MIT/WHOI Joint Program in Oceanography/ Applied Ocean Science & Engineering

WHOI Courses

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Applied Ocean Science & Engineering

COURSE CATALOG

The following is a listing of Joint Program courses offered at WHOI and at MIT. This is not a full listing of courses available to Joint Program students; they are encouraged to take other courses not listed here. Information regarding classes at MIT can be found online in the MIT course catalog at student.mit.edu/catalog/index.cgi.

Each course is assigned a course number. Courses starting with a 1. are in the area of civil and environmental engineering; those beginning with a 2. or 6. are in the area of ocean engineering; those starting with a 7. are in the area of biological oceanography; those starting with a 12. are in the area of earth and atmospheric sciences. They are all graduate-level courses.

Units are assigned to each course. Units are determined by adding the number of class hours, lab hours and expected homework hours per week.

Questions regarding courses, registration, and class schedules should be directed to the WHOI Registrar.

Applied Ocean Science & Engineering

1.69 Introduction to Coastal Engineering (12 units) Prereq: 1.061B
Basic hydrodynamics of waves in deep and shallow water. Linear theory, dispersion, superposition, and spectral representation. Energy, energy transport, and dissipation by bottom friction. Refraction and diffraction by breakwaters. Some nonlinear aspects and wave breaking. Emphasizes physical interpretation of mathematical results and their engineering application. Storm surges, coastal circulation, and forecasting of wind-wave characteristics. Wind-wave statistics, wave forces on piles, and breakwater stability. *J. Trowbridge*

WH1.699 Coastal and Estuarine Field Methods (units arranged)
This course is aimed at graduate students interested in coastal, estuarine, and nearshore dynamics and transport processes. The purpose of the course is to provide the students with experience in modern field methods as motivated by fundamental research questions. The course will include one week of intensive lectures in Woods Hole followed by a three-day field component that provides hands-on experience in measurement techniques in estuarine, nearshore, and inner-shelf settings. The students will be involved with all aspects of planning, deployment, processing, and analysis of data. Students will be awarded 6 units of credit for participation in the class and 12 units if they also perform independent analysis of some aspect of the field data. *R. Geyer and others*

1.THG Graduate Thesis (Units arranged) Prereq: Permission of instructor
Program of research leading to the writing of an SM, MEng, CE, PhD, or ScD thesis in Civil and Environmental Engineering/AOSE, Biological Oceanography, or Chemical Oceanography; to be arranged by the student and an appropriate faculty member.

2.681 Environmental Ocean Acoustics (12 units) Prereq: 18.075, 2.066 or permission of instructor
Fundamentals of underwater sound, and its application to mapping and surveillance in an ocean environment. Wave equations for fluid and elastic media. Reflection and transmission of sound at plane interfaces. Wave theory representation of acoustic source radiation and propagation in shallow and deep ocean waveguides. Interaction of underwater sound with elastic waves in the seabed and an Arctic ice cover, including effects of porosity and anisotropy. Numerical modeling of the propagation of underwater sound, including spectral methods, normal mode theory, and the parabolic equation method, for laterally homogeneous and inhomogeneous environments. Doppler effects. Effects of oceanographic variability and fluctuation - spatial and temporal coherence. Generation and propagation of ocean ambient noise. Modeling and simulation of signals and noise in traditional sonar systems, as well as modern, distributed, autonomous acoustic surveillance systems. *H. Schmidt (MIT)*

2.682 Acoustical Oceanography (12 units) Prereq: 2.681
Course will begin with brief overview of what important current research topics are in oceanography (physical, geological, and biological) and how acoustics can be used as a tool to address them. Three typical examples are climate, bottom geology, and marine mammal behavior. Will then address the acoustic inverse problem, reviewing inverse methods (linear and nonlinear) and the combination of acoustical methods with other measurements as an integrated system. Last part of course will concentrate on specific case studies, taken from current research journals. *J. Lynch*

2.683 Marine Bioacoustics and Geoacoustics (12 units) Prereq: 2.681
Both active and passive acoustic methods of measuring marine organisms, the seafloor, and their interactions are reviewed. Acoustic methods of detecting, observing, and quantifying marine biological organisms are described, as are acoustic methods of measuring geological properties of the seafloor, including depth, and surficial and volumetric composition. Interactions are also described, including effects of biological scatterers on geological measurements, and effects of seafloor scattering on measurements of biological scatterers on, in, or immediately above the seafloor. Methods of determining small-scale material properties of organisms and the seafloor are outlined. Operational methods are emphasized, and corresponding measurement theory is described. Case studies are used in illustration. Principles of acoustic-system calibration are elaborated. *K. Foote*

2.684 Wave Scattering by Rough Surfaces and Randomly Inhomogenous Media (12 units) Prereq: 2.066
An advanced-level subject designed to give the student working knowledge of current techniques in scattering and wave propagation through random media theory. Major application of theory presented is to ocean acoustics, but can be used in other acoustic and electromagnetic applications. Includes basics of wave propagation through random media theory, volume scattering by discrete scatterers (aerosols), scattering by rough surfaces, and acoustic propagation through ocean internal waves and mesoscale eddies. *T. Stanton, A. Lavery*

