Earth Science and Engineering Course Descriptions

ErSE 201. Geophysical Fluid Dynamics I (3-0-3) (Same as MarSE 212) *Prerequisite: ME 250 and ErSE 203 or consent of instructor.* Topics include governing equations of mass and momentum conservation; wave kinematics, dispersion, group velocity; surface and internal gravity waves, shallow water theory; stratified fluids and normal mode analysis; waves in rotating fluids: Kelvin, Poincare and Rossby waves; the Rossby adjustment problem and conservation of potential vorticity; the quasigeostrophic approximation.

ErSE 202. Computational Groundwater Hydrology (3-0-3) (Same as EnSE 224) *Prerequisite:Basic programming skill in MATLAB or consent of instructor. Co-requisites: ErSE 203.* Derivation of mathematical models for porous media flow. Development and application of massconservative simulator models of single phase, miscible fluids in porous media. Solution of the pressure equation. Numerical methods for convection diffusion equations.

ErSE 203. Geophysical Continuum Mechanics (3-0-3) *Prerequisite: AMCS 231 or consent of Instructor.* The course provides physical background foundation and overview of mathematical continuum models of geophysics. The goal of the course is to allow students to learn modeling ideas and utilize them in simulation. The course will include a basic introduction to finite difference and finite element methods and their application to continuum modeling and simulation. Topics discussed include: brief introduction to Cartesian tensors, their calculus and algebra; deformations and strain measures; balance laws and equations of motion; thermodynamical relations and constraints; mixture theory and phase change.

ErSE 210. Seismology I (3-0-3) *Prerequisite: ErSE 203 or consent of instructor.* Introductory and advanced concepts of seismic wave propagation. Vectors and tensors, Hooke's law, elastic coefficient tensors, Christoffel equation, group and phase velocities, and Green's theorem. The following concepts will also be covered: reflection and transmission coefficient formulas for a layered medium, attenuation, Snell's law, Hooke's law, Fermat's principles, Fresnel zone, finite-difference solutions to the wave equation and eikonal equation, transport equation, and traveltime tomography.

ErSE 211. Global Geophysics (3-0-3) *Prerequisite: ErSE 203 or consent of instructor.*The course provides introductory descriptions of the Earth solid and fluid natural systems and their interaction. It discusses Earth early geological history, plate motions, magnetism and sea floor spreading, earthquakes and earth structure, gravity, geochronology, heat flow, mantle convection and earth's magnetic field; history of earth climate, formation of oceans and atmosphere, biological history, energy balance climate model, general circulation of ocean and atmosphere, climate change, coupled ocean-atmosphere-biosphere climate models
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ErSE 212. Geophysical Geodesy and Geodynamics (3-0-3) *Prerequisite: ErSE 211 or consent of instructor.* Satellite geodesy, gravimetry, GPS, Interferometric Synthetic Aperture Radar (InSAR), radar altimetry. Plate tectonics and paleomagnetism, plate motions, plate-boundary deformation, seismic cycle, heat flow, basin subsidence, plate-flexure, post-glacial rebound, geoid determination, gravity anomalies, sea-level measurements, tides, earth rotational variations, volcano geodesy.

ErSE 213. Inverse Problems and Data Assimilation (3-0-3) *Prerequisite: Background in linear algebra, multivariable calculus (gradients, hessians, ...), probability theory, and programming in Matlab*. This course will introduce the principles of Inverse theory and data assimilation with applications to geophysics and other sciences. Both deterministic and stochastic viewpoints will be covered. Subjects studied will include topics such as least squares, generalized inverses, regularization, Kalman filter, adjoint method, etc. Techniques for solving nonlinear inverse and data assimilation problems will be also covered.

ErSE 214. Seismic Exploration (2-1-3) An introductory course on Seismic exploration covering the basics of seismic waves, seismic data, seismic acquisition, data processing, filters, seismic velocities, and stacking. The course includes an introduction to seismic imaging.

ErSE 215. Geomechanics I (3-0-3) Concepts of linear elastic fracture mechanics as applied to the classification, origin and evolution of all types of rock fractures; continuum theory in rock mechanics; rock strength and failure criteria; rock mechanics testing; stress tensors; elastic theory; poroelasticity and thermoelasticity; inelastic behaviour; stress regimes; geological applications.

ErSE 217. Seismotectonics (3-0-3) Stress and strain, tensor analysis, rheology, brittle vs. ductile deformation, fracture, fault mechanics, friction, stable and unstable sliding, double-couple representation of earthquake sources, moment tensors, coulomb failure stress changes, earthquake triggering, stress drop, Kostrov's summation, comparative seismotectonics.

