PhD Course in
EARTH SCIENCE, FLUID DYNAMICS AND MATHEMATICS. INTERACTIONS AND METHODS
2018-19 Courses

Course: NUMERICAL METHODS FOR PDEs
SSD: MAT/08
24 hours, 3 ECTS
Lecturer/s: S. Maset

Aims: introduce students to the numerical solution of partial differential equations

Syllabus:

A) Numerical methods for PDEs
The Five point discretization of the Laplacian: the discrete problem, analysis of the discrete problem via a maximum principle, Fourier analysis, analysis via an energy estimate, curved boundaries.
Difference method for the heat equation: the centered difference/forward difference method, Fourier analysis. the centered difference/backward difference method, the Crank-Nicolson method.
Difference method for the advection equation: hyperbolic systems, the method of characteristics, numerical methods, the CFL condition, the Lax-Friedrichs method, Fourier analysis.
The Finite Volume Method: a 1D example, the multidimensional case.

B) Numerical methods for incompressible flows
The Navier-Stokes Equations in Primitive Variables in the Cartesian Frame of Reference.
Grid topology: co-located versus staggered. Steady NS-Equations: the artificial compressibility method. Unsteady NS-Equations: the projection and MAC method, explicit method. semi-implicit method, the PISO-Algorithm.

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: ICE SHEETS AND GLACIERS IN THE CLIMATE SYSTEM: GEOPHYSICAL-GEOLOGICAL APPROACH AND CASE STUDIES (PART 1) (resp. Dr. Renata G. Lucchi)
SSD: GEO/02
15 hours, 3 ECTS
Lecturer/s: A. Camerlenghi, R. Colucci, L. De Santis, E. Forte, R. Francese, R. G. Lucchi, F. Pettenati, M. Rebesco
Aims: The course aims to give a current review of modern research into processes and dynamics of the global cryosphere and their connections with climate.

Syllabus:
GEOPHYSICS ON ICE
Franco Pettenati (OGS), Roberto Francese (University of Parma), Emanuele Forte (University of Trieste).
1. Active seismic method
The methodology, seismic data acquisition and elaboration, seismic tomography, Imaging, anisotropy of ice, physical properties of the ice and bedrock. Discussion of some case studies in the Alps and in Antarctica.
2. Passive seismic method
The methodology, seismic data acquisition and elaboration, Estimation of glaciers thicknesses and basal properties using the horizontal-to-vertical component spectral ratio (HVSR) technique. Discussion of some case studies in the Alps and in Antarctica.
3. Ground Penetrating Radar on Ice.
Introduction to GPR and its application to glacier monitoring.
4. Geoelectrical methods
Quick review of the electrical methods. The electrical resistivity tomography (ERT). Potentials and limitations of ERT applications in glacial and periglacial conditions. Discussion of some case studies in the Alps.

GLACIERS AND PERMAFROST
Renato R. Colucci (ISMAR, CNR),
1. Concepts on climatology and earth energy balance and the role of CO2 and other GHG
2. Concepts on Alpine meteorology and climatology of periglacial and glacial environment
3. Glacier morphology (ice sheets and ice caps, mountain glaciers, ice shelves, present and past distribution of glaciers) Energy balance at the glacier's surface, accumulation and ablation processes, Equilibrium Line Altitude (ELA), Glacier sensitivity to climate change
4. Debris transport and deposition: the little ice age.
5. Cold climate of non-glaciated regions, Frost action, Ground temperature regime, Latitudinal permafrost (small scale and large scale morphologies), Mountain permafrost and Rock glaciers

POLAR MARINE DEPOSITIONAL SYSTEMS AND CASE STUDIES
Angelo Camerlenghi (OGS), Rebesco Michele (OGS), Renata Giulia Lucchi (OGS), Laura De Santis (OGS),
1. General part on polar marine depositional systems (Camerlenghi)
- River-dominated versus Ice Sheet-dominated Marine Sedimentary Systems
- Ice Streams
- Troughs-mouth Fans
- Glacial maxima Debris Flows
- Meltwaters
- Tunnel Valleys
- Meltwater plumes and Plumites
- Sea ice sediment transport
- Contourites
- Turbidites
- Mass Transport Deposits
2. Case History: depositional systems south and west of Spitsbergen, geophysical data (Rebesco)
3. Case History: Storfjorden and Kveithola Trough-Mouth Fans, sediment core data (Lucchi)
4. Case History: Ross Rea and Wilkes Land margins (De Santis)
+ laboratory (Kingdom applied to seismic data interpretation)

Teaching methods: lectures
Assessment methods: -
Other information: the course is delivered in English

Course: ICE SHEETS AND GLACIERS IN THE CLIMATE SYSTEM: DATA-MODEL INTER-COMPARISON AND CASE STUDIES (PART 2) (resp. Dr. Florence Colleoni)
SSD: GEO/02
15 hours, 3 ECTS
Lecturer/s: F. Colleoni, , R. Colucci, B. Stenni, L. De Santis
Aims: The course aims to give a current review of modern research into processes and dynamics of the global cryosphere and their connections with climate.