2.685 Numerical Methods in Scattering (12 units) Prereq: 18.06 , 2.066
Fundamental equations for acoustic and electromagnetic waves are derived from first principles. Boundary, or interface, conditions are introduced. The course emphasizes the development of numerical methods to solve wave equations in interior or exterior domains using boundary-element and finite-element techniques. Spectral techniques are also developed. A number of technical computational issues are addressed: discretization of geometry, order of approximation, efficiency, and analysis of numerical schemes. Validation is an essential exercise. Validation examples are drawn from analytical solutions for separable shapes. Applications of numerical methods are presented for acoustic scattering by marine organisms of complex shape and structure, and optical scattering by dielectric bodies. Assignments will entail code development. *K. Foote*

2.687 Time Series Analysis and System Identification (12 units) Prereq: 18.06, 6.003, and 6.431 (or equivalent courses within the ME department)
Matched filtering, power spectral estimation and adaptive signal processing and system identification algorithms are introduced. Algorithm development is framed as an optimization problem, and methods of finding both optimal and approximate solutions are described. Course includes an introduction to time-varying systems, first and second moment characterizations of stochastic processes, and state-space models. Algorithm derivation, performance analysis and robustness to modeling errors are covered for matched filter and power spectral estimation algorithms, stochastic gradient algorithms (LMS and its variants), Least Squares algorithms (RLS, order- recursive approaches), and the discrete-time Kalman Filter and its derivatives. Course includes laboratory exercises involving working with experimental data from a variety of fields, and a term paper/ project is required. *J. Preisig*

2.688 Principles of Oceanographic Instrument Systems -- Sensors and Measurements (12 units) Prereq: 2.671, 18.075
Introduces theoretical and practical principles of design of oceanographic sensor systems. Transducer characteristics for acoustic, current, temperature, pressure, electric, magnetic, gravity, salinity, velocity, heat flow, and optical devices. Limitations on these devices imposed by ocean environment. Signal conditioning and recording; noise, sensitivity, and sampling limitations; standards. Principles of state-of-the-art systems being used in physical oceanography, geophysics, submersibles, acoustics discussed in lectures by experts in these areas. Day cruises in local waters during which the students will prepare, deploy and analyze observations from standard oceanographic instruments constitute the lab work for this subject. *H. Singh, E. Terray*

2.689J Special Projects in Oceanographic Engineering (units arranged)
Special problems in oceanographic engineering, carried out under supervision of members of the staff of the Woods Hole Oceanographic Institution. Given at Woods Hole Oceanographic Institution. *WHOI Staff*

2.THG Graduate Thesis (Units arranged) Prereq: Permission of instructor
Program of research leading to the writing of an SM, PhD, or ScD thesis in Mechanical Engineering/Applied Ocean Science and Engineering; to be arranged by the student and an appropriate faculty member.

6.456 Array Processing (12 units) Prereq: 2.004 or 6.003; 6.041; 18.075 or 18.085
Signal processing used in sonar, radar, and geophysical data analysis. Active sonar and radar systems: matched filters and ambiguity functions, signal design of range/doppler resolution, second moment characterizations of random processes with correlation functions and power density spectra, deconvolution, spectral estimation by Fourier techniques and adaptive methods, beam forming. *J. Preisig*

6.THG Graduate Thesis (Units arranged) Prereq: Permission of instructor
Program of research leading to the writing of an SM, EE, ECS, PhD, or ScD thesis in Electrical Engineering and Computer Science/AOSE; to be arranged by the student and an appropriate faculty member.

12.870 Air-Sea Interaction: Boundary Layers (9 units) Prereq: Permission of instructor
Examines the interaction of the atmosphere and ocean on time scales from minutes to months, with emphasis on effects within the near-surface boundary layers in both the air and water. Topics include the dynamics of the wave field and its role in mediating air-sea coupling, the scaling of surface layer turbulence, the effects of temperature stratification, and the mechanics of energy and momentum exchange across the interface. Methods for measuring and computing air/sea fluxes are reviewed. Modification of boundary layers by air/sea exchange, radiation, and turbulent mixing is treated using a hierarchy of boundary layer models made available for student use. *J. Trowbridge, E. Terray*

Biological Oceanography

1.88 Physical Ecology at the Microscale (12 units) Prereq: Permission of instructor
Designed for students in fluid mechanics and engineering who want to explore applications of physics and fluids to biology and ecology, and for students in the biological sciences seeking to understand the physical constraints of life at the microscale. Topics include mass exchange and flow at the scale of microbes, motility and chemotaxis, encouter rates and predation, and small-scale turbulence. Emphasizes the application of physical and fluid dynamical principles to life at the microscale, in particular (but not limited to) aquatic systems. *R. Stocker (MIT)*

1.THG Graduate Thesis (Units arranged) Prereq: Permission of instructor
Program of research leading to the writing of an SM, MEng, CE, PhD, or ScD thesis in Civil and Environmental Engineering/ Applied Ocean Science and Engineering, Biological Oceanography, or Chemical Oceanography; to be arranged by the student and an appropriate faculty member.

