]], 15.036[[]], 16.645[[]]

Prereq: None

Acad Year 2021-2022: Not offered

Acad Year 2022-2023: G (Fall; first half of term)

2-0-4 units

See description under subject 5.000[[]]. Limited to 100.

*J. Deutch, M. Zuber*



**12.885[J] Science, Politics, and Environmental Policy**

Same subject as 11.373[J]  
 Subject meets with 12.385  
 Prereq: Permission of instructor  
 G (Fall)  
 3-0-6 units

Examines the role of science in US and international environmental policymaking. Surveys the methods by which scientists learn about the natural world; the treatment of science by experts, advocates, the media, and the public and the way science is used in legislative, administrative and judicial decision making. Through lectures, group discussions, and written essays, students develop a critical understanding of the role of science in environmental policy. Potential case studies include fisheries management, ozone depletion, global warming, smog, and endangered species. Students taking the graduate version complete different assignments.

*S. Solomon, J. Knox-Hayes*

**12.900 EAPS First Year Graduate Seminar**

Prereq: None  
 G (Fall)  
 4-0-2 units

Provides a shared experience for first-year graduate students in EAPS and the MIT/ WHOI Joint Program. Facilitates opportunities to interact with senior graduate students and to meet a wide range of faculty. Familiarizes students with departmental research within the themes of Earth, planets, climate, and life. Discusses resources, graduate life at MIT, and the path to PhD.

*K. Bergmann, T. Cronin, J. de Wit, M. Pec*

**12.901 Proposals, Papers and Pathways (New)**

Prereq: None  
 Acad Year 2021-2022: Not offered  
 Acad Year 2022-2023: G (Fall)  
 2-0-3 units

This seminar builds skills for writing scientific proposals and papers, and facilitates investigation of career pathways. Topics covered include scientific writing and graphics, peer review, proposal writing for grants and fellowships, and exploration of academic and non-academic careers.

*P. O'Gorman*

**12.910 Communicating Ocean Science**

Prereq: None  
 Acad Year 2021-2022: G (Fall)  
 Acad Year 2022-2023: Not offered  
 3-0-6 units

For students interested in improving their ability to teach science, the focus is on inquiry-based instructional methods and application to various audiences. Includes an opportunity to teach in a course at a local state university and in a supervised elementary school classroom. Class meets twice a week for 11 sessions, and episodically thereafter. The undergraduate lesson is arranged in consultation with Bridgewater State University faculty. Outreach in local school classrooms involves one session observing and three sessions teaching.

*L. Mullineaux (WHOI), A. Michel (WHOI)*

**12.950, 12.951 Seminar in Physical Oceanography at MIT**

Prereq: Permission of instructor  
 G (Fall, Spring)  
 Not offered regularly; consult department  
 Units arranged [P/D/F]  
 Can be repeated for credit.

Topics in physical and dynamical oceanography. Content varying from term to term. 12.950 is letter-graded.

*Physical Oceanography Staff*

**12.970, 12.971 Current Research in Earth, Atmospheric and Planetary Sciences**

Prereq: Permission of instructor  
 G (Fall, Spring, Summer)  
 Units arranged [P/D/F]  
 Can be repeated for credit.

Original investigations, laboratory work, or field work on Earth, atmospheric, or planetary issues. 12.970 is letter-graded.

*EAPS Faculty*

**12.980, 12.981 Current Research in Joint Program at MIT**

Prereq: Permission of instructor  
 G (Fall, Spring, Summer)  
 Units arranged [P/D/F]  
 Can be repeated for credit.

Original investigations on problems in oceanography. 12.980 is letter-graded.

*EAPS Staff*

**12.982, 12.983 Current Research in Joint Program at WHOI**

Prereq: Permission of instructor

G (Fall, Spring, Summer)

Units arranged [P/D/F]

Can be repeated for credit.

Original investigations, laboratory work, or fieldwork in oceanography. 12.982 is letter-graded.

*WHOI Faculty*

**12.S488, 12.S489 Special Seminar in Structural Geology**

Prereq: Permission of instructor

G (Spring)

Not offered regularly; consult department

Units arranged [P/D/F]

Can be repeated for credit.