Syllabus:
1. PRESENT-DAY ICE SHEETS AND INTERACTION WITH LOCAL, REGIONAL, GLOBAL CLIMATE (*Florence Colleoni*)
Present-day state of the Greenland and Antarctica (isostasy, mass balance, sea level)
Gaps in the current knowledge: observation of surface mass balance and basal melting under the cavities
Ice sheets as a tipping point in the climate system: IPCC and beyond
2. GLACIERS MASS BALANCE (2 hours *Renato R. Colucci*) + GIS excercise
3. SEDIMENT CORE AND PALEOCLIMATE (3 hours *Laura De Santis*) *+ exercise on seismic stratigraphic interepretation*
- the need to couple with models to reconstruct the overall basin evolution; seismic horizon mapping and backstripping technique
- the Ross Sea and the Wilkes Land margins as key locations to provide data to improve our current knowledge and test the different hypothesis;
- The evidence of past ice sheet advance and retreat in the Ross Sea and in the Wilkes Land (geological and geophysical records);
- The modern oceanic circulation in the Ross Sea and in the Wilkes Land;
4. ICE CORES AND PALEOCLIMATE (2 hours)
Barbara Stenni (Ca' Foscari University of Venice)
- The ice core records: climate proxies: the water stable isotopes for temperature reconstructions from ice cores
-- The Present Interglacial (PIG) and the Last Interglacial (LIG) in the ice core records: Data – model comparison.
- PAGES2k and the last 2000 years in Antarctica
5. ICE-SHEET MODELLING (*Florence Colleoni*)
Light theory of ice dynamics: main physical assumptions
The hierarchy of ice-sheet models: from SIA to full Stokes models, coupled climate-ice-sheet models, coupled ocean-ice-sheet models
Interactions with ocean: Greenland context and Antarctic context, Marine Ice Sheet Instability
6. PALEO ICE SHEETS DYNAMICS FROM MODELS (*Florence Colleoni*)
Northern Hemisphere glaciations: how to simulate past glaciations using sea level, proxies, multibeam etc…
Antarctic past glaciations: the difficulties for ice sheet models
7. RECONSTRUCTION OF PAST ICE SHEET DYNAMICS: models-data exercise. (*Florence Colleoni*)

Teaching methods: lectures
Assessment methods: -
Other information: the course is delivered in English;

Course: ADVANCED SEISMIC PROCESSING
SSD: GEO/11
30 hours, 6 ECTS
Lecturer/s: M. Pipan, F. Poletto, G. Boehm

Aims: introduce students to advanced seismic processing

Syllabus:

Part 1: Seismic migration
Migration algorithms: finite difference, Kirchhoff, frequency domain, Stolt
Migration velocity analysis and Common-Image Gathers
Dip Move-Out and migration pre- and post-stack
Migration in time and depth domain
Migration in 2D and 3D

Part 2: Seismic tomography
Inversion algorithms and ambiguity
Tomography using irregular and staggered grids
Time-lapse tomography
Joint traveltime inversion of different wave types
Joint traveltime inversion of active and passive seismic data

Part 3: Seismic interferometry and borehole geophysics
Borehole geophysics and Vertical Seismic Profiles
Seismic-While-Drilling and geothermal applications
Seismic interferometry by correlation and deconvolution
Far-field and near-field analysis
Emission pattern of seismic sources

Teaching methods: lectures
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: ENGINEERING NUMERICAL ANALYSIS
SSD: ING-IND/34
30 hours, 6 ECTS
Lecturer/s: G. Pedrizzetti

Aims: provide students with the fundamentals of numerical analysis for engineering

Syllabus:

1 Interpolation

2 Numerical Differentiation – Finite Differences

3 Numerical Integration

4 Numerical Solution of Ordinary and Partial Differential Equations

Teaching methods: lectures/exercises
Assessment methods: homeworks
Other information: the course is delivered in English

Course: AN INTRODUCTION TO FLUID MECHANICS FOR CARDIOVASCULAR ENGINEERING
SSD: ING-IND/34
30 hours, 6 ECTS
Lecturer/s: G. Pedrizzetti

Aims: provide students expertise on the fluid motion inside the heart and the large vessel, with particular reference to what may be the relevant for clinical evaluations.

Syllabus:

1 . INTRODUCTORY ELEMENTS: Basic Concepts, overview of fluids and solids mechanics and Bio-flow Domains. Kinematics of fluid

2. FLUID DYNAMICS: CONSERVATION LAWS: Conservation of mass, of momentum and of energy and their applications to vessels, deformable chambers and transvalvular flows.

3. FUNDAMENTALS FOR MOSTLY UNIDIRECTIONAL FLOW: Steady, Oscillatory and Pulsatile Uniform Flow in a Circular Vessel. Elements Turbulent Flow near the walls. Quasi Unidirectional Flow in Large Vessels with slowly varying geometry. Pulse propagation and reflection in elastic vessels.

4. ANALYSIS OF SEPARATED FLOW: Dynamics of Vorticity, Boundary Layer Separation and Vortex Formation. Separated Flow in Large Arteries, Arteriosclerosis, Stenosis, Aneurism.