7.410 Applied Statistics (12 units) Prereq: Permission of instructor
This course serves as an introduction to modern applied statistics. Topics include likelihood-based methods of estimation, confidence intervals, and hypothesis-testing; bootstrapping; time series modeling; linear models; nonparametric regression; and model selection. The course is organized around examples drawn from the recent literature. *A. Solow*

7.411–7.419 Seminars in Biological Oceanography (units arranged)
Selected topics in biological oceanography. *Information: R. Gast*

7.421 Special Problems in Biological Oceanography (units arranged)
Advanced problems in biological oceanography with assigned reading and consultation. *Information: R. Gast*

7.430 – 7.431 Topics Courses Topics courses offered vary each term; some recent Topics courses include Quantitative Fisheries Oceanography, Marine Bio-optics, Biophysical Interactions in Pelagic Ecosystems, Chronobiology, Larval Ecology, Elements of Environmental Policy, and Deep Sea Ecosystems. *WHOI Staff*

7.430 Topics in Quantitative Marine Science (6 units) Prereq: Permission of instructor
Lectures and discussions on quantitative marine ecology. Topics and instructors vary from year to year.

7.431 Topics in Marine Ecology (6 units) Prereq: Permission of instructor
Lectures and discussions on ecological principles and processes in marine populations, communities, and ecosystems. Topics and instructors vary from year to year.

7.432 Topics in Marine Physiology and Biochemistry (6 units) Prereq: Permission of instructor
Lectures and discussions on physiological and biochemical processes in marine organisms. Topics and instructors vary from year to year.

7.433 Topics in Biological Oceanography (6 units) Prereq: Permission of instructor
Lectures and discussions on biological oceanography. Topics and instructors vary from year to year.

7.434 Topics in Zooplankton Biology (6 units) Prereq: Permission of Instructor
Lectures and discussions on the biology of marine zooplankton. Topics and instructors vary from year to year.

7.435 Topics in Benthic Biology (6 units) Prereq: Permission of instructor
Lectures and discussions on the biology of marine benthos. Topics and instructors vary from year to year.

7.436 Topics in Phytoplankton Biology (6 units) Prereq: Permission of instructor
Lectures and discussion on the biology of marine phytoplankton. Topics and instructors vary from year to year.

Biological Oceanography (cont.)

7.437 Topics in Molecular Biological Oceanography (6 units) Prereq: Permission of instructor
Lectures and discussion on molecular biological oceanography. Topics and instructors vary from year to year.

7.438 Topics in the Behavior of Marine Animals (6 units) Prereq: Permission of instructor
Lectures and discussion on the behavioral biology of marine animals. Topics and instructors vary from year to year.

7.439 Topics in Marine Microbiology (6 units) Prereq: Permission of instructor
Lectures and discussion on the biology of marine prokaryotes. Topics and instructors vary from year to year.

7.440 An Introduction to Mathematical Ecology (12 units) Prereq: 18.01, 1.018 or permission of instructor)
Covers the basic models of population growth, demography, population interaction (competition, predation, mutualism), food webs, harvesting, and infectious disease, and the mathematical tools required for their analysis. Because these tools are also basic to the analysis of models in biochemistry, physiology, and behavior, subject also broadly relevant to students whose interests are not limited to ecological problems. *M. Neubert*

7.47 Biological Oceanography (12 units)
Intensive overview of biological oceanography. Major paradigms discussed, and dependence of biological processes in the ocean on physical and chemical aspects of the environment examined. Surveys the diversity of marine habitats, major groups of taxa inhabiting those habitats, and the general biology of the various taxa: the production and consumption of organic material in the ocean, as well as factors controlling those processes. Species diversity, structure of marine food webs, and the flow of energy within different marine habitats detailed and contrasted.
L. Mullineaux, S. Beaulieu

7.491 Research in Biological Oceanography (units arranged)
Directed research in biological oceanography not leading to graduate thesis and generally done before the qualifying examination. Possible areas include population dynamics, physiology, and cytology of marine microorganisms; physiology, nutrition, and productivity of phytoplankton; influence of organisms on the composition of seawater; systematics, physiology, and ecology of pelagic larvae, zooplankton, benthos, and mesopelagic fishes; physiology and migration of large fishes; diving physiology; and use of sound by marine mammals. *WHOI Staff*

7.THG Graduate Biology Thesis (Units arranged) Prereq: Permission of instructor
Program of research leading to the writing of a PhD thesis in Biological Oceanography; to be arranged by the student and an appropriate faculty member.