Organized lecture or laboratory subject on an aspect of structural geology not normally covered in regularly scheduled subjects.

12.488 is letter-graded.

*EAPS Staff*

**12.S490, 12.S491 Special Seminar in Geology and Geochemistry**

Prereq: Permission of instructor

G (Spring)

Not offered regularly; consult department

Units arranged [P/D/F]

Can be repeated for credit.

Organized lecture or laboratory subject on an aspect of geology or geochemistry not normally covered in regularly scheduled subjects.

12.490 is letter-graded.

*Geology and Geochemistry Staff*

**12.S492, 12.S493 Special Seminar in Geobiology**

Prereq: Permission of instructor

G (Spring)

Not offered regularly; consult department

Units arranged [P/D/F]

Can be repeated for credit.

Organized lecture or laboratory subject on an aspect of geobiology not normally covered in regularly scheduled subjects. 12.492 is letter-graded.

*Geobiology Staff*

**12.S590 Special Seminar in Geophysics**

Prereq: Permission of instructor

G (Spring; first half of term)

Units arranged

Can be repeated for credit.

Organized lecture or laboratory subject on an aspect of geophysics not normally covered in regularly scheduled subjects.

*T. Herring and V. Pankratius*

**12.S591 Special Seminar in Geophysics**

Prereq: Permission of instructor

G (Fall, Spring)

Units arranged [P/D/F]

Can be repeated for credit.

Organized lecture or laboratory subject on an aspect of geophysics not normally covered in regularly scheduled subjects. 12.S590 is letter-graded.

*Consult EAPS Education Office*

**12.S592 Special Seminar in Earth, Atmospheric and Planetary Sciences**

Prereq: Permission of instructor

G (Spring)

Units arranged

Can be repeated for credit.

Organized lecture or laboratory subject on an aspect of the earth sciences, planetary sciences, or astronomy not normally covered in regularly scheduled subjects.

*EAPS Staff*

**12.S593 Special Seminar in Earth, Atmospheric and Planetary Sciences**

Prereq: Permission of instructor

G (Fall, Spring)

Units arranged [P/D/F]

Can be repeated for credit.

Organized lecture or laboratory subject on an aspect of the earth sciences, planetary sciences, or astronomy not normally covered in regularly scheduled subjects. 12.592 is letter-graded.

*EAPS Staff*

**12.S595 Special Seminar in Geophysics**

Prereq: None

G (Fall)

Units arranged [P/D/F]

Can be repeated for credit.

Organized lecture or laboratory subject on an aspect of geophysics not normally covered in regularly scheduled subjects. 12.S590 is letter-graded.

*EAPS Faculty***12.S597 Special Seminar in Earth, Atmospheric and Planetary Sciences**

Prereq: Permission of instructor

G (Fall)

Units arranged [P/D/F]

Can be repeated for credit.

Organized lecture or laboratory subject on an aspect of the earth sciences, planetary sciences, or astronomy not normally covered in regularly scheduled subjects. 12.S592 is letter-graded.

*EAPS Staff***12.S680, 12.S681 Special Seminar in Planetary Science**

Prereq: Permission of instructor

G (Fall, IAP, Spring)

Not offered regularly; consult department

Units arranged [P/D/F]

Can be repeated for credit.

Organized lecture or laboratory subject on an aspect of planetary science not normally covered in regularly scheduled subjects.

12.S680 is letter-graded.

*Planetary Science Staff***12.S990, 12.S991 Special Subject in Atmospheric Science**

Prereq: Permission of instructor

G (Fall, IAP, Spring)

Not offered regularly; consult department

Units arranged [P/D/F]

Can be repeated for credit.

Organized lecture or laboratory subject on an aspect of atmospheric science not normally covered in regularly scheduled subjects.

12.S990 is letter-graded.

*PAOC Staff***12.S992, 12.S993 Special Subject in Climate Science**

Prereq: Permission of instructor

G (Fall)

Not offered regularly; consult department

Units arranged [P/D/F]

Can be repeated for credit.

Organized lecture or laboratory subject on an aspect of climate not normally covered in the regularly scheduled subjects. 12.S992 is letter-graded.

*PAOC Staff*