5. CARDIAC MECHANICS: Cardiac electro-mechanical cycle. Fluid dynamics inside the normal and pathologic left ventricle. Aortic valve. Mitral valve

Teaching methods: lectures/exercises
Assessment methods: homeworks
Other information: the course is delivered in English

Course: FLUID DYNAMICS
SSD: ICAR/01, GEO/12
36 hours, 7 ECTS
Lecturers: R. Farneti, S. Salon

Aims: To introduce students to fluid mechanics basic principles and to the main topics of geophysical fluid dynamics

Syllabus: Part I (Fluid Mechanics) Lecture 1 Introduction to Fluid Mechanics, Properties of Fluids and Statics Lecture 2 Scalars, Vectors, Tensors; Gradient, Divergence, Curl; Stokes and Gauss Theorems Lecture 3 Kinematics: Material derivative, streamline, streamfunction, strain rates Lecture 4 Relative motion near a point, Vorticity and Circulation Lecture 5 Conservation laws I: Mass, tracer, Advection-Diffusion Equation Lecture 6 Conservation laws II: Momentum and the Navier-Stokes Equations Lecture 7 Conservation laws III: Momentum and the Navier-Stokes Equations Lecture 8 Conservation laws IV: Energy and Bernoulli equations Lecture 9 Dynamic similarity
Part II (Geophysical Fluid Dynamics) Lecture 10 Introduction to Geophysical FD: scales of motion, rotation/stratification in atmosphere and ocean Lecture 11 Rotating frame of reference: Coriolis force, inertial oscillations, acceleration on a 3-D rotating planet Lecture 12 Governing equations of GFD: momentum, mass conservation, energy, equation of state; Boussinesq approximation; scale analysis and further simplifications of governing equations; Rossby, Ekman, Reynolds numbers Lecture 13 Geostrophy: geostrophic flows; Taylor-Proudman theorem; non-geostrophic flows; vorticity dynamics Lecture 14 Friction and rotation: Ekman layers Lecture 15 Barotropic waves: Kelvin, Poincarè, Rossby, topographic waves and analogies Lecture 16 Stratification: static stability, Froude number, combination of rotation and stratification Lecture 17 Mixing 1: mixing of stratified fluids, Kelvin-Helmoltz instability – Instability of a stratified shear flow Lecture 18 Mixing 2: Taylor-Goldstein equation, Richardson number; turbulence in a stratified shear flow

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: PHYSICS OF THE ATMOSPHERE
SSD: GEO/12
24 hours, 5 ECTS
Lecturer/s: A. Tompkins

Aims: introduce students to the physics of the atmosphere

Syllabus:

1. Brief Introduction; Water in the atmosphere; adiabatic motion; clouds formation; earth's radiation balance
2. The planetary Boundary Layer; heat capacity of the surface ; structure of the PBL ; the laminar and turbulent layer; Diurnal cycle of the PBL; surface fluxes of heat and moisture
3. Atmospheric Convection; Shallow convection regimes; mid-level and upper-level convection; deep convection; turbulent entrainment; convective downdrafts; examples of mesoscale organised convection; static stability in a moist environment
4. Cloud Physics; introduction; cloud drop formation; diffusional growth; terminal velocity of particles; collision and coalescence; Ice crystal nucleation; ice saturation; Ice nucleation mechanisms; ice crystal growth; competition between ice nucleation mechanisms; aggregation; riming; ice particle fall-speeds; ice multiplication
5. Radiation; definitions of the radiative field; energy balance models of the atmosphere; Sun and Earth Geometry; radiation interactions with a slab; Direct Radiation; Emission from Slab; Scattering from other directions; Absorption by atmospheric gases; Scattering; Radiation budget of clouds

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: PHYSICS OF THE EARTH FOR GEOHAZARDS
SSD: GEO/10
24 hours, 5 ECTS
Lecturer/s: A. Aoudia
Aims: give a basic understanding that underlies the physics of a deforming solid-Earth and related geohazards before pursuing advanced computational models in the second semester

Syllabus:
Introduction to the Geophysical Continua
From the Atomic scale to the Continuum
Brief introduction to basic continuum mechanics
Geological deformation
Global Seismology and Earth Structure
Mantle dynamics and Earth boundary layers
Lithospheric deformation: continuous and discontinuous deformation
Rheology of the Earth
Continental Tectonics
Kinematics and dynamics of the Active Deformation
Monitoring and observational foundations of earthquake and volcanic hazards
Secondary hazards: Tsunami and landslides
Communicating Natural Hazards

Teaching methods: lectures/exercises/reading sessions
Assessment methods: oral examination
Other information: the course is delivered in English

Course: PHYSICS OF THE OCEANS
SSD: GEO/12
24 hours, 5 ECTS
Lecturer/s: M. Gacic

Aims: introduce students to the physics of the oceans

Syllabus:

Physics of the Oceans: Overview
- Lecture 1 Introduction physical oceanography – definition and aims;
World ocean geography; temporal and spatial variability of motion in the ocean. Temperature, salinity and density: Temperature and salinity, definitions; geographic distribution (spatial and temporal characteristics); density; measurements and calculations; potential temperature; The oceanic heat budget; Heat budget terms; direct and indirect calculations of heat fluxes; geographic distribution of terms; meridional heat transport; global warming.
-Lecture 2 The freshwater budget; Freshwater sources and sinks for the world ocean; geographic distribution of terms; global warming and freshwater budget; estuarine and anti-estuarine circulation.
Geostrophic currents Geostrophic approximation; hydrostatic equilibrium; thermal wind relation; barotropic and baroclinic flow; interior flow and boundary layers; limitations of the geostrophic approximation.
Wind influence and bottom friction Ekman layer and Ekman balance; Ekman mass transport; inertial oscillations; bottom boundary layer.
- Lecture 3 Vorticity in the ocean; Definition of vorticity; conservation of vorticity; vorticity and friction; Ekman pumping.
World ocean circulation and global processes Global conveyor belt; western intensification; coastal and open ocean upwelling.
- Lecture 4 Waves in the ocean; Rossby waves; Kelvin waves (equatorial and coastal); baroclinic and barotropic wave solutions. Equatorial dynamics and climate variability El Nino and teleconnections; Observing and predicting El Nino.