Geophysics and Geological, Geophysical, and Chemical Oceanography

1.76 Aquatic Chemistry (12 units) Prereq: 5.11 or 5.111 or 5.112 or 5.60
Quantitative treatment of chemical processes in aquatic systems such as lakes, oceans, rivers, estuaries, groundwaters, and wastewaters. A brief review of chemical thermodynamics is followed by discussion of acid-base, precipitation-dissolution, coordination, and reduction-oxidation reactions. Emphasis is on equilibrium calculations as a tool for understanding the variables that govern the chemical composition of aquatic systems and the fate of inorganic pollutants. *J. Seewald-even years, B. Kocar (MIT)-odd years*

1.83 Environmental Organic Chemistry (12 units) Prereq: 5.12, 5.60
Focuses on the processes affecting anthropogenic organic compounds in the environment. Uses physical chemical properties to predict chemical transfers between environmental compartments (air, water, sediments, and biota). Uses molecular structure-reactivity relationships to estimate chemical, photochemical, and biochemical transformation rates. Resulting process models are combined to predict environmental concentrations (and related biological exposures) of hazardous and natural organic compounds. *P. Gschwend (MIT)*

1.THG Graduate Thesis (Units arranged) Prereq: Permission of instructor
Program of research leading to the writing of an SM, MEng, CE, PhD, or ScD thesis in Civil and Environmental Engineering/ Applied Ocean Science and Engineering, Biological Oceanography, or Chemical Oceanography; to be arranged by the student and an appropriate faculty member.

12.521 Computational Geophysical Modeling (12 units) Prereq: Permission of Instructor
An introduction to theory, design, and practical methods of computational modeling in geodynamics. Covers the most effective and widely used numerical modeling approaches and emphasizes problem-solving skills through illustrative examples of heat and mass transfer in the mantle, mechanisms of lithosphere deformation, and other meso-scale geodynamical topics. 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 (12 units) Prereq: 8.03; 18.076 or 18.085
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. *C. Cenedese*

12.525 Mechanisms of Faulting and Earthquakes (12 units) Prereq: Permission of instructor
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. Lin, J. McGuire*

12.707 The History of Earth's Climate (12 units) Prereq: Permission of instructor
Climate history of the Earth from the formation of the early atmosphere and ocean to the present. Evaluation of geochemical, sedimentological, and paleontological evidence for changes in ocean circulation, global temperatures, and atmospheric carbon dioxide levels. Theories and models of Phanerozoic climate change. Long-term history of the global carbon cycle. *D. McGee (MIT)*

12.708 Special Topics in Paleoclimatology (Units arranged) Prereq: Permission of instructor
Advanced seminar focusing on areas of current interest in paleoceanography and paleoclimatology. Includes discussion of current and classic literature. Topics vary; recent topics include Atlantic circulation during the last deglaciation, The Cenozoic Ocean, Climate of the Common Era, and Deglacial Atmospheric CO2 Rise. *D. Oppo, O. Marchal (even years) and J. Tierney, K. Anchukaitis (odd years)*

12.710 Marine Geology and Geophysics (12 units)
An introduction to marine geology and geophysics suitable for any student interested in the ocean sciences. Also intended as part of a two-semester sequence for first-year MIT-WHOI Joint Program students in marine geology and geophysics (MG&G). Topics include: deposition and preservation of marine sediments, climate proxies, Cenozoic to Holocene climate history, paleoceanography, marine stratigraphy and geochronology, structure of the earth, structure of oceanic crust, evolution of the oceanic lithosphere, mantle geodynamics, plate tectonics, ocean altimetry, and coastal sediment processes. *D. Lizarralde, S. Soule, A. Ashton*

12.712 Advanced Marine Seismology (12 units) Prereq: 12.710, 12.711
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*

12.714 Computational Data Analysis (12 units) Prereq: 18.03
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. Chave, T. Herring (MIT)*

12.716 Igneous Processes at Oceanic Margins (9 units) Prereq: 12.710, 12.711 or permission of instructor
Quantitative analysis of melting, melt transport, and igneous crustal accretion at oceanic spreading centers, rifted continental margins, and subduction-related arcs, applied to understanding variation in composition and volume of the Earth's crust in different tectonic environments. Theoretical methods for calculation of melt volume and composition, solid-liquid equilibria and reaction rates, and liquid density and viscosity combined with field, petrographic, geochemical, and computational techniques. Topics vary from year to year. *H. Dick, G. Gaetani*

12.717 Coastal Geomorphology (12 units)
Explores mechanisms behind the formation and reshaping of coastal environments. The focus will be on a process-based understanding of both the fluid dynamic and sediment transport aspects of coastal landforms, and, most importantly, the importance of feedbacks between the two. Coastal evolution at many scales will be investigated, 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. Will investigate the effect of storms, sea-level rise, and interactions with biological and anthropogenic influences. Course 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 (9 units) Prereq: Permission of instructor
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, G. Gaetani*

12.721 Special Problems in Marine Geology and Geophysics at Woods Hole (units arranged)
For graduate students desiring to perform special investigations, special laboratory work, or special fieldwork in marine geology and geophysics. *WHOI Staff*

12.722 Special Problems in Chemical Oceanography at Woods Hole (units arranged)
For graduate students desiring to perform special investigations, special laboratory work, or special fieldwork in chemical oceanography. *WHOI Staff*

12.740 Paleoceanography (12 units) Prereq: Permission of instructor
The history of the earth-surface environment is deduced from the records preserved in deep-sea sediments, ice cores, and corals. Micropaleontological, isotopic, geochemical, and mineralogical changes are used to infer changes in seawater composition, atmospheric chemistry, and climate. These observations are interpreted as consequences of changes in ocean temperature, circulation, and chemistry and used to evaluate theories proposed to account for glacial/interglacial cycles (e.g. orbital forcing). The past 2 million years are emphasized, but major processes and events from the past 100 million years are included. *E. Boyle (MIT)*