ErSE 225. Physical Fields Methods in Geophysics I (2-1-3) *Prerequisite: PDEs and course in basic EM physics.* Measurement and theory of gravity and magnetic fields of the earth; small- to large-scale gravity and magnetic anomalies in exploration and global geophysics; reduction of gravity and magnetic data and forward modeling; applications to exploration, tectonics, and environmental problems. Thermal properties, temperatures, and heat transfer within the context of global geological and geophysical processes, such as plate tectonics and sedimentary basin evolution.

ErSE 253. Data Analysis in Geosciences (3-0-3) *Prerequisite: Background in linear algebra, probability theory, statistics, and programming in Matlab.* Time Series (filtering, correlation, deconvolution, spectral analysis, regression), processing of multidimensional data, spatial statistics including variogram, covariance analysis and modeling, multipoint estimation, spatial interpolation including statistical methods (kriging) and dynamical methods (Kalman filter), uncertainty assessment, cross validation, multivariate analysis including principal component analysis and canonical analysis.

ErSE 260. Seismic Imaging (3-0-3) *Prerequisite: ErSE 210 or ErSE 214 or consent of instructor.* Seismic migration methods are developed. Green's theorem is used to derive Lippmann-Schwinger equation and the following migration methods: phase-shift migration, split-step and PSPI migrations, Fourier Finite Difference migration, phase-encoded multi-source migration, Kirchhoff migration, beam migration, diffraction stack migration, reverse time migration, and migration velocity analysis.

ErSE 296. Special Seminar (1 credit) Master-level seminar focusing on special topics within the field.

ErSE 297. MS Thesis Research (variable credit) *Prerequisite: Approval of Advisor.* Master-level Thesis Research.

ErSE 298. Graduate Seminar (1 credit) Master-level seminar focusing on special topics within the field.

ErSE 299. Directed Research (variable credit) *Prerequisite: Approval of Advisor* Master-level supervised research.

ErSE 301. Geophysical Fluid Dynamics II (3-0-3) *Prerequisite: ErSE 201 or consent of instructor.* Climate and climate change, large-scale atmospheric and oceanic motions, fine-scale processes. Quasigeostrophic motion of a stratified fluid on a sphere, the equations of motions in spherical coordinates, scaling and asymptotic analysis, potential-vorticity equation. Rossby waves in a stratified fluid. Theory of instability, baroclinic instability, barotropic instability, instability of flows with horizontal and vertical shear. Energy and enstrophy. Numerical models of general circulation of atmosphere, pressure vertical coordinate, linear and nonlinear numerical instabilities.

ErSE 303. Numerical Models of Geophysics (3-0-3) *Prerequisite: ErSE 203 or consent of instructor.* Built on the modeling and simulation foundation developed in ErSE203, this specialized course will discuss advanced ideas of multi-scale modeling, linear and non-linear finite element methods, investigate modern approaches to numerical simulations of hydrodynamic and geophysical turbulence, problems of theoretical glaciology and material science of ice for the prediction of ice sheet evolution, and wave propagation in linear and non-linear media.

ErSE 305. Multiphase Flows in Porous Media (3-0-3*)* *Prerequisite: AMCS 252 or consent of instructor.* Thermodynamics of pressure, volume, temperature and composition relationships in water, oil or nonaqueous phase liquids and gas mixtures. Modeling compositional and thermal fluids, including streamline flow, fractional flow and both immiscible and miscible flow.

ErSE 306. Ocean Physics and Modeling (3-0-3) *Prerequisites: ErSE 201, ErSE 203, AMCS 252 or consent of instructor.* This course will introduce the theory and numerical modeling of ocean circulation. This includes the theory of steady and time-dependent large-scale circulation, effects of earth's curvature, wind-driven Sverdrup circulation, western boundary currents, eastern boundary upwelling, effects of buoyancy forcing, wind- and buoyancy-forced circulation in the thermocline. The course will also review the theoretical models of ocean circulation, including shallow water, barotropic, quasigeostrophic, and primitive equation models; adjustment times, internal length and time scales; the role of advection, bathymetry and coastlines; global models, basin models, regional models.

ErSE 307. Atmospheric Chemistry and Transport (3-0-3) *Prerequisite: ErSE 203, AMCS 252 or consent of instructor.* The course provides an introduction in atmospheric chemical processes and their role in climate system. It covers fundamentals of reactions kinetics, photochemical processes, chemistry of troposphere and stratosphere, tropospheric ozone and air-pollution, stratospheric ozone and ozone hole, atmospheric aerosols, chemistry of clouds, atmospheric transport, chemistry transport models, chemistry climate models.