Physics of the Oceans: Instrumentation
- Lecture 1 Introduction. Classical methods (Research vessels, XBT, CTD, Rosette, current meters, tide gauges, etc.)
- Lecture 2 Autonomous systems (moored buoys, surface drifters, sub-surface floats and profilers, gliders, AUVs, etc.)
- Lecture 3 Remote sensing: ADCP, acoustic tomography, HF coastal radar
- Lecture 4 Remote sensing from satellites (Sea surface temperature & ocean color , altimetry, scatterometry, SAR)

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: ATMOSPHERIC DYNAMICS
SSD: GEO/12
30 hours, 5 ECTS
Lecturer/s: F. Kucharski

Aims: introduce students to the main topics of the atmospheric dynamic

Syllabus:

Lecture 1 Vorticity equation for synoptic-scale motion; potential; vorticity conservation
Lecture 2 Quasi-geostrophic motion; Thermo-Hydrodynamic equations in pressure coordinates
Lecture 3 Rossby waves; free Rossby waves; forced Rossby waves
Lecture 4 Baroclinic instability; two-layer model
Lecture 5 Equatorial waves; Rossby-gravity waves; Kelvin waves
Lecture 6 ENSO atmosphere and ocean feedback mechanisms; Gill model; Reduced Gravity Model
Lecture 7 Boundary Layer Processes; turbulent fluxes; Ekman pumping
Lecture 8 Mechanisms for tropical rainfall responses to equatorial heating; Aqua-planet GCM simulations
Lecture 9 The General Circulation; Hadley Cell; Ferrell Cell
Lecture 10 Tropical zonal and meridional circulations; Walker circulation; Sverdrup balance
Lecture 11 Energetics of the General Circulation; Lorenz' energy cycle
Lecture 12 Analysis of climate Variability; EOF analysis, PCA analysis
Lecture 13 Predictability; Lorenz model for Chaos
Lecture 14 Predictability measures; Signal-to-noise ratio; Theoretical Limit of Predictability;
Lecture 15 Lab application of predictability analysis to seasonal hindcast products

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: OCEAN DYNAMICS
SSD: GEO/12
32 hours, 5 ECTS
Lecturer/s: R. Farneti, A. Crise

Aims: introduce students to the ocean dynamics

Syllabus:

1. Fundamentals: Geostrophy, Thermal Wind and Hydrostasy
2. Ekman Dynamics: the introduction to Friction I
3. Ekman Dynamics: the introduction to Friction II
4. Wind-Driven Gyres I: Sverdrup Flow
5. Wind-Driven Gyres II: Stommel Model
6. Wind-Driven Gyres II: Munk Model
7. Wind-Driven Gyres III: Topographic Effects
8. Thermocline Dynamics
9. Meridional Overturning Circulation: Buoyancy-driven Overturning
10. Meridional Overturning Circulation: Wind-driven Overturning
11. Introduction to the role of the ocean in the Global Carbon Cycle (GCC)
12. The ocean dynamics and GCC: principles and key processes
13. Ocean transport processes of passive tracers
14. Mesoscale and upper layer dynamics and effects on GCC

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: CLIMATE MODELLING AND CHANGE
SSD: GEO/12
36 hours, 5 ECTS
Lecturer/s: A. Tompkins

Aims: introduce students to climate modelling

Syllabus:

-Energy Balance models
1.1 Introduction
1.2 Zero dimension energy balance model
1.3 Climate system perturbations
1.3.1 Natural climate variability 1.3.2 Anthropogenic climate variability
1.4 Climate Sensivity
1.5 Fast climate feedbacks
1.5.1 water vapour feedback 1.5.2 lapse rate feedback 1.5.3 cloud feedback 1.5.4 ice albedo feedbacks 1.5.4.1 land surface feedbacks
-Atmospheric models
2.1 Introduction
2.2 Spatial discretization
2.3 Physical processes in models
2.3.1 Numerical weather prediction models 2.3.2 Seasonal climate prediction models 2.3.3 Climate and earth system models
2.4 Sub-gridscale processes in the atmosphere
2.4.1 Parametrization concept 2.4.2 Turbulence processes 2.4.3 Convection 2.4.4 Cloud microphysics 2.4.5 Cloud macrophysics
-Earth System Models
3.1 Ocean models
3.1.1 mixed layer ocean model 3.1.2 3D ocean model 3.1.2.1 Horizontal grids 3.1.2.2 Subgrid scale parameterizations
3.1.3 Sea ice 3.1.4 Glaciers 3.1.5 Snow cover
3.2 Land surface and vegetation
3.2.1 Land surface properties 3.2.2 Soil Moisture and hydrology 3.2.3 Tiles approach 3.2.4 Interactive vegetation
3.3 carbon and nitrogen cycle
3.4 Aerosols and chemistry
-IPCC
4.1 IPCC Overview
4.2 CMIP
4.3 Representative Concentration Pathways
4.4 Climate projections
4.4.1 Temperature 4.4.2 precipitation 4.4.3 sea ice 4.4.4 sea level 4.4.5 ocean acidification 4.4.6 ocean circulation
4.5 uncertainty
-Exercises
A.1 Energy Balance Models
A.2 ESM - fast processes
A.2.1 Parameterization
A.3 ESM - fast processes

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: EARTH SYSTEM THERMODYNAMICS
SSD: GEO/12
24 hours, 5 ECTS
Lecturer/s: A. Tompkins

Aims: introduce students to earth system thermodynamics

Syllabus:

1 Dry Thermodynamics
Lecture 1 Kinetic theory of heat, Equation of state: The ideal gas law
Lecture 2 The first law of thermodynamics, Rules for differentiating
Lecture 3 Enthalpy and specific heat, Hydrostatic balance, Adiabatic Processes
Lecture 4 Potential Temperature, Entropy
Lecture 5 Thermodynamic charts
Lecture 6 Buoyancy force
Lecture 7 Introduction to convection
Lecture 8 Atmospheric Stability
2 Moist Thermodynamics
Lecture 9 Saturation, Other measures of water vapour
Lecture 10 Water variables in the liquid and ice state
Lecture 11 Specific heat of moist air
Lecture 12 Ways of reaching saturation

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: MECHANICS OF EARTHQUAKES AND TECTONOPHYSICS
SSD: GEO/10
24 hours, 5 ECTS
Lecturer/s: A. Aoudia

Aims: introduce students to the mechanics of earthquakes and tectonophysics

Syllabus:

Brittle deformation
Stress tensor; Mohr circles; states of stress; Stress and strain. Griffith theory and fracture mechanics: Theoretical Fracture Strength, Stress concentration; Fracture. Strength in Presence of Atomically Sharp Crack, Thermodynamic basis for fracture, Crack. Extension Force, Crack Resistance, Stress Intensity Factor and Critical Stress Intensity Factor. Crack models: elastic, Dugdale and small-scale yielding models
Macroscopic failure criteria: faulting, fracture, friction. Macroscopic strength
Fracture energies. Pore fluid effects on fracture. Brittle-plastic transition
Friction and earthquakes
Theoretical concepts: adhesion theory, elastic contact theory, other frictional interactions. Experimental observations of friction. Physics of faults: Stick-slip and stable sliding rate and state variable friction laws, frictional stability regimes, dynamics of stick-slip
Earthquake Mechanics
The dynamic energy balance. Dynamic shear crack propagation. Earthquake ruptures (field, seismology, geodesy, laboratory). Scaling relations. Aseismic slip. Slow earthquakes, Creep events, Tsunamogenic earthquakes. Slow precursors to “normal” earthquakes. Earthquakes with a distinct nucleation phase. Afterslip and transient postseismic deformation Normal (fast) earthquakes
Viscoelasticity
Simple shear flow. Newton’s law of viscosity. Newtonian fluids. Plasticity and yield stress. Creep curve
Stress relaxation and creep experiments. Elastic (solid-like) response. Viscous (liquid-like) response
Network formulation of viscoleasticity: Maxwell, Voigt-Kelvin, Standard-linear solid. Creep and relaxation functions. Generalized Maxwell model. Relaxation spectrum. Generalized Voigt-Kelvin model. Boltzman’s principle. Dynamic (Oscillatory) Testing. Complex and Dynamic Viscosity
Active deformation
Tools and techniques: GPS, DinSAR, Seismology, direct observations. Tectonic geodesy and GPS seismology
Velocity field. Models of active deformation: distributed vs. localized. Kinematics and dynamics of the deformation. Strength and rheology of the lithosphere. Mechanics of the earthquake cycle inclusive of transient deformation

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: THEORETICAL SEISMOLOGY
SSD: GEO/10
24 hours, 5 ECTS
Lecturer/s: F. Romanelli

Aims: introduce students to the theoretical seismology

Syllabus:

Part I Seismic sources
1. Faulting. Rupture process. Faults and their geometry. Strike, dip, rake and slip
Brittle deformation and stresses. Tensile cracking. Shear fracture and Coulomb criterion
Frictional sliding. Byerlee's law. Stresses and faulting. Stress cycle & Stick slip
2. Faults and their representation. Elastodynamic basic theorems. Elastodynamic Green function. Representation theorem
3. Faults and body forces. Equivalent body forces. Moment density tensor. Shear Dislocation Far source condition.
Moment tensor. Seismic moment. Double couple. Faults and moment tensor components. Application to a specific case
4. The elastodynamic Green function. Impulse response & Transfer function. Transformed domain. Convolution theorem.
Spherically symmetric problem. Lamè theorem GF in a isotropic and homogeneous medium. Near and far field. Response to a double-couple. Near, intermediate and far field
5. Focal mechanisms. Faulting and radiation pattern. Basic fault plane solutions. Faults and plates

Part II Earthquakes and their measurement
6. Earthquakes and seismometry. Extended faults. Haskell model. Rupture time. Directivity. Source spectra. Omega square model. Seismometry. Inertial instruments. Mechanical and electromagnetic instruments. Response curves
7. Earthquakes size and seismometry. Astatic instruments. Digital signals; sampling & dynamic range. Broad band instruments; Feedback & Force balance. Strong motion; noise
8. Intensity and magnitude measurements. Intensity Magnitude. ML, mb, MS. Saturation Similarity conditions: geometric and dynamic. Moment Magnitude
9. Viscoelasticity. Rheology. Viscoelasticity. Viscoelastic models: Maxwell, Kelvin-Voigt.
Standard Linear Solid. Complex moduli.
10. Viscoelasticity and attenuation. Intrinsic Attenuation: Q of the Earth. Intrinsic Dispersion. Scattering and application to seismic waves.

Part III Tsunami Physics and Hazard
11. Tsunami Physics. Long Gravity waves. Excitation by seismic sources. Tsunami modelling
Tsunami measurements
12. Tsunami and seismic hazard. Hazard and risk.
Tsunami hazard. Seismic Hazard. Recap of the course.