12.741 Marine Bioinorganic Chemistry (12 units) Prereq: Permission of instructor
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 (12 units) Prereq: Permission of instructor
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*

12.743 Geochemistry of Marine Sediments (12 units) Prereq: 5.11 or 5.111 or 5.112 or 3.091; 5.60
Factors influencing the composition of deep-sea sediments and their spatial and temporal variability. Carbonate, silicic, organic, and detrital phases: sources and reactivity. Pore water: diffusion, reaction, and chemical fluxes across the sediment-water interface. Sediment dating and accumulation rate and mixing rate estimates. Stable isotopes, natural-series radioisotopes, and trace elements. Effect of climate change on sedimentary processes. Mathematical techniques and modeling in sedimentary systems. *D. McCorkle, W. Martin, A. Spivak*

12.744 Marine Isotope Chemistry (12 units)
Focuses on isotope systematics applied to important problems in marine chemistry, specifically isotope systematics of light stable isotopes and intermediate mass stable isotope systematics. *B. Peucker-Ehrenbrink, W. Jenkins*

12.746 Marine Organic Geochemistry (9 units) Prereq: Permission of instructor
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*

12.747 Modeling, Data Analysis, and Numerical Techniques for Geochemistry (12 units) Prereq: Permission of instructor
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. Glover, W. Jenkins, S. Doney*

12.749 Solid Earth Geochemistry (12 units)
This course is aimed at integrating methods in mineralogy, petrology (both igneous and metamorphic), trace element geochemistry and isotope geochemistry to address scientific issues of the solid earth. It is thematic; it begins with processes in the solar nebula, accretion and early differentiation of the earth, and discusses topics in three representative geodynamic environments: mid-ocean ridges, subduction zones and mantle plumes. For each, lectures on the physical framework will be followed by those on petrological/geochemical aspects. *N. Shimizu, S. Nielsen*

12.751–12.759 Seminar in Oceanography at Woods Hole (Units arranged)
Topics in marine geology and geophysics, physical, dynamical, and chemical oceanography. Content varies from term to term; some recently offered seminars include Marine Chemistry Seminar, Marine Geodynamics Seminar, Climate Change Science, Marine Microbiology and Geochemistry, and Communicating Ocean Science. 12.754, 12.755 and 12.756 are letter-graded. *WHOI Staff*

12.754 Presenting Scientific Research (formerly Seminar in Geology and Geophysics) (6 Units)
The goal of this class is to help students improve skills at presenting scientific research. As such, all students will be asked to give several presentations geared toward a scientific audience. Each student will give one 30-minute talk, one AGU-style 15-minute talk, and one poster presentation. Students are encouraged to present their on-going research and use the class as a forum to practice for upcoming talks in more formal settings. Abstracts will be prepared for each presentation and discussed in class. *M. Behn, S. Nielsen*

12.THG Graduate Thesis (Units arranged) Prereq: Permission of instructor
Program of research leading to the writing of an SM, PhD, or ScD thesis in Earth, Atmospheric, and Planetary Sciences/Chemical Oceanography, Marine Geology and Geophysics, or Physical Oceanography; to be arranged by the student and an appropriate faculty member.

12.751–12.759 Seminar in Oceanography at Woods Hole (Units arranged)
Topics in marine geology and geophysics, physical, dynamical, and chemical oceanography. Content varies from term to term; some recently offered seminars include Classic Papers in Physical Oceanography; Climate Change Science: Current Topics, Controversies, and Communication; Communicating Ocean Science; and The Arctic System: An Interdisciplinary Approach. 12.754, 12.755 and 12.756 are letter-graded. *WHOI Staff*

Physical Oceanography

12.800 Fluid Dynamics of the Atmosphere and Ocean (12 units) Prereq: 8.03, 18.04
Introductory subject for first-year graduate students in meteorology, climate, and oceanography. Eulerian and Lagrangian kinematics. Equations of mass, momentum, and energy in Eulerian form in rotating frame of reference. Vorticity and divergence. Scaling and geostrophic approximation. Potential vorticity. Ekman layers. Vortex motion. *J. Marshall (MIT)*

12.801 Steady Circulation of the Oceans (12 units) Prereq: 12.800
Fundamental principles in modeling steady flows in the ocean and their analogues in the atmosphere. Illustrates general methods that apply to either fluid and the contrasts between them. Includes quasi-geostrophy on the beta plane and planetary geostrophy on the sphere, Ekman pumping, wind- and thermally driven ocean circulation models, western-boundary current dynamics, and abyssal circulation. *R. Ferrari (MIT)*

12.802 Wave Motions in the Ocean and Atmosphere (12 units) Prereq: 12.800
Basic ideas of geophysical wave motion in rotating, stratified, and rotating-stratified fluids. Subject begins with general wave concepts of phase and group velocity. The dynamics and kinematics of gravity waves with a focus on dispersion, energy flux, initial value problems, etc. Subject foundation used to study internal and inertial waves, Kelvin, Poincare, and Rossby waves in homogeneous and stratified fluids. Laplace tidal equations are applied to equatorial waves. Other topics include: resonant interactions, potential vorticity, wave-mean flow interactions, and instability. *G. Flierl, P. O'Gorman*