ErSE 308. Atmospheric Physics and Modeling (3-0-3) *Prerequisite: ErSE 203, AMCS 252 or consent of instructor.* The course discusses main physical processes in the Earth's atmosphere and their role in the formation of weather and climate including atmospheric dynamics and general circulation, sub-grid fine-scale processes and their parameterizations, atmospheric convection, cloud and precipitation formation, atmospheric turbulence and the planetary boundary layer, air-sea interaction, energy balance, radiative-convective equilibrium, general circulation models, coupled ocean-atmosphere models.

ErSE 310. Seismology II (3-0-3) *Prerequisite: ErSE 253 and any of ErSE 210, ErSE 211, ErSE 216.* Part I: Whole Earth wave propagation (body waves, surface waves, normal modes); imaging Earth 3D structure with ray-based methods; introduction to methods beyond ray-theory; attenuation and scattering of seismic waves. Part II: Earthquake source mechanics; earthquake kinematics and scaling laws; earthquake dynamics, fracture modes and crack propagation; introduction to probabilistic seismic hazard assessment.

ErSE 315. Geomechanics II (3-0-3) *Prerequisite: ErSE 215, ErSE 203 or consent of instructor.* Application of Geomechanics I to reservoir characterization; borehole imaging and borehole stresses; borehole failure analysis; pore pressure prediction and effective stress concepts; sand production and sand failure modeling; effects of water on sand production; wellbore stability; drilling practice.

ErSE 324. Parallel Scientific Computing in Earth Sciences (3-0-3) (Same as AMCS 292) *Prerequisite: AMCS 252, ErSE 203 or consent of instructor.* Introduction to the basics of modern parallel computing: parallel architectures, message passing, data and domain decomposition, parallel libraries, programming languages, data management and visualization and parallel numerical algorithms. Applications to scientific computing problems in earth sciences and engineering.

ErSE 325. Physical Fields Methods in Geophysics II (3-0-3) *Prerequisite: PDEs and course in basic EM physics.* General concepts of electromagnetic field behavior. Electromagnetic properties of rocks. Direct current methods, natural-field electromagnetic methods, magnetotelluric field, numerical modeling, magnetotelluric survey methods. Controlled source electromagnetic methods, electromagnetic sounding and profiling. Computer simulation and interpretation of electromagnetic geophysical data.

ErSE 328. Advanced Seismic Inversion I (3-0-3) *Prerequisite: Include courses in linear algebra and partial differential equations. Knowledge of linear inversion and exploration seismology is helpful. Consent of instructor* *is required.* Overview of non-linear seismic inversion methods that invert for earth parameters from seismic data. The inversion procedure is a multiscale iterative method (typically, non-linear conjugate gradient) that employs preconditioning and regularization. Solution sensitivity is analyzed by model covariance matrices, the slice-projection theorem, and the generalized Radon transform. Methods for waveform inversion, wave path traveltime tomography, and least squares migration are presented.

ErSE 329. Advanced Seismic Inversion II (3-0-3) *Prerequisite: ErSE 328.* Codes for waveform tomography, wavepath traveltime tomography, traveltime tomography, least squares migration, and skeletalized inversion are used to help student evaluate limits and benefits of these methods, and extend the frontier of seismic inversion. A term project is required that will be written as a paper, and possibly submitted to a relevant scientific journal.

ErSE 345. Seismic Interferometry (3-0-3) Main objective is to present the key ideas of seismic interferometry and illustrate them with seismic examples from marine data, land data, and synthetic data. MATLAB exercises will be presented that educate the user about the benefits and pitfalls of interferometric imaging. Examples will be presented that use interferometry for 2D deconvolution, data extrapolation, data interpolation, super-stacking, passive seismology, surface-wave interferometry, and super-illumination.

ErSE 395. Special Topics in Earth Science (3-0-3) Computational Science and Engineering Programming experience and familiarity with basic discrete and numerical algorithms and experience with one or more computational applications. Case studies of representative and prototype applications in partial differential equations and meshbased methods, particle methods, ray-tracing methods, transactional methods.

ErSE 396. Special Seminar (1 credit) Doctoral-level seminar focusing on special topics within the field.

ErSE 397. Ph.D. Dissertation Research (variable credit) *Prerequisite: Approval of Advisor.*

ErSE 398. Graduate Seminar (1 credit) Doctoral-level ErSE program seminar.

ErSE 399. Directed Research (variable credit) *Prerequisite: Approval of Advisor*.
Doctoral-level supervised research.