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: WAVE PHYSICS
SSD: GEO/10
24 hours, 5 ECTS
Lecturer/s: F. Romanelli

Aims: introduce students to wave phenpomena

Syllabus:

<u>**Part I Fundamentals of vibrations and waves**</u>
1. Introduction to the course: what is a wave?
2. 1-Degree of Freedom (DOF) Systems Harmonic oscillator, Natural frequency. Damping, Damping regimes, Q factor. Forcing, Transients and stationary regime. Resonance.
3. 2&N DOF systems Coupled oscillators. Discrete propagating systems. Acoustical phonons, Optical phonons, Dispersion. “Free” modes.
4. The wave equation Transverse waves on a string. Sound waves.
- The wave function The wave function. Harmonic waves. Energy, Power & Intensity.
5. Wave phenomena Superposition principle. Interference. Beats. Heterogeneous string, Reflection and transmission. Boundary conditions & modes. String with fixed and free ends. Air columns with fixed and free ends.
6. Vibration in lattices Brillouin zone. Modes of monoatomic lattices. Phonons
- Wave propagation Huygens and Fermat principles. Reflection and refraction, Snell’s law.

<u>**Part II Waves in solids**</u>
7. Elasticity Theory of elasticity. Deformation, Strain tensor. Stress tensor.
Body waves Generalized Hooke’s law. Navier equations. Body waves (P and S).
8. Rays and body waves Harmonic and spherical body waves. Body waves at interfaces. Free surface, Apparent velocity. Traveltimes in layered media. Direct, reflected and head waves. Ray Parameter. Traveltimes in layered spherical media.
9. Surface waves and Dispersion Surface waves. Rayleigh waves in a halfspace. Phase velocity. Group and phase velocity
10. Surface waves and Dispersion SH waves in plates.
11. Surface waves in layered media Surface waves in layered halfspaces. Love waves. Rayleigh waves.
12. Free modes of the Earth 2D: wave equation in cylindrical coordinates; Bessel functions. Free modes of a membrane. 3D: wave equation in spherical coordinates; Spherical harmonics. Torsional modes; Spheroidal modes.
Tutorial: Fourier and other wave phenomena Complex sound waves; Fourier synthesis & analysis; Vibrating string; Waveguides

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: SPACE GEODESY AND InSAR
SSD: GEO/10
24 hours, 5 ECTS
Lecturer/s: A Borghi

Aims: introduce students to the space geodesy

Syllabus:
1. Fundamentals of Geodesy
• Definition of the Earth gravity field.
• Reference surfaces: geoid and ellipsoid.
2. Fundamentals of Space Geodesy
• Definition of Space Geodesy
• Definition of global and local coordinate systems
• Description of the satellite motions
• Forces acting on the satellites
3. GPS observables
• Pseudo ranges
• Carrier phases
• RINEX format
4. Errors in the GPS observables
• ionosphere
• troposphere
• multipath
• phase center variation
5. Mathematical model of GPS observables
• relative and absolute positioning
• linear combination of observables
6. Methods of processing GPS data
• Commercial software
• Scientific software
7. GPS Time series analysis
• Deterministic model
• Stochastic model
8. Kinematic applications
• DGPS
• NRTK
9. SAR
• Definition of RADAR
• Definition of SAR
10. Interferometry
• Definition of InSAR
• phase unwrapping
• applications
11. DinSAR
• Definition of DinSAR
• applications
12. GPS and InSAR geophysical applications
• case studies

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: APPLIED SEISMOLOGY
SSD: GEO/10
24 hours, 5 ECTS
Lecturer/s: S. Parolai

Aims: introduce students to applied an engineering seismology
Syllabus:
1. Fundamentals of Seismology
What is seismology? Branches of seismology. Spectrum of seismic waves. Historical development of seismology. Earthquakes. Elastic moduli and body waves. P-waves, S-waves and their velocity. Surface waves. Surface wave dispersion.
Earth structure and seismic phases - Seismogram interpretation Origin time, arrival time and travel time. Seismic rays, travel times amplitudes and phases. Hypocentre and epicenter. Local, regional and teleseismic earthquakes.
2. Basics of signal analysis. Fourier transform. Response spectra. pga, pgv, pgd. Introduction to site effects.
3. Seismic hazard definition. Principle of seismic hazard assessment. Introduction to exposure and vulnerability. Introduction to seismic risk assessment.
5. Geophysical inverse theory
Geophysical inverse theory. Parameter estimation and inverse problems. Forward problems and inverse problems.
4. Site effect estimation: direct methods Standard spectral ratio. GIT. HVSR. Borehole data interferometry
6. Site effes estimation: indirect methods. Active source methods. MASW,CASW. SASW.
7. Site effect estimation: indirect methods. Seismic noise. H/V. ESAC. Concept of tomography.
8. Soil-structure interaction. Seismic recordings in buildings. Joint analysis of borehole and building data.
98. Earthquake early warning systems.