12.803 Quasi-balanced Circulations in Oceans and Atmospheres (12 units) Prereq: 12.800, [12.804]
Dynamics of large-scale circulations in oceans and atmospheres, taken concurrently with the laboratory subject 12.804. Basic concepts include mass and momentum conservation, hydrostatic and geostrophic balance, and pressure and other vertical coordinates. Barotropic vorticity equation: potential vorticity (PV) and invertibility; Greens functions/point vortices; balance in forced flow, waves, and vortices. Shallow water equations, geostrophic adjustment. Stratified atmospheres and oceans: thermodynamics. The quasi-geostrophic (QG) equations, pseudo potential vorticity. Barotropic and baroclinic instabilities and the Rayleigh, Fjortoft and Chanrey-Stern theorems. Eady and Charney models. The superposition theorem and the continuous spectrum. Effects of boundary friction, upward wave radiation, and phase change of water. Frontogenesis and semigeostrophy. *G. Flierl (MIT)*

12.804 Large-scale Flow Dynamics Laboratory (12 units) Prereq: 12.800, [12.803]
Laboratory component of subject 12.803. Analysis of observations of oceanic and atmospheric quasi-balanced flows, computational models, and rotating tank experiments. Illustrates the basic principles of potential vorticity conservation and inversion, Rossby wave propagation, baroclinic instability, and the behavior of isolated vortices. *L. Illari, G. Flierl (MIT)*

12.805 Laboratory in Physical Oceanography (9 units) Prereq: 12.808
An introduction to standard data analysis methods including time series analysis, objective mapping, empirical orthogonal functions, and dynamic analysis of hydrographic data. Emphasis on working with data in a computer laboratory setting using packaged software. Where appropriate, comparison is made with simple models. Some attention given to the instruments and algorithms used to acquire the data. *K. Brink*

12.808 Introduction to Observational Physical Oceanography (9 units) Prereq: Permission of instructor
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. *M. Andres, J. Gebbie*

12.809 Hydraulic Phenomena in Geophysical Fluid Flows (9 units) Prereq: Permission of instructor
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*

12.810 Dynamics of the Atmosphere (12 units) Prereq: 12.800
Discusses the dynamics of the atmosphere, with emphasis on the large scale. Topics include zonally symmetric circulations and the tropical Hadley circulation; internal gravity waves; balanced flows, potential vorticity conservation and Rossby waves; stability of zonal flows; baroclinic instability and extratropical storms; tropical waves, the Walker circulation, and El Niño and the Southern Oscillation; and the role of eddies in the general circulation. Students taking graduate version complete different assignments. *A. Plumb*

12.820 Turbulence in Geophysical Systems (9 units) Prereq: 12.803
Introduction to turbulence in geophysical systems, including 3-dimensional, 2-dimensional, and quasi-geostrophic turbulence. Transition to turbulence through primary and secondary instabilities. Statistical theories of fully-developed turbulence. Influence of stratification and rotation. Parameterization of turbulent processes in ocean models. *R. Ferrari, G. Flierl (MIT)*

12.823 Modeling the Biology and Physics of the Ocean (9 units) Prereq: 18.075 or 18.085
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 (9 units) Prereq: 12.802 or permission of instructor
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*

12.860 Climate Variability and Diganostics (12 units) Prereq: Permission of instructor
The perspective and techniques used in diagnosing variability in the modern atmosphere and ocean offer insight into connections across a range of disciplines and time scales. Students will gain hands-on experience accessing and analyzing instrumental data sets and climate model outputs toward a practical understanding of the mechanisms governing the climate system from regional to global scales. Emphasis will be placed on dominant modes of interannual variability (*e.g.*, the El Niño-Southern Oscillation [ENSO], North Atlantic Oscillation [NAO]), decadal variability (*e.g.,* the Pacific Decadal Oscillation [PDO]), as well as observed and projected manifestations of anthropogenic climate change. Learning will be driven by data, and supplemented by examples from the published literature. *K. Karnauskas*

Physical Oceanography (cont.)

12.862 Coastal Physical Oceanography (12 units) Prereq: 12.800
Introduction to the dynamics of flow over the continental shelf, 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. Clark*

12.870 Air-Sea Interaction: Boundary Layers (9 units) Prereq: Permission of instructor
Examines the interaction of the atmosphere and ocean on time scales from minutes to months, with emphasis on effects within the near-surface boundary layers in both the air and water. Topics include the dynamics of the wave field and its role in mediating air-sea coupling, the scaling of surface layer turbulence, the effects of temperature stratification, and the mechanics of energy and momentum exchange across the interface. Methods for measuring and computing air/sea fluxes are reviewed. Modification of boundary layers by air/sea exchange, radiation, and turbulent mixing is treated using a hierarchy of boundary layer models made available for student use. *J. Trowbridge, E. Terray*

12.950 Numerical Ocean Modeling (12 units) Prereq: Permission of instructor
The course is designed to teach numerical modeling in oceanography and environmental fluid mechanics. It focuses on the building of computational models that describe processes such as transport (advection, diffusion), reaction, and boundary forcing, of relevance in natural water systems. Models will be 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- and three-dimensions. The students will acquire the skills to build their own models using a finite volume approach, and gain an appreciation and understanding of the working of general circulation models. *A. Mahadevan*

12.971 Special Problems in Physical Oceanography at Woods Hole (units arranged)
For pre-thesis students, reading, consultation, and original investigation on oceanographic problems. *WHOI Staff*

12.THG Graduate Thesis (Units arranged) Prereq: Permission of instructor
Program of research leading to the writing of an SM, PhD, or ScD thesis in Earth, Atmospheric, and Planetary Sciences/Chemical Oceanography, Marine Geology and Geophysics, or Physical Oceanography; to be arranged by the student and an appropriate faculty member.

Joint Program Course Schedules

Course #	Course Title	Units	Last Taught	Annual (1) Biannual (2)
	Applied Ocean Science & Engineering			
2.682	Acoustical Oceanography	12	SP 12	2
2.683	Marine Bio-Acoustics & Geo-acoustics	12	SP 09	2
2.684	Wave Scattering by Rough Interfaces & Randomly Inhomogeneous Media	12	SP 09	2
2.687	Time Series Analysis & System Identification	12	SU 13	2
2.688	Principles of Oceanographic Systems – Sensors & Measurements	12	FA 13	1
2.689	Special Projects in Oceanographic Engineering	--		
6.456	Adaptive Array Processing	12	FA 13	2
12.870	Air-Sea Interaction: Boundary Layers	9	SP 08	2
1.ThG	Graduate Thesis (CEE)			
2.ThG	Graduate Thesis (ME)			
6.ThG	Graduate Thesis (EECS)			
	Biological Oceanography			
7.410	Applied Statistics	12	SP 14	1
7.411–.419	Seminars in Biological Oceanography	6		
7.421	Special Problems in Biological Oceanography	--		
7.430	Topics in Quantitative Marine Science	6		
7.431	Topics in Marine Ecology	6		
7.432	Topics in Marine Physiology and Biochemistry	6		
7.433	Topics in Biological Oceanography	6		
7.434	Topics in Zooplankton Biology	6		
7.435	Topics in Benthic Biology	6		
7.436	Topics in Phytoplankton Biology	6		
7.437	Topics in Molecular Biological Oceanography	6		
7.438	Topics in the Behavior of Marine Animals	6		
7.439	Topics in Marine Microbiology	6		
7.440	An Introduction to Mathematical Ecology	9	SP 13	2
7.47	Biological Oceanography	12	SP 14	1
7.491	Research in Biological Oceanography	--		
7.ThG	Graduate Thesis (Biology)			
	Chemical Oceanography			
1.76	Aquatic Chemistry	12	SP 14	2
12.722	Special Problems in Chemical Oceanography	--		
12.740	Paleoceanography (MIT)	12	SP 13	
12.741	Marine Bioinorganic Chemistry (formerly 12.755)	12	FA 11	2
12.742	Marine Chemistry	12	FA 13	1
12.743	Geochemistry of Marine Sediments	12	SP 13	2
12.744	Marine Isotope Chemistry	12	FA 12	2
12.746	Marine Organic Geochemistry	9	SP 13	2
12.747	Modeling, Data Analysis & Numerical Techniques for Geochemistry	12	FA 12	2
12.759*	Marine Chemistry Seminar	6	SP 14	1
12.ThG	Graduate Thesis (EAPS)			

* 12.751-12.759: Various Seminars in Oceanography at Woods Hole for CO, MGG, and PO; 12.754, 12.755, and 12.756 are letter graded; all others are P/D/F.

Joint Program Course Schedules

Course #	Course Title	Units	Last Taught	Annual (1) Biannual (2)
	Marine Geology & Geophysics			
12.521	Computational Geophysical Modeling	9	SP 14	2
12.522	Geological Fluid Mechanics	12	FA 12	2
12.525	Mechanisms of Faulting & Earthquakes	12	FA 05	2
12.707	Pre-Pleistocene Paleoceanography & Paleoclimatology	12	SP 13	2
12.708	Advanced Seminar in Paleoclimatology	9	FA 13	1
12.710	Marine Geology & Geophysics	12	SP 14	1
12.712	Advanced Marine Seismology	9	FA 13	2
12.714	Computational Data Analysis	12	SP 14	2
12.716	Igneous Processes at Oceanic Margins	9	FA 12	2
12.721	Special Problems in MG&G	--		
12.743	Geochemistry of Marine Sediments	12	SP 13	2
12.749	Solid Earth Geochemistry	12	FA 11	2
12.752*	Oceanic Faulting & Earthquakes	6	FA 11	2
12.753*	Marine Geodynamics Seminar	6	SP 14	1
12.754*	Student Seminar in MG&G	6	FA 13	1
12.754*	Coastal Geomorphology	6	SP 12	2
12.755/56(52)*	Advanced Marine Geophysics	6	SP 07	2
12.ThG	Graduate Thesis (EAPS)	--		
	Physical Oceanography			
12.758*	Classic Papers in Physical Oceanography	6	SP 13	1
12.800	Fluid Dynamics of the Atmosphere & Ocean	12	FA 13	1
12.802	Wave Motions in the Ocean & Atmosphere	12	SP 14	1
12.805	Laboratory in Physical Oceanography	9	FA 13	1
12.808	Introduction to Observational Physical Oceanography	9	FA 13	1
12.809	Hydraulic Phenomena in Geophysical Flows	9	FA 13	2
12.862	Coastal Physical Oceanography	12	FA 11	2
12.950	Computational Ocean Modeling	12	FA 12	2
12.971	Special Problems in Physical Oceanography	--		
12.ThG	Graduate Thesis (EAPS)			
	Interdisciplinary			
12.754*	Communicating Ocean Science	12	SP 14	2
12.756*	Marine Microbiology and Geochemistry	12	FA 13	2
12.757*	The Arctic System: An Interdisciplinary Approach	6	FA 12	2
12.757*	Science & Society	6	FA 10	2
12.757*	Climate Change Science	6	SP 14	2
12.860	Climate Variability & Diagnostics	12	SP 14	2