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: PHYSICS OF VOLCANOES
SSD: GEO/10
24 hours, 5 ECTS
Lecturer/s: E. Rivalta

Aims: introduce students to the physics of volcanoes

Syllabus:

General introduction on volcanoes. Shapes of volcanoes. Types of volcanism. Volcano-tectonics. Magma composition, thermodynamics of magma generation, shallow and deep geotherms, decompression melting, role of water and other volatile species, physical properties of magma, magma evolution at differentdepths. Magma transport through the crust. Different schools of thought for dike propagation (viscosity-dominated regime and fracturing-dominated regime). Analogue experiments on fluid-filled crack propagation. Examples of deep magma transport for some volcanoes (Ell Hierro, Ejyafjallajokull). Models of pressure evolution in the plumbing system due to top-down effects (eruption, unloading) or bottom-up (fresh intrusions from below heeating and stirring the magma in reservoirs). Crustal deformation for different tectonic settings, Mogi model, Sills, ellipsoids, calderas. Elemetary dislocations. Rectangular dislocations. Distributed models of slip. Equivalence of different shapes in terms of crustal deformaiton. Dike dynamics in the volcanic edifice. Examples of volcano seismicity linked to dike intrusions and conduit processes, moment tensor, full moment tensor, earthquake scaling laws for volcanic events. Overview of the types of eruption including the physical mechanism behind it (lava flow, lava fountain, explosive eruptions, dome collapse, pyroclastic flow, lahar). Bubble nucleation, bubble expansion and cohalescence, anular flow, slug flow, strombolian eruptions, hawaiian eruptions. Models of conduit flow, models of magma viscosity, crystallization, effects of crystals and bubbles, criteria of fragmentation Analytical models of caldera collapse. Analog experiments of caldera collapse, critical magma output to cause collapse, comparison of caldera collapse episodes, vertical-CLVD focal mechanisms. Volcano statistics. Volcano-volcano and earthquake-volcano interactions. Eruption triggers (earthquakes, sudden changes of surface mass load). Volcanic hazard. Cascade effects, landlslide, tsunamis.

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: NUMERICAL METHODS I
SSD: MAT/08
30 hours (20 class lectures + 10 lab sessione), 5 ECTS
Lecturers: E. Coppola, F. Di Sante

Syllabus:

Lecture 1 Linux Operating System, Unix Commands, bash shell.
Lecture 2 Fortran 90 programming: basic operations, input/output, flow control
Lecture 3 Fortran 90 programming: functions/subroutines, array/matrices, strings, dynamic allocation, use of modules, notions of object oriented programming.
Lecture 4 Roots of equations: Bisection, Newton, Secant and Regula Falsi methods.
Lecture 5 Integration: trapezium and Simpson methods, Newton-Cotes formulas, Gaussian quadrature.
Lecture 6 Ordinary Differential Equations: Euler midpoint method, Runge-Kutta method, Lecture 7 introduction to molecular dynamics (Verlet algorithm).
Lecture 8 Random Numbers: linear congruent generators, statistical analysis of pseudo-random number generators, non-uniform distributions (transformation method, Box-Muller, rejection method).
Lecture 9 Crude Monte Carlo integration: statistical error estimations, importance sampling.
Lecture 10 Introduction to Monte Carlo simulations: Markov chains, Metropolis algorithm.

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

Course: NUMERICAL METHODS II
SSD: MAT/08
24 hours, 5 ECTS
Lecturer: G. Giuliani

Aims: introduce students to the numerical solutions of some classes of differential equations

Syllabus:

Lecture 1 Introduction to Finite Differences and floating point representation.
Lecture 2 Ordinary Differential Equations discretization: accuracy and stability.
Lecture 3 The 1D linear advection equation: the Forward in Time Forward in Space scheme. Stability analysis.
Lecture 4 The 1D linear advection equation: the upstream scheme. CFL condition.
Lecture 5 The 1D Linear advection equation: the leapfrog scheme.
Lecture 6 The leapfrog computational mode. Robert-Asslin and Robert-Asslin-Williams filters.
Lecture 7. The 1D linear advection equation: thesemi-Lagrangian technique.
Lecture 8 The 1D linear advection equation: an implicit time discretization.
Lecture 9 The 1D diffusion equation: an explicit discretization and stability analysis.
Lecture 10 The 1D advection-diffusion equation.
Lecture 11 The linearized 1D shallow water equations system: an explicit discretization.
Lecture 12 Summary and review of selected topics.

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

ECTSCourse: ENVIRONMENTAL HYDRAULIC
SSD: ICAR/01
50 hours, 6 ECTS
Lecturer/s: V. Armenio

Aims: introduce students to the Environmental Fluid Mechanics.

Syllabus:

- Introduction to Environmental Fluid Mechanics
- Fluid properties and transport mechanisms
- Differential form of conservation laws (Boussinesq approximation)
- Integral form of conservation laws
- Vorticity and circulation
- Turbulence and mixing convection
- Jets, puffs e plumes
- Diffusion and Dispersion theory
- Dynamics of lakes and reservoirs
- The atmospheric boundary layer

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is delivered in English

~~ECTS~~Course: GEOPHYSICAL FLUID DYNAMICS
SSD: ICAR/01
50 hours, 6 ECTS
Lecturer/s: V. Armenio

Aims: provide students with the fundamentals of the mechanics of fluids and knowledge of basic phenomena that characterize the geophysical scales.