* 12.751-12.759: Various Seminars in Oceanography at Woods Hole for CO, MGG, and PO; 12.754, 12.755, and 12.756 are letter graded; all others are P/D/F.

2014

FALL TERM

65 Class Days (9/3-12/10): 12 Mondays, 13 Tuesdays, 15 Wednesdays, 13 Thursdays, 12 Fridays

September		
1	Monday	Labor Day – Holiday
23	Tuesday	Registration Day – Fall term
3	Wednesday	First day of classes
4	Friday	Degree application deadline for February degrees
		Registration deadline
19	Friday	Student holiday – no JP classes
October		
3	Friday	Add date – Last day to add subjects to registration
		Cross-registration deadline
13	Monday	Columbus Day – Holiday (Joint Program students) – no classes
November		
10, 11	Monday, Tuesday	Veterans' Day – No classes
19	Wednesday	Last day to drop subjects from registration
		Last day to add half-term subjects offered in 2nd half
27	Thursday	Thanksgiving Day – Holiday
28	Friday	Thanksgiving vacation (Joint Program students) – no classes
December		
1	Monday	On-line preregistration for spring term begins (12/30 deadline)
10	Wednesday	Last day of classes (Online course evaluations 12/3-12/14)
12	Friday	Last day to submit or change advanced degree thesis title
15	Sunday	Application deadline – Joint Program (EECS only)
16	Tuesday	Grade deadline
25	Thursday	Christmas Day - Holiday
31	Monday	Spring preregistration deadline ($50 late fee)

2015

January		
1	Thursday	New Year's Day - Holiday
5	Monday	Application deadline – Joint Program (EAPS, Biology, ME, CEE)
		Application deadline – Postdoctoral Programs
		First day of Independent Activities Period
9	Friday	Thesis due for doctoral degrees*
16	Friday	Thesis due for engineer's and master's degrees*
		Last day to go off February degree list
19	Monday	Martin Luther King Jr. Day – Holiday
30	Friday	Last day of Independent Activities Period

SPRING TERM (2015)

65 Class Days (2/3-5/14): 12 Mondays, 12 Tuesdays, 14 Wednesdays, 14 Thursdays, 13 Fridays

February		
2	Monday	Registration Day – Spring Term
3	Tuesday	First day of classes
5	Friday	Degree application deadline for June degrees; Registration deadline
15	Sunday	Application deadline – Geophysical Fluid Dynamics Program and Summer Student and Minority Fellow Programs
16	Monday	Presidents' Day – Holiday
17	Tuesday	**Monday schedule of classes to be held**
March		
6	Friday	Add date – Last day to add subjects to registration Cross-registration deadline
TBD	Monday, Tuesday	Joint Program Open House at MIT and WHOI
23-27	Monday-Friday	Spring Break (Joint Program students) – no classes or T/Th bus
April		
3	Friday	Last day to submit or change advanced degree thesis title
20,21	Monday, Tuesday	Patriots' Day – Vacation (Joint Program students) – no classes
23	Thursday	Drop date – Last day to cancel subjects from registration
May		
1	Friday	On-line preregistration for summer & fall begins (5/30 deadline) Thesis due for doctoral degrees*
8	Friday	Thesis due for engineer's and master's degrees*
14	Thursday	Last day of classes (Online course evaluations 5/6-5/17)
19	Tuesday	Grade deadline
22	Friday	Last day to go off the June degree list
25	Monday	Memorial Day – Holiday
29	Friday	Fall and summer preregistration deadline ($50 late fee)
June		
4	Thursday	MIT Doctoral Hooding Ceremony
5	Friday	MIT Commencement
6	Saturday	WHOI Commencement
8	Monday	Joint Program summer session begins; first day of classes
12	Friday	Summer registration deadline; deadline for September degree application
15	Monday	Fall preregistration deadline
July		
3	Friday	Independence Day – Holiday
August		
7	Friday	Thesis due for all September degree candidates*
14	Friday	Last day to go off September degree list; last day of classes
21	Friday	Grades for summer session due