Syllabus:

1) Introduction to fluid dynamics
    a. fluid properties
    b. the laws of thermodynamics
    c. Molecular transport phenomena
    d. Stability of a column of fluid
    e.Potential Temperature and potential density
2) Kinematics
    a. Eulerian and Lagrangian approach
    b. flow lines, acceleration of a fluid element
    c. Relative motion between two points: The deformation rate and rotation tensors
    d. Reynolds Transport Theorem
3) Conservation laws
    a. conservation of mass
    b. Conservation of momentum
    c. constitutive laws
    d. Navier-Stokes equations
    e. non-inertial reference systems: The Coriolis force
    f. Bernoulli's Principle
    g. The Boussinesq approximation for flows with density variation
    h. Boundary conditions
4) Dynamics of vorticity
    a. Kelvin theorem
    b. of Helmholtz theorem
    c. Vorticity equation in inertial and non-inertial reference system
    d. Biot-Savart law
5) Dimensional analysis
    a. nondimensionali forms of conservation laws
    b. Theorem P Buckingham
    c. The laboratory tests
6) The boundary layer theory
    a. definitions
    b. analytical solution for flat plate
    c. boundary layer separation
    d. Notes to flow around bluff bodies
7) Turbulence
    a. Introduction to statistical turbulence
    b. Reynolds averaged equations
    c. Turbulence closure

Teaching methods: lectures/exercises
Assessment methods: oral/written examination
Other information: the course is delivered in English

Course: HEAT TRANSFER
SSD: MAT/08
18 hours, 3 ECTS
Lecturer: M. Piller

Aims: introduce students to the physical mechanisms underlying the major heat transfer processes and to the mathematical models for the solution of heat transfer problems.

Syllabus:

Heat conduction
- Steady, one-dimensional heat conduction
- Transient and multidimensional heat conduction

Convective Heat Transfer
- The energy equation
- Laminar incompressible thermal boundary layer on a flat surface
- Heat transfer in turbulent boundary layers
- Forced convection in a variety of configurations
- Natural convection in single-phase fluids and during film condensation

Thermal Radiation Heat Transfer
- The general problem of radiant heat transfer
- Radiant exchange in general and within gray-body cavities

Teaching methods: lectures/exercises
Assessment methods: written/oral examination
Other information: the course is offered in English

Course: STATISTICAL MACHINE LEARNING
SSD: INF/01
60 hours, 7 ECTS
Lecturer/s: L. Bortolussi

Aims: Introduce students to machine learning, with a probabilistic perspective.

Syllabus:
0. Introduction to statistical machine learning
1. Graphical models and exact inference.
2. Approximate inference for models latent variables.
3. Sampling methods.
4. Bayesian linear regression and classification.
5. Kernel based methods and Gaussian Processes.
6. Deep Learning: classic, recurrent and convolutional neural networks. Regularization and generative models.

Teaching methods: lectures/hands on exercises.
Assessment methods: group project and oral presentation
Other information: the course is delivered in English. A basic knowledge of Python is helpful

Course: STOCHASTIC MODELLING AND SIMULATION
SSD: INF/01
60 hours, 6 ECTS
Lecturer/s: L. Bortolussi

Aims: Introduce students to stochastic models of population processes and to simulation algorithms and approximation techniques.

Syllabus:
1. Discrete stochastic modelling. Markov chains in discrete and continuous time, discrete event simulation, Petri Nets.
2. Stochastic approximations: mean field, linear noise, moment closure, Langevin approximation, hybrid approximations.
3. Parameter estimation and system design.
4. Formalization and verification of emergent behavioural properties (if time).
Examples from systems biology, epidemiology, performance of computer networks, ecology.**Teaching methods:** lectures/hands on exercises.

Teaching methods: lectures/hands on exercises.
Assessment methods: project and oral presentation
Other information: the course is delivered in English. A basic knowledge of Python is helpful.

Course: BIFURCATION THEORY
SSD: MAT/05
30 hours, 6 ECTS
Lecturer: J. Lopez-Gomez

Aims: introduce students to bifurcation theory with applications to differential equations

Syllabus:

1.- Topological degree. Theorem of existence and uniqueness of Amann and Weiss.
2.- Global bifurcation theory: local and global theorem. Global alternative of Rabinowitz.
3.- Bifurcation from simple eigenvalues. Theorem of Crandall and Rabinowitz.
4.- Application to the study of nodal solutions of 1-D linear boundary value problems.
5.- Lyapunov-Schmidt decompositions. Spectrum of Linear analytic operator families.
6.- Theorem of Westreich and first characterization of nonlinear eigenvalues.
7.- Theorem of characterization of nonlinear eigenvalues of Esquinas and Lopez-Gomez.
8.- Theorem of transversalization. Generalized algebraic multiplicity, m, of Esquinas and Lopez-Gomez.
9.- Multiplicity of Magnus. Fundamental theorem. The parity of m as an optimal invariant to detect any change of the topological degree. Topological characterization of nonlinear eigenvalues.
10.- Uniqueness of the algebraic multiplicity. Theorems of Mora-Corral.

Teaching methods: lectures/exercises
Assessment methods: oral examination
Other information: the course is delivered in English

Course: FIXED POINTS AND ZEROS OF NONLINEAR MAPPINGS
SSD: MAT/05
8 hours, 2 ECTS
Lecturer: J. Mawhin

Aims: introduce students to fixed point theory with applications to differential equations

Syllabus:

1. Brouwer fixed point theorem
(a) some history
(b) an analytic proof
(c) remarks on other proofs
(d) remarks on the infinite dimensional case

2. Hadamard and Poincaŕe-Miranda's theorems
(a) proofs using Brouwer fixed point theorem
(b) equivalence with Brouwer fixed point theorem
(c) remarks on the infinite dimensional case

3. The case of holomorphic mappings
(a) simple proofs using complex analysis
(b) uniqueness conditions

4. Some applications
(a) variational inequalities
(b) existence of Nash equilibria in game theory
(c) differential equations

Teaching methods: lectures/exercises
Assessment methods: oral examination
Other information: the course is delivered in English